TRB Standing Committees

ACS10 – Transportation Safety Management Systems

ACS20 – Safety Performance Analysis

Synthesis Report on Safety-Related Papers

presented at the 104th TRB Annual Meeting

Prepared by

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TRB 104th ANNUAL MEETING
January 5–9, 2025 • Washington, DC

ACS10 – Standing Committee on Transportation Safety Management Systems

The committee will be concerned with the development and coordination of integrated safety management programs to reduce death and injury on transportation systems. Areas of concern include: 1) the advancement of safety management systems, 2) research and technology to improve safety, and 3) models of safety delivery systems.

Website: https://sites.google.com/view/trbcommitteeacs10

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ACS20 – Standing Committee on Safety Performance and Analysis

This Committee deals with the advancement, integration and institutionalization of quantitative highway safety information to support transportation decision-making at all levels. The function of this committee is to foster the continual development, validation and increased knowledge of science-based methods, procedures and measures that will increase the safety of the nation's highways and roadways.

Website: https://trbacs20.org/

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1 Introduction

This report is mainly aimed at facilitating access to Committees ACS10-ACS20 related presentations and events at the 104th Annual Meeting of the Transportation Research Board. With this aim, papers sponsored by the Committees ACS10 – Transportation Safety Management Systems and ACS20 – Safety Performance and Analysis have been split into subthemes and the abstracts reproduced. For each subtheme, a brief comment on the methodological and application perspectives of the presented papers is reported.

This year, twenty-eight events sponsored by ACS10 and ACS20 are planned:

- Three Committee meetings;
- Eight Subcommittee meetings;
- Two workshops;
- Six lectern sessions; and
- Nine poster sessions.

The Transportation Safety Management Systems Committee meeting will be held on Wednesday morning, January 8, from 8:00 AM to 12:00 PM, at Marriott Marquis, Salon 12 (M2).

The Safety Performance and Analysis Committee meetings will be held on Wednesday afternoon, January 08, from 3:45 PM to 7:30 PM, at Marriott Marquis, Salon 6 (M2), and on Thursday morning, January 09, from 9:00 AM - 12:00 PM, at Marriott Marquis, Chinatown (M3).

Sunday, January 5, there are two planned events (Table 1): two workshops in the morning. Topics relate to collaborative strategies for impaired driving and integrating target speed in roadway design to improve safety and system effectiveness.

Monday, January 6, there are ten planned events (Table 2): four subcommittee meetings, two poster sessions, and four lectern sessions.

Tuesday, January 7, there are seven planned events (Table 3): three subcommittee meetings, and four poster sessions.

Wednesday, January 8, there are eight planned events (Table 4): the ACS10 Committee meeting in the morning, the first part of the ACS20 Committee meeting in the afternoon, one subcommittee meeting, three poster sessions, and two lectern sessions.

Thursday, January 9, there is one planned event (Table 5): the second part of the ACS20 Committee meeting.

The safety-related papers identified by the sub-committee address the following topics (some papers are classified in more categories):

a) Crash Data and Safety Analysis (176);
b) Network Screening (18);
c) Safety Performance Functions (15);
d) Crash Severity Prediction (93);
e) Crash Modification Factors and Functions (10);
f) Surrogate Measures of Safety (62);
g) Real-Time Safety Prediction (15);
h) Safety Effects of Connected and Automated Vehicles (77); and
i) Transportation Safety Management (72).

Table 1 ACS10 and ACS20 Events, Sunday, January 5

Schedule	Event type	#	Location	Event name	Details
9:00 AM-12:00 PM	Workshop	1005	CC, Salon B	The Safe System Approach in Action: Building Relationships to Address Impaired Driving	https://annualmeeting.mytrb.org/OnlineProgram/Details/22644
9:00 AM-12:00 PM	Workshop	1014	CC, 202B	"Life in the Fast Lane" or "Slow Ride"?: Designing Roadways to Target Speed in an Evolving Multimodal Context	https://annualmeeting.mytrb.org/OnlineProgram/Details/22586

Table 2 ACS10 and ACS20 Events, Monday, January 6

Schedule	Event type	#	Location	Event name	Details
8:00 AM-9:45 AM	Lectern	2004	CC, Salon B	Doctoral Student Research in Transportation Safety: A Lectern-Poster Session	https://annualmeeting.mytrb.org/OnlineProgram/Details/22687
8:00 AM-9:45 AM	Subcommittee		MM, Salon 13 (M2)	Surrogate Safety Measures Subcommittee, ACS20(3)	https://annualmeeting.mytrb.org/OnlineProgram/Details/22384
10:15 AM-12:00 PM	Subcommittee		MM, Salon 13 (M2)	School Transportation Subcommittee, ACS10(3)	https://annualmeeting.mytrb.org/OnlineProgram/Details/22380
10:15 AM-12:00 PM	Subcommittee		MM, Salon 10 (M2)	Pedestrian and Bicycle Safety Analysis, ACS20(4), Joint Subcommittee of ACS20, ACH10, ACH20	https://annualmeeting.mytrb.org/OnlineProgram/Details/22385
1:30 PM-3:15 PM	Lectern	2123	CC, Salon B	Creating a Safer System: A Lectern-Poster Session	https://annualmeeting.mytrb.org/OnlineProgram/Details/23041
1:30 PM-3:15 PM	Subcommittee		MM, Salon 13 (M2)	Motorcycle and Moped Safety, ACS10(5), Joint Subcommittee of ACS10, ACH60	https://annualmeeting.mytrb.org/OnlineProgram/Details/22498
3:45 PM-5:30 PM	Lectern	2171	CC, Salon A	Decision Making with Safety Surrogates	https://annualmeeting.mytrb.org/OnlineProgram/Details/23043
3:45 PM-5:30 PM	Lectern	2174	CC, 150A	New-Generation Transport Safety Analysis Using High-Resolution Data: Advanced Statistical and Machine Learning Models	https://annualmeeting.mytrb.org/OnlineProgram/Details/22657
3:45 PM-5:30 PM	Poster	2206	CC, Hall A	Safety Performance and Analysis with Crash Predictions	https://annualmeeting.mytrb.org/OnlineProgram/Details/23002
6:00 PM-7:30 PM	Poster	2240	CC, Hall A	Safety Performance and Analysis for Safe Roads	https://annualmeeting.mytrb.org/OnlineProgram/Details/22991

Table 3 ACS10 and ACS20 Events, Tuesday, January 7

Schedule	Event type	#	Location	Event name	Details
8:00 AM-9:45 AM	Poster	3039	CC, Hall A	Transportation Safety Management Systems from Start to Finish	https://annualmeeting.mytrb.org/OnlineProgram/Details/23055
8:00 AM-9:45 AM	Subcommittee		MM, Salon 13 (M2)	Safety Analytical Methods Subcommittee, ACS20(1)	https://annualmeeting.mytrb.org/OnlineProgram/Details/22382
10:15 AM-12:00 PM	Poster	3109	CC, Hall A	Transportation Research Board Minority Student Fellows	https://annualmeeting.mytrb.org/OnlineProgram/Details/22716
10:15 AM-12:00 PM	Subcommittee		MM, Salon 13 (M2)	Rural Road Safety Policy, Programming, and Implementation, ACS10(4), Joint Subcommittee of ACS10, ACS20, AKD30	https://annualmeeting.mytrb.org/OnlineProgram/Details/22381
1:30 PM-3:15 PM	Poster	3147	CC, Hall A	Safety Performance and Analysis Using Machine Learning or Artificial Intelligence	https://annualmeeting.mytrb.org/OnlineProgram/Details/22985
6:00 PM-7:30 PM	Poster	3213	CC, Hall A	Safety Performance and Analysis for Safe Road Users and Safe Speeds	https://annualmeeting.mytrb.org/OnlineProgram/Details/22989
6:00 PM-7:30 PM	Subcommittee		MM, Independence Salon D (M4)	Emergency Response Subcommittee, AMR00(1), Joint Subcommittee of AMR00, ACP10, ACS10, ACS30	https://annualmeeting.mytrb.org/OnlineProgram/Details/22269

Table 4 ACS10 and ACS20 Events, Wednesday, January 8

Schedule	Event type	#	Location	Event name	Details
8:00 AM-9:45 AM	Lectern	4004	CC, 103A	The Future of Safety Performance and Analysis	https://annualmeeting.mytrb.org/OnlineProgram/Details/23005
8:00 AM-9:45 AM	Lectern	4015	CC, 146B	Responder Ready: Elevating Responder Safety and Incident Reporting with Innovative Traffic Incident Management	https://annualmeeting.mytrb.org/OnlineProgram/Details/22692
8:00 AM-9:45 AM	Poster	3202	CC, Hall A	Landscape and Environmental Design	https://annualmeeting.mytrb.org/OnlineProgram/Details/22911
8:00 AM-12:00 PM	Committee		MM, Salon 12 (M2)	Transportation Safety Management Systems	https://annualmeeting.mytrb.org/OnlineProgram/Details/22070
10:15 AM-12:00 PM	Poster	4073	CC, Hall A	Safety Performance and Analysis for Safe Vehicles	https://annualmeeting.mytrb.org/OnlineProgram/Details/22987
10:15 AM-12:00 PM	Poster	4081	CC, Hall A	Advancements in Emergency Response, Incident Management, and Post-Crash Care: Innovative Approaches to Enhancing First Responder Safety and Efficiency	https://annualmeeting.mytrb.org/OnlineProgram/Details/22806
12:15 PM-1:15 PM	Subcommittee		MM, George Washington	Safety Performance and Analysis User Liaison Subcommittee, ACS20(2)	https://annualmeeting.mytrb.org/OnlineProgram/Details/22383

			University (M1)		
3:45 PM-7:30 PM	Committee		MM, Chinatown (M3)	Safety Performance and Analysis	https://annualmeeting.mytrb.org/OnlineProgram/Details/22470

Table 5 ACS10 and ACS20 Events, Thursday, January 9

Schedule	Event type	#	Location	Event name	Details
8:00 AM-12:00 PM	Committee		MM, Liberty Salon JK (M4)	Safety Performance and Analysis	https://annualmeeting.mytrb.org/OnlineProgram/Details/22470

2 Crash Data and Safety Analysis

Mohamad Banihashemi, FHWA
Simone Fucito, University of Naples Federico II

Crash Data and Safety Analysis section contains many papers in wide variety of subjects in highway safety. The subcommittee identified **one-hundred-seventy-six** (176) papers dealing with this topic.

Most paper dealing with crash data and safety analysis are presented in the following sessions:

- 2004 Doctoral Student Research in Transportation Safety: A Lectern-Poster Session (Monday, January 6, 08:00 AM – 09:45 AM);
- 2123 Creating a Safer System: A Lectern-Poster Session (Monday, January 6, 01:30 PM – 03:15 PM, 6 papers);
- 2206 Safety Performance and Analysis with Crash Predictions (Monday, January 6, 03:45 PM – 05:30 PM, 14 papers);
- 2174 New-Generation Transport Safety Analysis Using High-Resolution Data: Advanced Statistical and Machine Learning Models (Monday, January 6, 03:45 PM – 05:30 PM);
- 2240 Safety Performance and Analysis for Safe Roads (Monday, January 6, 06:00 PM – 07:30 PM, 29 papers);
- 3039 Transportation Safety Management Systems from Start to Finish (Tuesday, January 7, 08:00 AM – 09:45 AM, 47 papers);
- 3147 Safety Performance and Analysis Using Machine Learning or Artificial Intelligence, (Tuesday, January 7, 01:30 PM – 03:15 PM, 21 papers);
- 3213 Safety Performance and Analysis for Safe Road Users and Safe Speeds (Tuesday, January 7, 06:00 PM – 07:30 PM, 23 papers);
- 4073 Safety Performance and Analysis for Safe Vehicles (Wednesday, January 8, 10:15 AM – 12:00 PM, 14 papers);
- 4081 Advancements in Emergency Response, Incident Management, and Post-Crash Care: Innovative Approaches to Enhancing First Responder Safety and Efficiency (Wednesday, January 8, 10:15 AM – 12:00 PM, 15 papers).

The subcommittee identified six sub-categories related to the main topics addressed and discussed in the papers:

- **General data, data analysis and new analytics** (77 papers): 25-05833, 25-00232, 25-03724,25-03857, 25-00754, 25-01229, 25-01577, 25-02120, 25-02491, 25-02539, 25-02725, 25-02795, 25-02797, 25-03178, 25-03526, 25-03881, 25-04039, 25-04351, 25-04485, 25-04805, 25-04862, 25-05732, 25-02136, 25-02288, 25-02405, 25-04781, 25-03631, 25-04756, 25-04831, 25-04901, 25-05657, 25-00996, 25-02751, 25-01145, 25-02287, 25-00148, 25-00170, 25-02613, 25-04393, 25-04510, 25-04668, 25-05031, 25-05277, 25-06211, 25-05753, 25-03039, 25-03536, 25-04696, 25-02956, 25-02358, 25-02415, 25-05030, 25-05661, 25-01335, 25-01767, 25-02687, 25-03124, 25-03514, 25-04823, 25-05032, 25-05368, 25-05485, 25-06171, 25-04468, 25-05236, 25-01359, 25-04855, 25-05534, 25-05799, 25-03811, 25-04444, 25-03330, 25-01012, 25-03192, 25-04113, 25-05546.
- **Vulnerable road users and emergency responders** (42 papers): 25-02461, 25-02906, 25-03225, 25-03255, 25-04043, 25-04271, 25-04729, 25-04774, 25-05595, 25-05599, 25-05800, 25-06096, 25-06141, 25-06278, 25-02082, 25-02346, 25-05226, 25-00241, 25-01564, 25-01597, 25-01894, 25-02541, 25-02845, 25-04169, 25-04759, 25-01181, 25-03146, 25-06160, 25-03101, 25-03664, 25-05580, 25-05655, 25-03741, 25-00524, 25-01266, 25-01286, 25-02110, 25-02123, 25-05417, 25-04099, 25-05004, 25-04975, 25-00341.
- **Specific crash types and geometric factors** (20 papers): 25-00102, 25-00294, 25-01151, 25-04703, 25-00395, 25-01271, 25-01768, 25-01960, 25-03242, 25-03138,25-04787, 25-05301, 25-05589, 25-05600, 25-05914, 25-00155, 25-05015, 25-03617, 25-01324, 25-05407.
- **Human factors and environmental factors** (26 papers): 25-01709, 25-01152, 25-01298, 25-01631, 25-03180, 25-03364, 25-04640, 25-04997, 25-05447, 25-06437, 25-06465, 25-00712, 25-05859, 25-01386, 25-01011, 25-02616, 25-00613, 25-03697, 25-03750, 25-03910, 25-05286, 25-05322, 25-06072, 25-01522, 25-02168, 25-01258.
- **Crash data and data analysis related to connected and autonomous vehicles** (7 papers): 25-05636, 25-00443, 25-00827, 25-03841, 25-06076, 25-06120, 25-02400.
- **Safe System Approach** (4 papers): 25-04148, 25-03897, 25-04729, 25-00478.

General data, data analysis and new analytics

This subcategory contains 77 papers concerning crash data and safety analysis. Various topics are addressed:
A first group of papers focuses on **crash data analysis** with the application of various models (25-05833, 25-00232, 25-03857, 25-00754, 25-01577, 25-02797, 25-03526, 25-04351, 25-04805, 25-05732, 25-02136, 25-02288, 25-02405, 25-03631, 25-04756, 25-04831, 25-04901, 25-05657, 25-00996, 25-02751, 25-01145, 25-02287, 25-04668, 25-06211, 25-03039, 25-02956, 25-02687, 25-05368, 25-04468, 25-01359, 25-04444, 25-01012, 25-05546).

Several papers are dedicated to **spatial analysis** (25-02725, 25-02795, 25-03178, 25-03881, 25-05753, 25-05485). Two papers focus on **economic and cost-benefit analysis** (25-02120, 25-02491).

Numerous papers propose the application of **machine learning methods** (25-03124, 25-03514, 25-04823, 25-01229, 25-02539, 25-04862, 25-04781), large language models (25-05236), and deep generative models (25-06171). Particular attention is given to crash data analysis in various **infrastructural** or **maneuver contexts**: speed (25-03724, 25-05534, and 25-05799), barriers (25-00170), pavement conditions (25-02613), median treatments (25-04393), breakaway luminaire poles (25-04510), lane change (25-05277), exit ramps (25-03536), wrong-way driving crashes (25-00148), chain conflict risks (25-01767), work zones (25-04696 and 25-04855), intersections (25-02358, 25-02415, 25-05799, and 25-03330), road characteristics (25-01335).

Analyses are also proposed for various incident types and/or depending on the **vehicles involved**: animal crashes (25-05031), heavy vehicles (25-05032), bus crashes (25-04113 and 25-04485), vehicle mix (25-03192), motorcycles and rear-end collisions (25-04039). Furthermore, great emphasis is given in Lectern Session 2174 with a particular focus on high-resolution data (P25-20158, P25-20153, P25-20154, P25-20155, P25-20156, P25-20157, P25-20159) and in Lectern Session 4015 (P25-20603, P25-20664) with a focus on data collection.

Vulnerable road users and emergency responders

This subcategory contains 42 papers related to vulnerable users and emergency responders. Among the vulnerable road users, a distinction between pedestrians, cyclists, motorcyclists and users of personal mobility devices (e.g., e-scooters, e-bikes) is made. The topic is of considerable importance as the lack of vehicle protection exposes VRUs to a greater risk of serious injury. Particular attention is given to school zones (25-03225, 25-03255, 25-04043, 25-04774, 25-06141, 25-06278, 25-02346), pedestrians (25-02461, 25-04271, 25-03146, 25-00524, 25-01266, 25-02110, 25-00341, 25-05800, 25-04099, 25-05004, 25-04975), Emergency Medical Services and first responders (25-00241, 25-01564, 25-01597, 25-01894, 25-02541, 25-04169), cyclists (25-05655, 25-02123, 25-05417, 25-05800, 25-06160, 25-05004) and personal mobility devices (25-06096, 25-01181, 25-03101, 25-03741, 25-01286, 25-05580, 25-06160).

Specific crash types and geometric factors

This subcategory contains 20 papers related to specific crash types and geometric factors. The main topics covered are secondary crashes (25-01768, 25-01960, 25-05407), intersections (25-03617 and 25-01324 for signalized intersections, 25-05015 for all way stop controlled intersections), specific areas (Hilly areas 25-00395, toll plazas 25-03242, merging and diverging areas 25-03138, accesses 25-00155), specific crash types (overtaking 25-01271, head on 25-05589), specific vehicles (motorcycles 25-00102, E-scooters 25-00294 and 25-01151, large vehicles 25-05600, vehicle group mechanism 25-05301) and specific geometric factors (horizontal curvature 25-04703, rumble strips 25-04787, median cable barrier 25-05914).

Human factors and environmental factors

This subcategory contains 26 papers related to human and environmental factors. A series of papers analyze speeds and speeding behavior (25-01631, 25-05322, 25-01522); various papers examine human and environmental factors with respect to two-wheelers (25-03364), motorcycles (25-04640, 25-05447, 25-06437), motor scooters (25-01298) and pedestrians (25-03750); some papers analyze behavioral differences, for example between professional and non-professional drivers (25-03180) or related to gender and age (25-06072); other topics covered are intersections and roundabouts (25-01386, 25-01152), risky driving behavior (25-00613), car following (25-01011), lane changing (25-02168) augmented reality (25-05286), CAVs (25-01258), mixed flow with CAVs and HDVs (25-06465), task complexity evaluation (25-02616).

Crash data and data analysis related to connected and autonomous vehicles

Seven papers are related to connected and autonomous vehicles. Paper 25-05636 uses probe data to model speeding on interstate horizontal curves and ramps; paper 25-00443 proposes a machine learning approach to prioritize driving safety indicators using connected vehicle system data; paper 25-00827 uses connected vehicle data for accident detection through traffic impact analysis; paper 25-03841analyzes hard braking events; paper 25-06076 identifies high risk locations on expressways using connected vehicle data; paper 25-06120 uses CAV data in order to identify hazardous infrastructures; paper 25-02400 uses CAV data to predict crash likelihood at intersections.

Safe System Approach

Four papers are dedicated to the Safe System Approach: paper 25-04148 supports safe System Approach decision-making through crash sequence analysis; paper 25-03897 propose a roadway classification framework for speed limit setting in the US aligned with the Safe System framework; paper 25-04729 quantifies the impacts of transport infrastructure with a systematic analysis; paper 25-00478 describes cross-agency coordination.

Below, for each of the 176 papers involving crash data and safety analysis, the following information is provided: authors, sponsoring committee, session number, session title, paper number, paper title, and abstract or introduction in case of missing abstract.

Authors Cesar Andriola, University of Wisconsin, Madison
Madhav Chitturi, University of Wisconsin, Madison
Andrea Bill, University of Wisconsin, Madison
David Noyce, University of Wisconsin, Madison

Sponsoring Committee Standing Committee on Transportation Safety Management Systems (ACS10)

Session Number **Lectern Session 2123**

Session Title Creating a Safer System: A Lectern-Poster Session

Paper Number TRBAM-25-04148

Paper Title **Supporting the Safe System Approach Decision-Making Through Crash Sequence Analysis**

Introduction The Safe System Approach (SSA) is part of the United States Department of Transportation (USDOT) National Roadway Safety Strategy (NRSS) (U.S. Department of Transportation, 2024a), providing a comprehensive framework and strategies to achieve Vision Zero's goal of eliminating road traffic fatalities and severe injuries (Porter et al., 2021). It is built upon the idea that death and serious injury are unacceptable, and accounts for the fact that humans are vulnerable and make mistakes. The USDOT has embraced a whole system perspective, defining five elements that apply to all roads, including freeways, local roads, and rural roads: safer people, safer roads, safer vehicles, safer speeds, and post-crash care (Finkel et al., 2020). The SSA aims to incorporate, but go beyond, the traditional approach based on the E's of Engineering, Education, Enforcement, and the later inclusion of Emergency Medical Services and Equity (Ritter et al., 2022). An important issue in traditional safety analysis is the incorrect identification of crash contributory factors (Imprialou & Quddus, 2019), which diverges from the holistic view of the road system presented by the SSA. This incorrect identification issue is related to the current practice of crash characterization in highway engineering, which simplifies crashes by grouping diverse contributing factors into broad crash categories primarily based on manner of collision (e.g., head-on, sideswipe), hindering the development of effective countermeasures as these categories are outcome-based and do not capture preceding events and specific characteristics (Wu et al., 2016). In this context, the present study supports the SSA framework by using crash sequences to generate clusters that provide better insights into crash progression and contributing factors. Then, the relevant crash variables of each cluster are used to relate these clusters to multiple SSA elements, showing the importance of moving away from a silo-based approach into a holistic one. Based on these results, cluster-specific countermeasures are presented, which can be used by state or local jurisdictions in transportation safety prioritization programs. Furthermore, countermeasures relevant to multiple clusters can be considered for systemwide improvements.

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Yixiao Lei, Tongji University
Xueyu Zhang, Tongji University
Lulu Zhou, Traffic Police Headquarters of Shanghai Public Security Bureau

Sponsoring Committee Standing Committee on Transportation Safety Management Systems (ACS10)

Session Number **Lectern Session 2123**

Session Title Creating a Safer System: A Lectern-Poster Session

Paper Number TRBAM-25-05833

Paper Title **Evaluation of Traffic Safety Improvement Effect Based on "Shanghai Traffic Safety Improvement Program"**

Introduction Traffic safety policies, such as Sweden's "Vision Zero" and the UN's "Decade of Action for Road Safety 2021-2030," aim to improve road safety, but most still lack comprehensive effectiveness evaluation.
5 "Shanghai Traffic Safety Improvement Program", launched to address high traffic violations and crashes, utilizes advanced technologies for enforcement and targets major violations, but its effectiveness is still primarily evaluated through basic before-and-after comparisons. Traditional policy evaluation methods like randomized controlled trials face challenges with bias and parametric uncertainties, while quasi-experimental designs, such as Difference-in-Differences and Regression Discontinuity, have their own limitations. The Interrupted Time Series method, while effective for assessing overall policy impact, can still be influenced by confounding factors. To address these issues, this study employs the Interrupted Time Series method and introduces the Bayesian causal interrupted time series model with covariates to quantitatively evaluate traffic crash and violation data in Shanghai from 2014 to 2019.

Authors	Tianren Zhang, Tongji University Yajie Zou, Tongji University Yubin Chen, Tongji University Yuanchang Xie, University of Massachusetts, Lowell
Sponsoring Committee	Standing Committee on Transportation Safety Management Systems (ACS10)
Session Number	**Lectern Session 2123**
Session Title	Creating a Safer System: A Lectern-Poster Session
Paper Number	TRBAM-25-01709
Paper Title	**Safety-Oriented Route Guidance System Considering the Impact of Driving Behaviors**
Abstract	Modern navigation systems prioritize fuel efficiency and time savings, often overlooking the critical aspect of road safety. This study addresses this gap by developing an advanced safe route guidance approach for Electronic Route Guidance Systems that incorporates personalized safety metrics based on individual driving behaviors and road conditions. Using the Safety Performance Function to evaluate the overall risk of road segments, and the copula model to capture the 6 correlation between driving behaviors and roadway risk, this research uses conditional probability theory to quantify the safety levels of road segments for drivers with different driving behaviors to tailor safer route recommendations. The proposed approach is validated using the crash data, roadway geometric data, and driving behavior data collected from Los Angeles, demonstrating its capability to customize navigation based on individual driving behavior and significantly enhance route safety. The findings suggest that the safest route may vary depending on driving behavior. This research not only incorporates individualized traffic safety in navigation but also offers a scalable framework for future navigation systems to incorporate safety as a fundamental component. Keywords: Copula theory, Driving behavior, Road crash, Personalized navigation

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Sponsoring Committee	Standing Committee on Transportation Safety Management Systems (ACS10)
Session Number	**Lectern Session 2123**
Session Title	Creating a Safer System: A Lectern-Poster Session
Paper Number	TRBAM-25-00232
Paper Title	**The Benefits of High-speed Rail on Reducing Traffic Accidents: Evidence from China**
Abstract	To assess the nexus between High-Speed Rail (HSR) and road traffic accidents in China, this study analyzes how HSR influences accidents and then conducts a battery of empirical checks using the Difference-in-Differences (DiD) estimator and city-level data from 2005-2017. We find that new HSR routes lead to a 0.417-point reduction in accidents and a 1.511-point reduction in total traffic fatalities, translating to a 20% and 17% decrease respectively after accounting for meteorological variables and fixed effects. Heterogeneity analyses reveal more pronounced effects in economically developed cities with larger urban populations, better public transit infrastructure, and those in western regions. Furthermore, utilizing Tencent migration big data, we demonstrate that these reductions stem from substituting road passenger transport with HSR, especially for medium-to-short journeys. This paper addresses an academic gap in understanding HSR's impact on road safety and provides an idea for future road traffic safety management, that is, should corresponding measures to build an HSR-friendly environment be considered. Keywords: High speed rail, Road traffic accident, Difference-in-Differences, Modal shift

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Sponsoring Committee	Standing Committee on Transportation Safety Management Systems (ACS10)
Session Number	**Lectern Session 2123**
Session Title	Creating a Safer System: A Lectern-Poster Session
Paper Number	TRBAM-25-03724
Paper Title	**Impact of the 20mph Speed Limit in the UK: What Does the Evidence Show?**
Abstract	To assess the nexus between High-Speed Rail (HSR) and road traffic accidents in China, this study analyzes how HSR influences accidents and then conducts a battery of empirical checks using the Difference-in-Differences (DiD) estimator and city-level data from 2005-2017. We find that new HSR routes lead to a 0.417-point reduction in accidents and a 1.511-point reduction in total traffic fatalities, translating to a 20% and 17% decrease respectively after accounting for meteorological variables and fixed effects. Heterogeneity analyses reveal more pronounced effects in economically developed cities with larger urban populations, better public transit infrastructure, and those in western regions. Furthermore, utilizing Tencent migration big data, we demonstrate that these reductions stem from substituting road passenger transport with HSR, especially for medium-to-short journeys. This paper addresses an academic gap in understanding HSR's impact on road safety and provides an idea for future road traffic safety management, that is, should corresponding measures to build an HSR-friendly environment be considered. Keywords: High speed rail, Road traffic accident, Difference-in-Differences, Modal shift

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Sponsoring Committee	Standing Committee on Transportation Safety Management Systems (ACS10)
Session Number	**Lectern Session 2123**
Session Title	Creating a Safer System: A Lectern-Poster Session
Paper Number	TRBAM-25-03857
Paper Title	**A Comparison of Road Crash Reporting in High-, Middle-, and Low-Income Countries: Global Perspectives**
Abstract	The quality of road safety improvement is dependent on the quality of the respective data on which improvements are based. Due to the ability of police reported crash data to provide an overall outlook of crash factors, and the lack of an equally informative alternative, these data have become the standard for road safety research. Thus, enhancing police reported crash data is paramount to enhancing data driven road safety improvements. However, the type of data recorded often vary between regions, resulting in a lack of comparability. The United Nations recognizes the overall importance of improved quality, harmonization, and comparability of road safety data collection at the international, national, and regional levels as part of the Global Plan for the Second Decade of Action for Road Safety. In this regard, focus should be directed toward harmonizing and developing best practices for road safety data collection across high-income (HIC), and low- and middle-income countries (LMIC). This study synthesizes and compares road crash reports from various countries, internationally to improve crash reporting and subsequently the quality of crash data. Reportable variables are compared by assessing the level of data coverage and resolution between 12 HICs and 13 LMICs on a global scale. Further, attention is drawn to disparities in crash data collection among these countries, with the accompanying discussion having the potential to provide a basis on which current crash reporting systems may be enhanced. Results contribute to the improvement of road safety research, interventions, crash reporting methods, and promote collaboration among agencies.

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Sponsoring Committee	Standing Committee on Transportation Safety Management Systems (ACS10)
Session Number	**Lectern Session 2171**
Session Title	Decision Making with Safety Surrogates
Paper Number	TRBAM-25-01152
Paper Title	**Development of a Driver Safety Reward System Incorporating YOLO-based Traffic Violation Detection at Roundabouts under Highly Heterogeneous Traffic**
Introduction	Road safety is a pressing global concern, with intersections like roundabouts often seen as safer alternatives but increasingly marred by high violation rates, especially in low- and middle-income countries (LMICs) with heterogeneous traffic conditions. In the case of roundabouts, 11,410 crashes occurred, leading to 4,051 deaths and 10,636 injuries in 2022 in India (1). The traffic in developing countries is characterized by highly mixed traffic conditions with bicycles, cars, motorcycles, auto-rickshaws, trucks, buses, etc., plying on the same road, maintaining no lane discipline (2). The traffic condition coupled with traffic violations further compels to compromise with safety even in the case of roundabouts (3). Therefore, the “safer intersections,” i.e., roundabouts, have become junctions of confusion and violation, leading to near misses (4). Traditional methods of monitoring and enforcing traffic rules often fall short in addressing the complexities of modern urban traffic, necessitating innovative approaches to enhance road safety. This study introduces an innovative Driver Safety Reward System (DSRS) that integrates advanced AI technologies to detect traffic violations and incentivize safer driving behaviors at unsignalized roundabouts. The system utilizes Unmanned Aerial Vehicle (UAVs)-recorded high-resolution video data processed through YOLOv8m and ByteTrack to accurately detect and track vehicles (5–7), identifying violations such as wrong-way driving, improper U-turns, and anti-clockwise movements (8). The kinematic data from detected trajectories, including overspeed, sharp accelerations, and decelerations, form the basis for scoring driver behavior (9). A web-based reward platform developed using the MERN stack ranks drivers and allocates reward points, encouraging safer practices while generating critical data for traffic management. This approach addresses the unique challenges of mixed, non-lane-based traffic by shifting from reactive enforcement to proactive safety measures. Advancements in machine learning and UAV technologies have revolutionized traffic monitoring, addressing the limitations of conventional systems like fixed cameras and loop detectors (10, 11). UAVs offer a top-down perspective, enhancing data granularity for analyzing driver behaviors (12, 13). Studies have established YOLO's efficacy in real-time object detection, with YOLOv8m excelling in accuracy and computational efficiency, making it ideal for aerial imagery applications (14). ByteTrack, as a robust multi-object tracking algorithm (5), further improves trajectory analysis, which is crucial for monitoring non-lane-based traffic. Previous research has emphasized the impact of aggressive driving behaviors—speeding and abrupt maneuvers—on road safety (9, 10). Efforts like safety scoring frameworks and driver credit systems have explored behavior-based interventions (15, 16). However, existing approaches often overlook specific roundabout violations and the integration of comprehensive kinematic parameters. This study bridges the gap by leveraging UAV data, advanced detection models, and a reward mechanism to enhance safety at roundabouts, particularly under complex, heterogeneous traffic conditions.

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Sponsoring Committee	Standing Committee on Transportation Safety Management Systems (ACS10)
Session Number	**Poster Session 3039**
Session Title	Transportation Safety Management Systems from Start to Finish
Paper Number	TRBAM-25-00102
Paper Title	**Impact of COVID-19 Pandemic on Distraction-Related Motorcycle Crashes**
Introduction	The severe acute respiratory syndrome (SARS-CoV-2), also known as the 2019 novel coronavirus (COVID-19), had significant global consequences and was declared a pandemic by the World Health Organization (WHO) (1). Several studies have highlighted that traffic conditions and patterns have significantly changed worldwide since the COVID-19 pandemic (e.g., 2, 3). According to the National Highway Traffic Safety Administration (NHTSA) (4), distracted driving is any activity that diverts the driver's attention from the primary task of navigating the vehicle and responding to critical events. Moreover, distracted driving has significantly increased post-COVID-19 pandemic. For instance, a recent report from Cambridge Mobile Telematics (CMT) (5) highlighted that distracted driving in the U.S. has increased by more than 20%, and fatalities due to distraction increased by 10.4% post the pandemic. The risk of distraction-related casualties exponentially increases with motorcycles due to the lack of vehicle stability and in-vehicle protection for motorcyclists. Motorcyclists are among vulnerable road users and are highly prone to severe injury crashes. According to NHTSA (6), motorcycles accounted for 14% of total traffic fatalities in 2021, while only representing 3.5% of all registered vehicles. These statistics emphasize the need to investigate the causes and circumstances resulting in distraction-related motorcycle crashes and the changes in crash patterns post-pandemic. The review of existing literature revealed that several safety studies have highlighted the reduction of traffic volumes and crash frequencies during the COVID-19 pandemic, while there was an increase in crash injury severities, fatalities, and risky driving behaviors such as speeding and distracted driving. However, limited research efforts have been made to examine the detrimental effects on motorcycle crashes. Specifically, the impact of COVID-19 pandemic on distraction-related motorcycle crashes has not been widely investigated. This study takes the initiative and investigates the impact of COVID-19 pandemic on distraction-related motorcycle crashes through a comparative analysis of pre-COVID-19 (2015-2019) and post-COVID-19 (2020-2022) periods in Kentucky using comprehensive crash and roadway data. The study findings would help propose more targeted safety countermeasures to enhance motorcyclists' safety.

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Sponsoring Committee	Standing Committee on Transportation Safety Management Systems (ACS10)
Session Number	**Poster Session 3039**
Session Title	Transportation Safety Management Systems from Start to Finish
Paper Number	TRBAM-25-00294
Paper Title	**Assessing E-scooter Rider Safety Perceptions in Shared Spaces: Insights from Sweden**
Abstract	Shared spaces prioritise the role of micromobility in urban environments by separating vulnerable road users from motorised vehicles, aiming to enhance actual objective and subjective safety perceptions. However, various modes of transport with differing navigation characteristics impact road users' perception of safety. Despite the rise of emerging transport modes such as e-scooters, there is a lack of theoretical and empirical evidence regarding their safety perception in shared spaces. In response, we conducted an online video experiment and polled 920 e-scooter users in Sweden to assess their safety perceptions. We collected data on socio-demographics, travel habits, crash history, and responses to hypothetical video scenarios depicting interactions where riders overtake or meet cyclists in shared spaces. We then employed a random effect latent class ordered logit model to quantify the determinants of e-scooter riders' safety perceptions. The findings indicate that women feel less safe in shared spaces compared to men. Additionally, the direction of encounters significantly affected young adults, who perceived meeting other users as more unsafe than overtaking them. These findings highlight the importance of accounting for unobserved heterogeneity in safety perceptions, emphasise the significant role of demographic variables in understanding users' safety perceptions, and reinforce the need for inclusive design of shared spaces for all road users.

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Session Number	**Poster Session 3039**
Session Title	Transportation Safety Management Systems from Start to Finish
Paper Number	TRBAM-25-00754
Paper Title	**Comparative Analysis of Three Proposed Network Screening Methods on Rural Highways**
Introduction	Rural roads account for 40% of traffic fatalities in the U.S., despite representing only 20% of the population and 32% of vehicle miles traveled (1). These statistics demonstrate the need for improving rural road safety and the requirement to effectively include it in the ongoing state safety improvement programs. Network screening is a critical step in the highway safety improvement programs, aiming to identify sites within the network that warrant further examination for potential safety enhancements. This study focuses on evaluating three network screening methods tailored for rural highways—Global Risk Scoring (GRS), Crash Risk Index (CRI), and Predicted Empirical Bayes (P-EB) using rural two-lane road network in Oregon. The analysis revealed distinct strengths among the screening methods. The GRS method demonstrated a high level of consistency with historical crash data while the Predicted EB method exhibited superior consistency across different time periods, suggesting its value for long-term safety planning. The CRI method demonstrated reasonable consistency in performance, irrespective of the test carried out. While no single method outperforms the others in all scenarios, each has unique advantages and data requirements that can better suit the needs of the agency given available resources. While there has been a significant focus on developing various network screening methods, less attention has been given to evaluating and comparing their performances (2). Research on network screening methods has consistently highlighted the effectiveness of the Empirical Bayes (EB) method. Persaud and Hauer (3,4) demonstrated that EB outperforms nonparametric methods in hotspot identification. Italian studies (5,6) confirmed the superiority of EB and Potential for Safety Improvement (PSI) over crash frequency and rate methods. Elvik (7) validated reliability of EB method using Norwegian data, and Dhakal and Al-Kaisy (8,9) demonstrated the superiority of EB method on high-traffic segments. However, smaller agencies lack technical expertise and data to use the more sophisticated EB method. This research addresses this gap by testing methods requiring minimal data while evaluating their theoretical and practical relevance.

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Session Number	**Poster Session 3039**
Session Title	Transportation Safety Management Systems from Start to Finish
Paper Number	TRBAM-25-01151
Paper Title	**Spatial Analysis of E-Scooter Accidents, the Case Study of England and Wales**
Abstract	The recent surge in electric scooter (e-scooter) adoption for urban transportation has increased safety concerns. This study conducts a spatial analysis of e-scooter accidents in England and Wales using Geographic Information Systems (GIS) techniques to investigate crash patterns. Geographically Weighted Regression (GWR), Getis-Ord Gi*, and Moran's I were employed to understand spatial variations and identify significant hotspots. The study analyzed e-scooter crash data from STAT19, spanning three years (January 2020 to December 2022), alongside 2021 Census data from the Office for National Statistics (ONS). It identified 303 statistically significant hotspots and 48 cold spots, providing insights into spatial clustering. Analysis revealed peak incidents during weekday mornings, afternoons, and weekend evenings, predominantly on single-carriageways with 30 mph or lower speed limits. It was further revealed that e-scooter accidents are more prevalent on residential roads, followed by primary roads. Comparative analysis between Ordinary Least Squares (OLS) and GWR models demonstrated that GWR effectively captures spatial heterogeneity. Positive correlations were found with population density, single-carriageways, social housing areas, and minority Asian and Black populations, whereas increased green spaces showed a negative correlation. The study offers insights into e-scooter challenges in the UK's urban landscapes, informing safety interventions and urban planning. Keywords: E-scooter, Spatial Analysis, Geographically Weighted Regression (GWR), Hot spots, Moran's I, Getis-Ord Gi*

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Sponsoring Committee	Standing Committee on Transportation Safety Management Systems (ACS10)
Session Number	**Poster Session 3039**
Session Title	Transportation Safety Management Systems from Start to Finish
Paper Number	TRBAM-25-01229
Paper Title	**Impact of Operating Speed, Roadway Curvature, and Precipitation on Crash Risks in Rural Two-Lane Roads**
Abstract	Roadway departure crashes account for many annual crashes on Texas roadways. Understanding the effects of various risk factors is essential for developing cost-effective safety countermeasures. This study focuses on rural two-lane segments, introducing a data collection method that includes operating speed, road geometry, precipitation, and land use characteristics. Addressing the gap in understanding the equivalent property damage only (EPDO) rate, this study analyzes its distributional characteristics and develops a machine learning model using 7 Texas crash data from 2015 to 2019. The study compares risk factor modeling results for EPDO 8 and total crash frequency using SHapley Additive exPlanations (SHAP). The results indicate that 9 segment length, Average Annual Daily Traffic (AADT), AADT difference, curvature, land use 10 characteristics, and precipitation positively correlate with crash risk, while wider lane and right-11 of-way widths reduce risk. Operating speed measures show complex interactions. The EPDO 12 model demonstrates a higher impact of these factors compared to the total crash frequency 13 model. This study offers valuable insights and a comprehensive framework for understanding 14 crash risks on rural roadways, which can inform the development of targeted safety 15 interventions. 16 17 Keywords: roadway segment, roadway departure crashes, equivalent property damage only 18 score, machine learning, SHapley Additive exPlanations

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Session Number	**Poster Session 3039**
Session Title	Transportation Safety Management Systems from Start to Finish
Paper Number	TRBAM-25-01298
Paper Title	**Characterizing the Riding Behavior of Food Delivery Motor Scooters Based on Sensor Data Mining**
Introduction	The COVID-19 pandemic accelerated the growth of food delivery services, leading to increased use of motor scooters and a rise in related accidents. In Korea, both food delivery transactions and motor scooter accidents have shown significant increases. The number of motor scooter accidents rose from 17,611 cases in 2018 to 21,258 cases in 2020, with most accidents occurring during dinner time. Motor scooters are preferred by delivery riders for their accessibility and cost-effectiveness. However, delivery time constraints often lead to risky riding behaviors, increasing accident potential. In 2020, 3,268 delivery riders were involved in accidents, a 30% increase from 2019. The Korean government has responded by strengthening enforcement and providing safety education, but more quantitative and engineered countermeasures are needed. Naturalistic riding studies have been conducted to understand factors influencing hazardous motorcycle situations, collecting data from riders' daily trips to analyze riding characteristics. Several studies have analyzed riding characteristics of two-wheeled vehicles and classified riding patterns using naturalistic riding data. These studies typically use data from accelerometers, gyroscopes, and GPS sensors. While existing studies have focused on developing risky event detection methods, there is a need to define riding patterns based on the analysis of individual rider characteristics, specifically for food delivery motorcycles. This study aims to identify patterns of delivery rider behavior and characteristics by analyzing real-world riding data from food delivery platform riders. The insights gained will serve as a foundation for developing data-driven, engineering-based strategies to enhance safety for delivery riders.

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Sponsoring Committee	Standing Committee on Transportation Safety Management Systems (ACS10)
Session Number	**Poster Session 3039**
Session Title	Transportation Safety Management Systems from Start to Finish
Paper Number	TRBAM-25-01577
Paper Title	**Getting a “W” for Safety: Flipping the Script on the Safety “Es” in Search of a Winning Strategy**
Abstract	As we enter the second decade of Vision Zero in the US, this paper emphasizes the need to move beyond traditional safety silos and strategies. Historically, transportation safety has relied on the "Es" of safety: engineering, enforcement, education, and emergency services. The Safe System Approach represents a pivotal shift from those silos towards a system-based, proactive paradigm. While this approach has garnered substantial funding and support in the US, its implementation can still revert to the traditional Es mindset, missing the core principle of kinetic energy risk reduction. This paper argues that kinetic energy, the root cause of roadway injuries and deaths, must be central to safety strategies. By focusing on exposure, likelihood, and severity, the Safe System Approach can more effectively mitigate risks. Referencing the Safe Systems Pyramid, this paper explores safety through a public health lens, emphasizing systemic interventions over individual efforts. In alignment with the Pyramid, this paper proposes a "Ws of transportation safety" framework that examines who, what, when, where, why, and which policies influence travel behavior and the environment. This comprehensive view unlocks new safety tools and partnerships, highlighting the importance of upstream interventions such as land use planning, multimodal transportation options, and affordable housing. The paper concludes with practical applications of the Ws framework, illustrating its potential to transform roadway design and safety assessments. By institutionalizing these strategies, transportation practitioners can find a fresh set of tools, and hopefully refreshed motivation, funding, partners, and purpose, in support of Vision Zero 2.0.

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Session Number	**Poster Session 3039**
Session Title	Transportation Safety Management Systems from Start to Finish
Paper Number	TRBAM-25-01631
Paper Title	**Modeling the Drivers’ Over Speeding Choice Using Simultaneous Equations**
Abstract	One of the most significant factors in investigating of the likelihood, severity of car crashes, and safety research is drivers' speed choice. Understanding the impacts of the drivers’ overspeeding choice could significantly improve the roads safety and severity of crashes. In this article, drivers' choice of speed in Tehran's urban and rural roads models simultaneously via data collection through a survey to reach a more efficient estimation. The Seemingly Unrelated Regression Estimation (SURE) model and the Three-Stages Least Square (3SLS) model are deployed and compared. The results indicate that socio-economic factors, records of drivers' violations, besides behavioural and psychological parameters, affect the drivers' speed choice. Moreover, the results show that the SUR model provides a more powerful predicting power than the 3SLS models. Thus, although the drivers' speeding behaviours are correlated in error terms, these endogenous variables are not correlated.

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Sponsoring Committee Standing Committee on Transportation Safety Management Systems (ACS10)

Session Number **Poster Session 3039**

Session Title Transportation Safety Management Systems from Start to Finish

Paper Number TRBAM-25-02120

Paper Title **Estimating the Cost and Benefits of and Number of Lives Saved by Crash Avoidance Technologies**

Abstract Crash prevention systems play an important role in enhancing vehicle safety by alerting drivers about potential risks and, in some instances, taking corrective action to mitigate these risks. This research uses vehicle insurance claims reports and national crash datasets to evaluate the societal and private economic impacts of deploying crash avoidance technologies throughout the US light duty vehicle fleet across two scenarios. The first scenario focuses on warning systems, including blind spot monitoring (BSM), lane departure warning (LDW), and forward collision warning (FCW). The second scenario looks at the benefits of equipping vehicles with AEB in addition to the aforementioned warning systems. Based on the cost to deploy these technologies and the economic benefits that arise from crash prevention and crash severity changes, the fleet wide deployment of AEB in addition to warning systems could provide $79.2 and $65.2 billion in annual net-societal and net-private benefits, respectively. Because AEB has significantly higher reductions in crash frequency than the warning systems, adding AEB to vehicles would more than double the societal and private benefits than that from warning systems alone. Additionally, considering the different combinations of crash avoidance technologies available in vehicles today, there were around 110 lives saved in 2019 due to the ability for crash avoidance technologies to help drivers avoid crashes. Because the current penetration rate of crash avoidance systems are still low and effectiveness of the systems are likely to improve over time, the number of lives saved and economic benefits should increase over time.

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Session Number	**Poster Session 3039**
Session Title	Transportation Safety Management Systems from Start to Finish
Paper Number	TRBAM-25-02461
Paper Title	**A Comprehensive Assessment of Pedestrian Fatalities on High-Speed Roads in Rural Areas**
Introduction	Pedestrians are considered the most vulnerable road user groups (VRUs) due to the lack of physical protective casing. The pedestrian fatality is unevenly distributed all over the world. The high fatality rate in low- and middle-income countries (LMICs) is a major concern. India, being an LMIC, witnesses a very high share of pedestrian fatalities each year. In their published report, the Ministry of Road Transport and Highways (MoRTH) shows that in 2022, India witnessed a total of 461,312 crashes, claiming 168,491 lives, of which 18% were pedestrians. National Highways (NH), which are high-speed rural roads connecting all the major cities and states in India, are 2.1% of the total road network length and witnessed 151,997 (32.9%) crashes, claiming 61,038 (36.2%) lives, of which 10,160 (13.5%) deaths are of pedestrians (1). Pedestrian fatality data from the MoRTH report was analyzed and found to be non-uniformly distributed throughout the country. Pedestrian fatality rate per 100,000 population is highest for Tamil Nadu (62.4), followed by Haryana (41.8), Telangana (40.1), Karnataka (32.3), and Kerala (31.6), whose fatality rates are significantly higher than the national average (24.4). Pedestrian fatalities in rural areas are much higher than those from urban areas, and that too on NH is higher than on other roads. The pedestrian fatality on NHs in Haryana is 39.2% of total pedestrian fatalities, which shows that there is an urgent need to address this highly pressing issue on high-speed roads in rural areas. The pedestrian fatalities on high-speed rural roads in LMIC are a less addressed area (2). Most of these studies identify the factors contributing to and assessing the impact of present road infrastructure on pedestrian fatalities. Factors like age and gender of pedestrians, pedestrian action and location at the time of crash, junction, surface condition and quality, road geometry, median type, vehicle type, traffic movement, clear zone width, presence of settlement, service road, and vehicular speed (3). Some studies assess the effectiveness of present road infrastructure like foot over bridge (FOB) (4) in LMICs, and some developed pedestrian crash frequency models using some modelling techniques. As pedestrian crashes are random and rare events, many count data models are used to address the crash prediction depending on different variables (5). Some of these models address the over-dispersion nature of crash data, and some address the presence of excess zeros in the datasets. This study estimates the landcover along different roads in Haryana using the Sentinel-2 dataset due to its high resolution (10m) (6) and highly exposed population living in a buffer of 500m along all the rural roads in Haryana (7). Other variables like village density, access density and number of lanes are estimated for all the roads, and the Generalized Poisson (GP) and Negative Binomial (NB) models are used to find the impact of these exposure variables on pedestrian fatalities on high-speed roads. The pedestrian fatality rate per 10,000 people is also estimated for different roads so that the most affected roads can be compared and identified for detailed analysis and interventions. The roads with high pedestrian fatality rates are identified and should be prioritized above others for interventions.

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Sponsoring Committee	Standing Committee on Transportation Safety Management Systems (ACS10)
Session Number	**Poster Session 3039**
Session Title	Transportation Safety Management Systems from Start to Finish
Paper Number	TRBAM-25-02491
Paper Title	**Advanced Crash Weighting Techniques for Forecasting the Future Economic Impact of Collisions**
Abstract	This study evaluates the effectiveness of current methodologies used by Departments of Transportation (DOTs) for forecasting the future economic impact of roadway crashes. Although the amount of previous estimated property damage only (ePDO) is commonly used by transportation agencies to prioritize safety improvement decisions, there is limited research validating the adequacy of this approach. The purpose of this paper is to evaluate existing methods and propose a new methodology with increased accuracy. Utilizing over 285,000 crash records in over 125,000 road segments between 2013 and 2022, the research compares traditional forecasting methods, based on historical ePDO and past crash numbers, with a novel approach that employs a custom weighting scheme derived from Lasso regression. This novel approach is based on correlation with future crashes, rather than solely on economic costs. Findings indicate that the Lasso regression model, which addresses multicollinearity and emphasizes severe crashes, outperforms both traditional methods in predicting future ePDO. The model effectively balances crash frequency and severity, providing a more accurate framework for identifying high-risk locations. The results show that although fatal crashes are significantly more costly, they are only slightly better risk indicators of future ePDO compared to injurious crashes, emphasizing the necessity for a more nuanced approach to crash forecasting. The proposed methodology allows for DOTs to improve safety prioritization programs without requiring additional data. Furthermore, it provides a novel framework for future research on how to weight crash data based on the risk of future crashes rather than the economic impact of previous crashes. Keywords: Roadway Safety, Crash Forecasting, ePDO, Lasso Regression, Multicollinearity, High-risk Locations, Safety Improvements, Resource Allocation.

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Sponsoring Committee	Standing Committee on Transportation Safety Management Systems (ACS10)
Session Number	**Poster Session 3039**
Session Title	Transportation Safety Management Systems from Start to Finish
Paper Number	TRBAM-25-02539
Paper Title	**<u>Spatial Inequality in Socio-Demographic and Commute Patterns and their Impacts on Traffic Crash Rates: A Comparison of Interpretable Machine Learning and Spatial Statistical Modelling</u>**
Abstract	Traffic crash rates are often closely related to the region's socio-demographic, commuting behavior, motivated by the risks associated with increased region density and excessive congestion. However, crash rates of different severities may vary considerably due to socio-spatial disparities and the mitigation behaviors adopted across regions. Thus, this study elucidates the intricate effects of socio-demographic dynamics and commuting behavior on overall and fatal traffic crash rates across Florida's counties, with particular emphasis on the underlying factors of spatial inequality. Employing an interpretable machine learning model, specifically eXtreme Gradient Boosting (XGBoost), we demonstrate its superiority in detecting spatial heterogeneity and the complex effects of various factors compared to traditional spatial statistical models, e.g. Spatial Lag Model (SLM) and Multiscale Geographically Weighted Regression model (MGWR). The findings reveal the spatial variations in both overall and fatal crash rates, correlating significantly with socio-demographic and commute pattern variables. Key variables include population demographics, commute duration, education levels, unemployment rates, and intersection density. Notably, the study dispels the conventional belief that higher overall crash rates directly correlate with higher fatal crash rates within the same counties, underscoring the importance of distinct analysis. Policy initiatives should prioritize enhancing accessibility to road infrastructure and healthcare services, differentiating between sparse and densely populated regions. These insights highlight the importance of addressing spatial inequalities in transportation infrastructure and policy interventions to mitigate traffic crash risks and enhance road safety for all regions. Keywords: Traffic crash rates, Socio-demographic, Commute patterns, Spatial inequality, Interpretable ML, Policy-making support

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Sponsoring Committee	Standing Committee on Transportation Safety Management Systems (ACS10)
Session Number	**Poster Session 3039**
Session Title	Transportation Safety Management Systems from Start to Finish
Paper Number	TRBAM-25-02725
Paper Title	**<u>Comparing Location-Based and Home-Addressed Based Approaches in Evaluating Societal Crash and Congestion Costs</u>**
Abstract	Traffic congestion and safety pose two of the largest challenges for transportation planners and engineers worldwide, placing significant economic, environmental, and social burdens on the public. In the United States (US) crashes were estimated to have cost the American public $340 billion in 2019, with congestion costs estimated to be over $166 billion in 2017. With funding from the historic Infrastructure Investment and Jobs Act (IIJA) becoming available to transportation agencies around the US, it is vital that agencies identify the most impactful infrastructure projects to prioritize funding on to address these costs. At the same time, the US is seeking to address the lack of infrastructure spending in disadvantaged communities in previous decades. To guide this infrastructure spending, data is required to properly analyze the locations most in need of funding. This study assesses the trade-off between data accuracy and data availability in two methodologies to estimate societal crash and congestion costs, focusing on the comparison between county-level location-based aggregation and home-addressed based approaches. The study assessed crash data in the state of Massachusetts and utilized the results of the Boston Region MPO's TDM23 travel demand model to evaluate these trade-offs. Keywords: Transportation Equity, Regional Safety, Transportation Planning

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Session Number	**Poster Session 3039**
Session Title	Transportation Safety Management Systems from Start to Finish
Paper Number	TRBAM-25-02795
Paper Title	**The Role of Insurance in Nighttime Hit-and-Run Crashes: A Geo-Spatial Analysis**
Introduction	A hit-and-run occurs when a driver involved in a collision leaves without providing information or aiding the injured, a serious legal offense nationwide (9). These crashes pose significant public safety challenges, often leading to severe outcomes for victims and complicating emergency response (1). NHTSA's latest data indicates nearly 6,000 fatalities from hit-and-runs in 2021-2022 (14). Such crashes are especially dangerous for pedestrians and cyclists, accounting for 25% and 24% of related fatalities in 2022, respectively (14). Studies show nighttime hit-and-runs are more injury-prone than daytime ones (28) due to factors like poor visibility, reduced traffic, and impaired driving, emphasizing the need to understand what drives this behavior at night (2). Early studies aimed at identifying contributing factors included Solnick and Hemenway, who examined driver and collision characteristics in pedestrian hit-and-runs (19). Tay et al. expanded this to broader factors using logistic regression, identifying significant elements like vehicle and road type, collision nature, driver traits, and environmental features (23). Both studies noted a higher occurrence of nighttime hit-and-run crashes involving male drivers. Zhang et al. used logistic regression to explore 77 factors influencing hit-and-run decisions in China, introducing socioeconomic variables (28). Macleod et al., with a decade of pedestrian-vehicle data, found higher hit-and-run risks during early mornings, low-light conditions, and weekends (12). Logistic regression models are the common choice for such analyses (19, 21-23,28). Although crash data reveal spatial patterns, logistic regression often overlooks spatial dependencies, affecting model accuracy (9, 13, 17). Geographically Weighted Regression (GWR) addresses this by allowing coefficients to vary by location, capturing spatial heterogeneity (6,8,9,20,27). Liu et al.'s research in Michigan combined census and crash data, showing regional variations in how driving under the influence impacted hit-and-run risks, with higher risks in areas of higher unemployment and lower college graduation rates (9). Despite extensive studies on factors like vehicle type, road conditions, and driver traits, research on insurance factors is limited. Zhang et al. found insurance significantly influenced hit-and-run decisions in China (28). However, this finding has yet to be validated more broadly. No studies have considered insurance in nighttime hit-and-run contexts, making this study's inclusion of insurance factors to assess nighttime hit-and-run risks an essential contribution. This study explores nighttime hit-and-run crashes, focusing on spatial variations and unobserved heterogeneity influenced by geographic and socioeconomic factors. It also investigates the role of auto insurance status in nighttime hit-and-run behavior. Using 2023 Pennsylvania traffic crash data, the study applies geographically weighted logistic regression (GWLR) to analyze the relationship between hit-and-run decisions and factors such as insurance status, driver demographics, vehicle characteristics, crash severity, roadway and environmental conditions. The findings aim to inform policymakers, insurance companies, and local agencies, emphasizing region-specific strategies to reduce hit-and-run crashes and improve road safety.

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Sponsoring Committee Standing Committee on Transportation Safety Management Systems (ACS10)

Session Number **Poster Session 3039**

Session Title Transportation Safety Management Systems from Start to Finish

Paper Number TRBAM-25-02797

Paper Title **Segment-Level and Intersection-Level Driving Volatility Analysis Using Large-Scale Crowdsourced Vehicle Movement Data**

Introduction Traffic safety traditionally relies on crash data to evaluate roadway safety and implement nterventions. However, crash data, while critical, are inherently reactive and limited by the infrequency and delayed availability of incidents. This limitation underscores the need for proactive safety measures that can identify risk factors before crashes occur. Driving volatility, defined as the frequency and intensity of extreme driving maneuvers (e.g., hard braking, rapid acceleration, swerving), offers a promising metric to assess road safety dynamically. With advancements in connected vehicle technologies and the increasing availability of high-resolution, crowdsourced traffic data, driving volatility can be analyzed at a granular level. Unlike conventional metrics, driving volatility captures real-time behavioral patterns, providing a proactive measure of safety risks. Previous studies have demonstrated the correlation between driving volatility and crash frequency, but most have focused on aggregated or network-level analyses, leaving a gap in understanding the spatial distribution of volatility at finer scales, such as road segments and intersections. This study addresses this gap by examining driving volatility at the segment and intersection levels in Tuscaloosa, Alabama, using crowdsourced vehicle movement data. By integrating spatial algorithms to map driving behaviors to specific road features, the study quantifies the relationship between driving volatility and crash frequency. Using a Zero-Inflated Negative Binomial (ZINB) model, the analysis provides insights into the localized impact of driving behaviors on safety outcomes, highlighting areas of high risk and offering a foundation for targeted interventions.

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Session Number	**Poster Session 3039**
Session Title	Transportation Safety Management Systems from Start to Finish
Paper Number	TRBAM-25-02906
Paper Title	**Assessing the Level of Speed Stability with Reliability-based Empirical Indexes for Sustainable Urban Mobility Environment**
Abstract	On urban roads, where conflicts between vehicles and pedestrians are frequent, special attention is required for pedestrian safety. Because of the strong relationship between vehicle speeds and urban vulnerable road users' safety, the importance of speed management as a primary traffic management strategy for promoting sustainable transportation has been highlighted in numerous studies. In Korea, speed management focuses on enforcing speed limits to encourage vehicle deceleration, overlooking consideration of vehicle speeds with geometric and traffic conditions for each road segment. This study developed a methodology to determine speed stability, under the assumption that the speed stability to reduce pedestrian injury severity may vary depending on the road environment and traffic conditions. Additionally, a method to evaluate the level of speed stability for each road segment and time period was proposed based on vehicle trajectory, traffic crash, and road geometry data. Then, thresholds of the level were calculated reflecting regional characteristics, and validated through correlation analysis with crash occurrence patterns. Finally, policy implications of preparing countermeasures for each level were presented. The approach presented in this study is expected to contribute to creating a safe and healthy pedestrian environment by encouraging voluntary competition to ensure pedestrian safety among local governments. Keywords: Speed Stability, Traffic Safety, Urban Road, Speed Management, Sustainable Transportation

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Sponsoring Committee	Standing Committee on Transportation Safety Management Systems (ACS10)
Session Number	**Poster Session 3039**
Session Title	Transportation Safety Management Systems from Start to Finish
Paper Number	TRBAM-25-03178
Paper Title	**How does subjective perception of streetscape affect traffic crashes? A spatial analysis for integrating safety into street planning**
Abstract	In previous research, objective factors of the built environment have been found to play a significant role in traffic crash frequency. While limited research has evaluated how people's all-around subjective perception indicators of streetscape affect crash risks. On the other hand, in urban planning field, people’s subjective perception of streetscape is a fine-grained evaluation approach for urban street quality, and the integration of traffic safety perspectives into street planning has received considerable attention. Our study aims to examine the association between people’s subjective perception of streetscape and the traffic crashes counts. Apart from this, this study intends to explore the spatial heterogeneity and distribution of this association to inform targeted safety prevention measures for key streets during the street planning process. The study focuses on the urban area of Daejeon in South Korea. Six perceptual indicators were adopted to reflect the street quality and people’s psychological state. A Bayesian multivariate spatial-varying coefficients model was introduced to simultaneously account for spatial random effect and the shared effect across various crash severity. Results indicate that four of six perceptual variables present significant associations with slight injury crash counts, and there is obvious spatial heterogeneity in their effect. Road segments exhibiting the strongest traffic safety effects from perceptual factors, combined with those with low performance on perceptual indicators, were identified as key areas for additional traffic safety enhancing measures. Overall, the findings are expected to facilitate the safety-enhanced street planning project and contribute to a human-oriented city. Keywords: Road safety, Crash frequency, Subjective perception, Streetscape, Spatial heterogeneity, Street planning

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Sponsoring Committee	Standing Committee on Transportation Safety Management Systems (ACS10)
Session Number	**Poster Session 3039**
Session Title	Transportation Safety Management Systems from Start to Finish
Paper Number	TRBAM-25-03180
Paper Title	**<u>Do Riding Behavior, Speeding, and Law Adherence Differ between Professional and Non-professional Riders?</u>**
Abstract	Bangladesh has experienced a rapid rise in the use of motorcycles in recent years. The surge in non-professional as well as professional riders is due to demand, ride-sharing opportunities, self-employment, and the affordable cost of motorbikes. Although riding behavior is identified as one of the most influential precursors of motorcycle safety, there is very little research comparing the riding behaviors of professional and non-professional riders. This study, therefore, aims to differentiate professional and non-professional riders based on their distinct riding behavior. Data from 624 motorcycle riders were collected via online and face-to-face questionnaire surveys in Dhaka. Following the feature selection through mean decrease accuracy and mean decrease Gini, this study developed a random forest model to delve deeper into riders' behavior. Furthermore, the SHAP-based feature importance technique was employed to determine the differential factors like overtaking vehicles from the wrong side, carrying passengers without helmets, no speed reduction on intersections of clear roads, and riding without proper fitness in differentiating riders. Additionally, this study focused on the law adherence, alertness, and speed behaviors of the rider groups. Keywords: Motorcycle Riding Behavior, Machine Learning, Traffic Safety

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Sponsoring Committee	Standing Committee on Transportation Safety Management Systems (ACS10)
Session Number	**Poster Session 3039**
Session Title	Transportation Safety Management Systems from Start to Finish
Paper Number	TRBAM-25-03225
Paper Title	**<u>Effect of Traffic Characteristics on Pedestrian Crash Risk Around School¬¬—A Micro-level Pedestrian Casualty Model</u>**
Introduction	According to statistics from World Health Organization (WHO), there were 312,000 pedestrian fatalities worldwide, accounting for 23% of global road deaths (1). In Australia, road traffic fatalities increased by 5.8% in 2022, resulting in 1,194 deaths (2). Walking is widely promoted as part of the city's sustainability strategy. As a result, policymakers, urban planners and transportation engineers are looking for ways to mitigate the risk of pedestrian crashes. The urban built environment has been considered as a vital determinant of pedestrian crash risk. Factors affecting the built environment can be broadly categorized into three groups: roadway features, land use features, and key features (3). Roadway network characteristics include intersection density, intersection type, roadway density, speed limits, etc(4). Land use also has a significant impact on the chances of pedestrian collisions, with commercial land use and residential leading to an increased likelihood of collisions (5). In addition, specific facilities such as tram stations, bus stops, and schools increase the likelihood of pedestrian collisions (6). Exposure plays a crucial role in traffic crash risk prediction studies. Pedestrian exposure is the probability of contact or involvement in a collision between a pedestrian and a vehicle (7). Exposure is correlated with the risk of traffic crashes. Factors such as socio-economic indicators, demographics, the built and natural environments influence this correlation. In previous studies, metrics including population, population density, and trip data were used to estimate pedestrian crash exposure at the regional level (8). However, these indicators rely on long-term statistics, which prevents accurate quantification of pedestrian exposure. In previous studies, indicators including population density, demographics and socio-economics were used to estimate pedestrian crash. However, at the micro level (e.g., roadway segments), it is difficult to accurately estimate pedestrian crash exposure by relying on these macro indicators alone. Hence, the proposed pedestrian collision model leveraging granular street-level data, not only enhances precision but also holds significance in enhancing pedestrian safety.

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Sponsoring Committee	Standing Committee on Transportation Safety Management Systems (ACS10)
Session Number	**Poster Session 3039**
Session Title	Transportation Safety Management Systems from Start to Finish
Paper Number	TRBAM-25-03255
Paper Title	**Safe Route to Landels Elementary School in the City of Mountain View California**
Introduction	According to statistics from World Health Organization (WHO), there were 312,000 pedestrian fatalities worldwide, accounting for 23% of global road deaths (1). In Australia, road traffic fatalities increased by 5.8% in 2022, resulting in 1,194 deaths (2). Walking is widely promoted as part of the city's sustainability strategy. As a result, policymakers, urban planners and transportation engineers are looking for ways to mitigate the risk of pedestrian crashes. The urban built environment has been considered as a vital determinant of pedestrian crash risk. Factors affecting the built environment can be broadly categorized into three groups: roadway features, land use features, and key features (3). Roadway network characteristics include intersection density, intersection type, roadway density, speed limits, etc(4). Land use also has a significant impact on the chances of pedestrian collisions, with commercial land use and residential leading to an increased likelihood of collisions (5). In addition, specific facilities such as tram stations, bus stops, and schools increase the likelihood of pedestrian collisions (6). Exposure plays a crucial role in traffic crash risk prediction studies. Pedestrian exposure is the probability of contact or involvement in a collision between a pedestrian and a vehicle (7). Exposure is correlated with the risk of traffic crashes. Factors such as socio-economic indicators, demographics, the built and natural environments influence this correlation. In previous studies, metrics including population, population density, and trip data were used to estimate pedestrian crash exposure at the regional level (8). However, these indicators rely on long-term statistics, which prevents accurate quantification of pedestrian exposure. In previous studies, indicators including population density, demographics and socio-economics were used to estimate pedestrian crash. However, at the micro level (e.g., roadway segments), it is difficult to accurately estimate pedestrian crash exposure by relying on these macro indicators alone. Hence, the proposed pedestrian collision model leveraging granular street-level data, not only enhances precision but also holds significance in enhancing pedestrian safety.

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Sponsoring Committee	Standing Committee on Transportation Safety Management Systems (ACS10)
Session Number	**Poster Session 3039**
Session Title	Transportation Safety Management Systems from Start to Finish
Paper Number	TRBAM-25-03364
Paper Title	**Development of Composite Risk Index (CORSI) to evaluate risky situations while MTWs decide whether to follow or filter**
Abstract	Since Motorized Two Wheelers (MTWs) are compact and highly maneuverable, they often show filtering behavior in mixed traffic conditions. However, owing to their low visibility and lack of physical protection, this behavior poses substantial risks. This study proposes the development of an index to quantify and evaluate the risks that the MTWs face when choosing whether to follow or filter through mixed traffic. Composite Risk Index (CORSI) is a normalized index ranging from 0 (safest interactions) to 1 (riskiest interactions) and is calculated using key parameters: Clear Lateral Gap (CLG), Relative Speed, Speed of MTW, and Acceleration of MTW. Each parameter is normalized between 0 and 1, and the weights assigned to them represent how much of an impact they have on risk. Based on CORSI values, the study uses the K-means clustering technique to classify 803 interactions into "Safe," "Moderately Risky," and "Risky" clusters. According to the data, younger riders, men, and non-helmet wearers are more likely to engage in dangerous exchanges, which also tend to involve filtering behavior and higher accelerations and speeds. Safer encounters are correlated with larger leader vehicles. This research contributes to better safety tactics by improving understanding of MTW behavior in urban mixed traffic and offering a strong tool for real-time risk assessment. Keywords: Motorized Two Wheelers; filtering; urban mixed traffic; Surrogate Safety Measure; Composite 17 Risk Index.

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Sponsoring Committee	Standing Committee on Transportation Safety Management Systems (ACS10)
Session Number	**Poster Session 3039**
Session Title	Transportation Safety Management Systems from Start to Finish
Paper Number	TRBAM-25-03526
Paper Title	**Crash data availability and best practices across the United States**
Abstract	While fatal crashes are available through the Fatality Analysis Reporting System (FARS) and are readily available to the public, many states do not make their crash data easily accessible for the public and the research community. The public has an interest in knowing when and where crashes occur, partly so they can demand that authorities improve safety. Researchers have an interest in being able to download data and conduct analyses to better understand mechanisms that lead to crashes and assist decision makers in designing effective policies. The objective of our study is to document the state of crash data availability throughout the country and to determine the best practices for crash data management and procedures for making data open and easily accessible. We compiled a comprehensive nationwide dataset of open crash data characteristics for states and cities that provide such data. We followed this with structured interviews with crash data experts across the country to provide insights on both the challenges and solutions needed to make crash data accessible. Key themes from our analysis include: (1) the importance of linking crash data with other datasets (e.g., injury surveillance data), (2) the need for partnerships and collaborations between universities, advocates, and agencies, and (3) challenges with data ownership and quality control. We present the results of our quantitative and qualitative work to offer best practices and Vision Zero guidance for state policy makers and traffic crash data experts. Keywords: Crash data, open data, vision zero

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Sponsoring Committee	Standing Committee on Transportation Safety Management Systems (ACS10)
Session Number	**Poster Session 3039**
Session Title	Transportation Safety Management Systems from Start to Finish
Paper Number	TRBAM-25-03881
Paper Title	**A spatial analysis of safety perceptions across different transport modes: Insights from Athens and Munich**
Abstract	Perceived unsafety, particularly in car-dominated environments, induces mental stress, fear, and anxiety, thereby limiting the use of modes like e-bikes and e-scooters. As this factor seem to be related to the provided road infrastructure, it has a spatial dimension has not been extensively studied in the past. This study investigates the spatial patterns of safety perceptions considering four different modes, namely: private car driving, e-bike or e-scooter riding and walking. It uses Athens and Munich as study case and applies an already developed model to estimate safety scores per network link based on road infrastructure type, pavement conditions, existence of pedestrian crossings, and obstacles. Safety scores are visualized and compared between the two cities. Findings reveal that Munich's extensive cycling infrastructure and 30 km/h zones contribute to more balanced safety perceptions across transport modes. Walking received higher perceived safety scores compared to car driving. Conversely, Athens' insufficient infrastructure create significant disparities in perceived safety, particularly disadvantaging micromobility modes. Notably, high safety scores in Athens are concentrated in the city center, while Munich demonstrates a more uniform spatial distribution of safety perception. The results underscore the critical role of perceived safety in redistributing the urban road space. This will encourage the safe use of alternative transport modes leading to higher accessibility and more equitable conditions. Keywords: perceived safety, micromobility, road infrastructure, spatial patterns, urban road

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Session Number	**Poster Session 3039**
Session Title	Transportation Safety Management Systems from Start to Finish
Paper Number	TRBAM-25-03897
Paper Title	**A Context-sensitive Roadway Classification Framework for Speed Limit Setting in the US**
Abstract	In the US, speed limit setting (SLS) procedures have historically relied on driver-behavior-based methods, such as the 85th percentile speed, which are considered objective and allow for consistent application. This approach has notable shortcomings, including drivers' tendency to underestimate their speeds, speed creep, and insufficient consideration of vulnerable road users, which may conflict with the Safe System Approach and Vision Zero initiatives endorsed by the USDOT (US Department of Transportation). In contrast, context-sensitive approaches, which classify roads based on roadway typologies, have been developed in countries like New Zealand, Sweden, the Netherlands, and Australia. While effective, these approaches have largely been applied outside the US, leaving many US roads with speed limits that may not fit their surroundings or adequately address pedestrian and cyclist safety. Drawing on New Zealand's One Network Framework, we developed a US-based, context-sensitive roadway classification framework that incorporates "Place," which captures surrounding land uses and locational contexts, and "Movement," which relates to the road's transport function. Our work employs nationally available data from the Smart Location Database (SLD) and the Highway Performance Monitoring System (HPMS). We validated our roadway classification framework through internal reviews by our research team and external interviews with state-level practitioners, uncovering both opportunities and challenges in adopting a context-sensitive SLS approach in the US. Our findings demonstrate the feasibility of creating an objective context-sensitive roadway classification in the US and offer insights for developing new speed-limit guidance aligned with the Safe System framework. Keywords: Speed Management, Speed Limit Setting, Context-sensitive street classification, Safe System Approach, Place and Movement, United States

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Sponsoring Committee	Standing Committee on Transportation Safety Management Systems (ACS10)
Session Number	**Poster Session 3039**
Session Title	Transportation Safety Management Systems from Start to Finish
Paper Number	TRBAM-25-04039
Paper Title	**Motorcycle Following Distance and its Relationship to the Risk of Rear-End Collisions**
Abstract	This study classified motorcycle (MC) following distance based on trajectory traffic data and validated results using actual MC rear-end collisions. A total of 8,223 events of a MC following a vehicle were investigated in Pathum Thani, Thailand, and 41 cases of MC rear-end crashes were analyzed between 2017 and 2021. Time headway (TH), safe stopping distance (SSD) and time to collision (TTC) were applied to the proposed concept to determine safe following distance (SFD). Speed and following distance for actual rear-end crashes were applied to validate SFD. Results showed that the proposed SFD model identified the causes of MC rear-end collision events as mostly due to longitudinal critical area (38 cases, 92.68%), implying insufficient MC rider reaction and decision time for evasive action. The longitudinal warning area had relatively few chances for rear-end collisions to occur, with only 3 cases recorded. VDO clip extracts from MC rear-end crashes illustrated 11 cases (26.83%) of rider fatality. The study findings revealed that the SFD concept can help to prevent MC rear-end collision events by developing reminder systems when the rider reached the following distances of both warning and critical areas. Keywords: Motorcycle; Rear-end collision; Safe following distance; Stopping distance; Crash risk.

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Session Number	**Poster Session 3039**
Session Title	Transportation Safety Management Systems from Start to Finish
Paper Number	TRBAM-25-04043
Paper Title	**Multi-Faceted Walkability Analysis for School Zone Safety in Delhi**
Abstract	Pedestrian walkability in school zone areas for children and adults accompanying them is crucial to encourage walking trips in the daily commute to and from school. School zones demand extra caution from the stakeholders during design due to the presence of vulnerable road users. The case study chosen is the South Delhi region of New Delhi. A multi-faceted approach toward the assessment of walkability in a school zone is carried out with the help of community perception surveys, pedestrian walkability inventory analysis, pedestrian volume counts, and a microscopic simulation using the Social Force Model (SFM) model to compare the base scenario and a re-design scenario is done. This will enable the study of built environment changes, the impact of roadway geometric design modifications, and traffic management interventions on pedestrian walking behavior. The results reveal the influence of several factors that impact the walkability and vehicular speeds in a school zone. It adds to the research on child pedestrian safety in school zone settings, especially in the often-overlooked school zones in developing nations, and offers a replicable methodology for enhancing walkability. This study will benefit the policymakers, local government agencies, school zone communities, urban planners, researchers, and traffic management professionals by helping them understand how they can assess the walkability of a 16 school zone area using a simple, multi-faceted, and effective approach. Keywords: Walkability, Pedestrian, School Zone, Road Safety, Vulnerable Road Users

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Sponsoring Committee	Standing Committee on Transportation Safety Management Systems (ACS10)
Session Number	**Poster Session 3039**
Session Title	Transportation Safety Management Systems from Start to Finish
Paper Number	TRBAM-25-04271
Paper Title	**Investigating Factors Affecting Pedestrian Fatalities in the US: A Comparative Study of Pre-Pandemic, Pandemic, and Late-Pandemic Periods**
Abstract	The rising pedestrian fatalities were already a public health concern which has been exacerbated by the disruptions caused by the COVID-19 pandemic. The existing literature offers valuable insights into the general trends and factors influencing pedestrian crashes and fatalities, however, there is a significant gap in understanding how these dynamics have changed in the pandemic- affected years. As such, this study aims to conduct a comprehensive analysis to identify the factors that have differential impacts on pedestrian fatalities across three periods: pre-pandemic (2019), pandemic (2020-2021), and late-pandemic period (2022). For this, the data were obtained from various sources including the Fatality Analysis and Reporting System, National Transit Stop Maps, Smart Location Database, and disadvantaged community database. This study utilized a twofold approach, first, the analyses were conducted at the pedestrian level using a mixed effects multinomial logit model, and second, the analyses were conducted at the census tract level using mixed effects negative binomial models. The results showed some variables exhibited a temporal shift and were associated with a higher likelihood of pedestrian fatalities such as pedestrian and driver age (25-45 years), impairment, failure to yield, jaywalking, weekend evenings/nights, proximity to transit stops, population density, and non-intersections. Analyses revealed that urban areas, lower-income neighborhoods, transit stop density, auto-oriented road network density, percent population with poor mental health, and population below 17 years were associated with an incremental increase in pedestrian fatalities across the three periods. Keywords: pedestrian safety, vulnerable road user, pandemic, disadvantaged community, transportation equity

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Sponsoring Committee	Standing Committee on Transportation Safety Management Systems (ACS10)
Session Number	**Poster Session 3039**
Session Title	Transportation Safety Management Systems from Start to Finish
Paper Number	TRBAM-25-04351
Paper Title	**A Data-Driven Framework for Evaluating the Effectiveness of Traffic Safety Countermeasures**
Abstract	Conducting before-after safety evaluations is essential for road safety programs to identify and address safety issues through the installation of effective traffic safety countermeasures. Traditionally, these evaluations rely on historical crash data to estimate benefits through reductions in crash frequency. However, crash data often have quality issues, and long periods of data are needed before and after treatment for performing statistical analysis. To address these limitations and the need for short-term safety evaluations, this study proposes a framework using multiple real-world datasets. First, a Gower distance-based control site selection procedure was developed using probe speed data, crash data, and segment data to account for confounding bias and regression to the mean in statistical analysis. Interrupted time series (ITS) and difference-in-differences (DiD) methods were then introduced to evaluate safety using probe speed data and Michelin driving event data. A case study demonstrated the application of these methods to assess the effectiveness of installed countermeasures on MD 210 in Prince George's County, Maryland. Finally, the study discusses the robustness and performance of the datasets and statistical methods used in the analysis, highlighting their potential for providing reliable safety evaluations. Keywords: countermeasures, probe speed, Michelin driving event, interrupted time series, difference-in-16 differences Keywords: pedestrian safety, vulnerable road user, pandemic, disadvantaged community, transportation equity

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Session Number	**Poster Session 3039**
Session Title	Transportation Safety Management Systems from Start to Finish
Paper Number	TRBAM-25-04485
Paper Title	**A Data-Driven Framework for Evaluating the Effectiveness of Traffic Safety Countermeasures**
Introduction	School buses are among the safest forms of transportation for delivering children to. However, boarding, alighting, and approaching the bus heightens student risks, accounting for 23.8% of school-bus related injuries (2) that typically result from drivers improperly overtaking a stopped bus (1, 3). Mitigating these dangerous stop arm violations requires a deep understanding of the circumstances under which they occur. However, accurately assessing the efficacy of countermeasures is difficult without accurate and complete data on the occurrence of the events. This study aimed to determine the prevalence of stop-arm violations in Minnesota, the extent to which the events are documented, and the extent to which police enforce violations. A mixed-methods approach was taken to analyze three main datasets of stop-arm violation event, reporting, and citations from January 1, 2021 to February 27, 2024. Analyses of estimated base rates concluded that 113,426 to 473,112 stop-arm violations occur across the state each year. Yet reports submitted to Minnesota State Patrol captured only 1-3% of these estimated violations. Further, the number of statewide citations issued each year were estimated to represent less than 1% of the estimated violations statewide. Community violation reporting volume moderately predicted citations, but neither were predicted by population, population density, size of police force, or number of injury crashes, indicating a potential breakdown in the current reporting and enforcement process. Additionally, interviews and observational analyses were synthesized to determine common issues related to complex processes for documentation, incomplete resource allocation, and strained communication processes that attribute to both under-reporting and under-enforcement.

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Session Number	**Poster Session 3039**
Session Title	Transportation Safety Management Systems from Start to Finish
Paper Number	TRBAM-25-04640
Paper Title	**Recent Trends and Factors Associated with Risky Motorcyclist Behaviors**
Introduction	Motorcycle safety is an important public health concern. As increasingly more motorcyclists are killed in traffic crashes, it is essential to understand trends in motorcyclists' risky behaviors to better enhance their safety. This study examines data from three annual surveys conducted in Florida from 2021 to 2023, focusing on six unique risky behaviors reported by motorcyclists, including riding after alcohol consumption, helmet non-use, speeding, distracted riding, riding fatigue and riding anger. The analysis aimed to identify recent trends and factors associated with these behaviors. Results of this study reveal that several risky behaviors are linked to each other, although the at-risk group for each risky behavior differs. In particular, motorcyclists who engaged in "nontraditional" risky riding behaviors—anger, fatigue, and distraction—were also more likely to ride after alcohol consumption and exceed speed limits. Furthermore, rider anger is strongly linked to motorcyclists' perceptions of a decline in drivers' awareness of motorcycles in recent years. These findings highlight the importance of considering these nontraditional risky riding behaviors in safety interventions and the need for further research into crashes associated with these behaviors. The study concludes with tailored recommendations for addressing each specific risky behavior. Keywords: Motorcycle Safety; Risky Behavior; Helmet Non-use; Motorcycle Anger

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Session Number	**Poster Session 3039**
Session Title	Transportation Safety Management Systems from Start to Finish
Paper Number	TRBAM-25-04703
Paper Title	**Prioritizing Safety Treatment of Rural Corridors using Curve Context**
Abstract	Horizontal curves are a significant source of crash risk on rural road networks. Historically, high-risk curves are identified reactively, based on examination of crash history. However, to reduce the influence of random variation in observed crashes, proactive approaches, which estimate underlying crash risk, are increasingly preferred. To efficiently target road safety investment, a scalable, proactive approach to estimating rural crash risk is required. This paper presents a proactive corridor prioritization framework for rural roads in the United States, based on horizontal curve risk. Road centerline geometry and speed limit data is used to estimate typical operating speeds and "curve context" – the degree to which the estimated operating speed of a curve differs from its safe traversal speed. A Safety Performance Function is used to estimate underlying risk, based on curve context and other geometric and traffic variables. Estimation and validation of the model using Arkansas and California datasets indicates that poor curve context is a significant predictor of crash risk. Variables used in the model are readily available for the entire United States, allowing estimation of crash risk without reliance on crash or detailed roadway data. Corridors are prioritized according to predicted crash risk for out-of-context curves per unit of corridor length. This approach, which facilitates the display of corridor prioritization via an interactive map based tool, highlights corridors where treatments to address curve context are expected to deliver the greatest crash reductions relative to treatment costs. A case study of the Arkansas network is also presented. Targeting safety improvements on prioritized corridors is expected to produce significant reductions in rural road crashes. Keywords: Curve, Safety, Risk, Proactive, Road Safety, Prioritization, Horizontal, Priority, Context, Rural, Network, Spatial, Safety Performance Functions, SPF

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Sponsoring Committee Standing Committee on Transportation Safety Management Systems (ACS10)

Session Number **Poster Session 3039**

Session Title Transportation Safety Management Systems from Start to Finish

Paper Number TRBAM-25-04729

Paper Title **Safe System for Whom? Quantifying the Impacts of Transport Infrastructure Using a Systematic Analysis**

Abstract In this paradigm shift to the safe systems, empirical research lacks a systematic analysis of the safety impacts of transport infrastructure. This study contributes to the literature by asking (1) What are the impacts of transport infrastructure on the likelihood of fatalities (versus socioeconomic factors)? (2) What are the heterogeneous effects of transport infrastructure on fatalities for cyclists, pedestrians, relative to vehicle occupants? (3) To what degree does one traveling in areas outside the city boundaries impact the likelihood of fatality, relative to cities? In doing so, I measured the prevalence of transport infrastructure across California using three indicators: the presence, lane miles, and density, and quantified the effects of three types of infrastructure (major roads, residential streets, and cycling infrastructure) on fatalities using the logistic regression. Results show that increases in the lane miles of major roads is associated with increases in the likelihood of fatalities for all - vehicle occupants [ORs: 2-2.4], cyclists [ORs: 1.3-1.4], and pedestrians [ORs: 1.4]; yet, one unit increase in the density of cycling infrastructure is associated with a 6% and 3% decrease in the likelihood of fatality for cyclists and pedestrians, respectively. I also found that a larger proportion of Black and Hispanic residents is associated with increases in the likelihood of fatalities for all [ORs: 1.01-1.02]; cyclist fatalities are 1.3 times as likely to occur in non-cities as in cities. Findings highlight the heterogenous effects of transport infrastructure on fatalities and sociodemographic disparities, which merits attention in the policy intervention processes.
Keywords: Safe System; Zero Fatalities; Infrastructure; City Status

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Sponsoring Committee Standing Committee on Transportation Safety Management Systems (ACS10)

Session Number **Poster Session 3039**

Session Title Transportation Safety Management Systems from Start to Finish

Paper Number TRBAM-25-04774

Paper Title **How Can We Ensure Traffic Safety Funds Improve Safety? A Conversation with Transportation Engineering Professionals.**

Abstract Traffic related crashes are a leading cause of death among children in the United States. Improving children’s safety in school zones is an efficacious means of mitigating children’s injuries. Federal funding for pedestrian and bicycle infrastructure has increased, yet fatal traffic injuries are on the rise. How can we ensure that funded projects achieve safety goals? We analyzed projects that used federal transportation funds to see what sort of improvements were implemented. We found that just 10% of the 48 school zone infrastructure projects had implemented some traffic calming measure. With that, we sought to conduct focus groups with transportation engineering professionals who are in positions of implementing change. We presented case studies of infrastructure projects to elicit expert opinion on how to focus on protecting vulnerable populations most effectively during project development and implementation. While participants were knowledgeable of traffic calming measures and the Federal Highway Administration 1FHWA)’s Proven Safety Countermeasures, there appeared to be a disconnect between theory and practice. Participants expressed that they often faced barriers to implementing safety countermeasures, whether political, structural, or financial. They emphasized the importance of crossing guards within school zones, noting that they would not feel comfortable allowing children to cross alone at most intersections. Participants urged the need for increased collaboration with and engagement of communities, schools, and elected officials during all aspects of school zone infrastructure improvements.
Keywords: School zones, Traffic safety, Traffic calming

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Sponsoring Committee Standing Committee on Transportation Safety Management Systems (ACS10)

Session Number **Poster Session 3039**

Session Title Transportation Safety Management Systems from Start to Finish

Paper Number TRBAM-25-04805

Paper Title **Community Perceptions of Vision Zero: A case Study of Tacoma, Washington**

Abstract Vision Zero initiative gained momentum in the United States in the 2010s after successfully being implemented across European countries. The city of Tacoma adopted Vision Zero in 2020 and is planning to achieve zero traffic deaths and serious injuries by 2035. As part of its outreach plan to engage the local community, the city of Tacoma's Vision Zero team surveyed critical issues affecting traffic safety as perceived by road users. One of the Vision Zero strategies is to implement safer speeds across streets by reducing speed limits that are too high. This study analyzes the community's perceptions of speeding and high-speed limits in Tacoma using Bayesian Networks to understand community safety concerns. Narratives from respondents who perceive speeding and high-speed limits as safety concerns were analyzed using a text-mining approach. Bayesian Networks results show that responders familiar with Vision Zero and those who used active transportation were more likely to perceive speeding and high-speed limits as affecting their level of safety. Specifically, the likelihood to attribute speeding and high-speed limit to safety increased by 3.01% and 101.99%, respectively, for respondents familiar with Vision Zero, and for respondents who walk around Tacoma, the likelihood increased by 20.26% and 6.45%. Text network results revealed that driving at high speeds and on roadways with high-speed limits are perceived as critical safety issues in Tacoma. This study informs policymakers on promoting traffic safety through engineering solutions, law enforcement, and public knowledge outreach. Keywords: Vision Zero, Safety, Speeding, High-speed limits, Bayesian network, Text network

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Sponsoring Committee Standing Committee on Transportation Safety Management Systems (ACS10)

Session Number **Poster Session 3039**

Session Title Transportation Safety Management Systems from Start to Finish

Paper Number TRBAM-25-04862

Paper Title **Analyzing School Bus-Related Crashes in New Jersey Using Machine Learning Techniques**

Abstract Despite various safety initiatives, school bus-related crashes remain a significant concern in the United States. National data from the NHTSA reveals that from 2007 to 2016, 4% of fatal motor vehicle crashes were school-transportation-related, resulting in 1,282 deaths, including 281 school-age children. In 2018, 117 fatalities and 13,000 injuries were reported due to school bus-related crashes in the U.S., with three fatalities in New Jersey. This issue underscores the urgent need to study the safety of school bus passengers and crashes involving school buses. This paper investigates school bus crashes in New Jersey from 2016 to 2024. Advanced machine learning models, including XGBoost, Random Forest (RF), Support Vector Machine (SVM), Decision Tree and AdaBoost, were employed to evaluate the contributing factors to these crashes. The models were trained and tested to predict crash factors, with their effectiveness assessed based on performance metrics and accuracy. Additionally, SHapley Additive exPlanations (SHAP) analysis was conducted to interpret the impact of various factors on different crash outcomes, such as property damage, injury, and fatality. Our findings provide critical insights into the dynamics of school bus-related crashes and offer data-driven recommendations for enhancing safety measures, contributing to the protection of school children, and informing future safety policies and interventions.
Keywords: Crash severity, school bus safety, machine learning techniques, decision tree, random forest.

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Session Number	**Poster Session 3039**
Session Title	Transportation Safety Management Systems from Start to Finish
Paper Number	TRBAM-25-04997
Paper Title	**Investigating Trends in High-Risk Driving Behaviors Before and After the Onset of the COVID-19 Pandemic**
Abstract	The COVID-19 pandemic brought about significant changes in day-to-day life, including people's travel behavior. This included significant reductions in travel due to travel restrictions that were imposed to contain the pandemic. Surprisingly, despite marked reductions in travel, fatal and severe injuries significantly increased post-pandemic. Various explanations have been provided for this result, including higher travel speeds due to lower levels of congestion, as well as increases in various types of high-risk behaviors, such as impaired driving and the non-use of seatbelts. Interestingly, even after the travel restrictions were relaxed, these negative trends have continued to persist to varying degrees in the subsequent years. This study investigates trends in various high-risk driving behaviors before and after the onset of the COVID-19 pandemic using data from the National Highway Traffic Safety Administration Crash Reporting Sampling System for the years 2018 to 2022. The study examines changes in alcohol-impaired driving, seatbelt usage, and speeding, before and after the pandemic, in addition to evaluating changes in the level of injury sustained by crash-involved drivers. Results indicated a significant increase in each of these high-risk behaviors, which persisted after the pandemic. Several groups of drivers were at elevated risks for these behaviors, particularly male and younger drivers. There were also interesting regional and temporal variations across the United States. The findings underscore the need for targeted road safety interventions to mitigate the long-term impacts of the pandemic on driver behavior and crash outcomes. Keywords: COVID-pandemic, high-risk driving behaviors, alcohol impairment, seatbelt usage, speeding, crash severity

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Sponsoring Committee	Standing Committee on Transportation Safety Management Systems (ACS10)
Session Number	**Poster Session 3039**
Session Title	Transportation Safety Management Systems from Start to Finish
Paper Number	TRBAM-25-05447
Paper Title	**Analysis of Motorcycle Riders' Gap Acceptance at Unsignalized Mid-Block Crosswalks**
Abstract	Unsignalized mid-block crosswalks can often lead to conflicts between motorcyclists and pedestrians especially in Thailand where a high number of motorcycles exist in the road system. Generally, motorcyclists must yield to the crossing pedestrians. However, many pedestrian-motorcycle crashes occurred due to unstop or unyielding behavior of motorcyclists. This risky decision of motorcyclists is caused by too short gap acceptance which may cause damage on lives for both motorcyclists and pedestrians. This study aims to investigate critical gap of motorcyclists when facing pedestrian crossing at unsignalized mid-block crosswalks and to determine the significant factors influencing motorcyclists' decision when passing unsignalized mid-block crosswalks. The critical gap was estimated by using Raff's Methods, Wu's Method, and binary logistic regression, and then the influencing factors on motorcyclists' decision were analyzed by using the binary logistic regression model. From the results of this study, the motorcyclists' critical gaps when facing a single movement of pedestrian are very short (0.54-1.07 sec.). It was found that the factors influencing motorcyclists' decision to stop or not to stop at the crosswalks include headway time, direction of pedestrians' movement, availability of nearby obstacles, pedestrian crossing locations, number of crossing pedestrians, and crosswalk colors. The interaction effect between crosswalk colors and median types was also significant to the model. The short critical gap reflects the risky behavior of motorcyclists in Thailand. To improve safety of motorcyclists and pedestrians, the findings in this study are very important for the improvement of geometric design and law enforcement at the unsignalized mid-block crosswalks. Keywords: gap acceptance, mid-block crosswalks, critical gap, motorcycle

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Sponsoring Committee Standing Committee on Transportation Safety Management Systems (ACS10)

Session Number **Poster Session 3039**

Session Title Transportation Safety Management Systems from Start to Finish

Paper Number TRBAM-25-05595

Paper Title **ROADFIRST: A Comprehensive Enhancement of the Systemic Approach to Safety for Improved Risk Factor Identification and Evaluation**

Abstract As an essential supplement to the traditional hotspot crash analysis, the systemic approach to traffic safety, which develops region-wide safety projects based on identified risk factors, has been widely adopted. However, this approach focuses on specific crash and facility types, causing inefficient use of crash and inventory data and a non-optimal risk evaluation and countermeasure selection for each location. To improve the comprehensiveness of the systemic approach to safety, we develop an enhanced process, ROADFIRST, that allows users to identify all potential crash contributing factors at any location. As the knowledge base for such a process, the quantitative relationships between the contributing factors and features of interest, such as traffic-related and environment-related features, are identified using Random Forest and analyzed with the Shapley Additive exPlanations (SHAP)analysis. This study identifies and ranks features impacting the likelihood of three sample contributing factors, i.e., alcohol-impaired driving, distracted driving, and speeding, according to crash and road inventory data from North Carolina, and quantifies state-wide road segment risk for each contributing factor. The introduced models and methods serve as a sample for the further development of ROADFIRST by state and local agencies, which benefits the planning of more comprehensive region-wide safety improvement projects.

Keywords: Systemic approach to safety, SHAP analysis, crash contributing factors

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Sponsoring Committee Standing Committee on Transportation Safety Management Systems (ACS10)

Session Number **Poster Session 3039**

Session Title Transportation Safety Management Systems from Start to Finish

Paper Number TRBAM-25-05599

Paper Title **Safety Contributing Factors Analysis of Elderly Vulnerable Road Users: Global and Local Perspectives**

Abstract During the rapid increase in the elderly population, the demand for the elderly in terms of life, health and spirituality continues to grow. By the end of 2023, there are 297 million elderly people aged 60 and above in China, accounting for 21.1% of the total population. China has the largest elderly population in the world and it becomes particularly important to tackle the population aging while improving the road traffic safety of the elderly. However, due to their declining physical, cognitive and self-protection abilities, the elderly are the most vulnerable road users (VRUs) when it comes to traffic safety. The elderly (61+) account for 37.18% of total fatalities in 2021, up from 25.77% in 2015. The percentage of injured elderly in the total injuries increases from 15.50% in 2015 to 23.44% in 2019 (1). The abundance of zero crashes in many analysis units for some specific types of crashes, makes traditional models unsuitable for accurate analysis in spatial modeling. Few studies have revealed the spatial heterogeneity in the effects of contributing factors on older VRU crashes. Ignoring this spatial heterogeneity can lead to inaccurate predictions. The GWRF model has the dual capability to capture effectively the spatial heterogeneity and nonlinear relationships. Therefore, the GWRF model is employed in this study to understand how factors contribute to older VRU crashes in different spatial areas. To improve elderly safety, this study proposes an analytic approach for contributing factors analysis of elderly VRU safety, which uses global and local models to analyze elderly VRU crashes. The study framework mainly includes three parts: (1) data collection and preprocessing, (2) global and local safety modeling, and (3) analyzing global and local results, including global relative influences, marginal effects, variables influences that vary across spatial analysis units of elderly-involved pedestrian crashes and non-motorized vehicle (NMV) crashes.

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Session Number **Poster Session 3039**

Session Title Transportation Safety Management Systems from Start to Finish

Paper Number TRBAM-25-05636

Paper Title **Using Probe Data to Model Speeding on Interstate Horizontal Curves and Ramps**

Introduction

Lane departure crashes comprise the majority of severe and fatal collisions in the United States (U.S.) (1–3). Many of these crashes occur on horizontal curves and ramps. Speeding is a major factor influencing lane departure collisions on horizontal curves and ramps. While several research studies investigated the influence of driver behavior on lane departure crashes on horizontal curves or ramps (3-5), limited research has been devoted to understanding the factors influencing speeding on these roadway elements. This research addresses this gap by exploring the relationship between various factors and speeding on Interstate horizontal curves and ramps. The independent and dependent variables are as follows.
Independent variables:
•Area type: urban and rural.
•Time Variables: time of the day (morning, evening, or off-peak hours), time of the week (weekdays and weekends), and month of the year (January to December),
•Traffic density: reflected as the level of service.
•Geometric characteristics (e.g., arc angle, superelevation, curve radius, shoulder width, lane width, and curvature.)
Dependent variable:
•Odds of speeding on Interstate horizontal curves and ramps. This paper has the following contributions.
•By developing statistical models, this research examines various factors influencing 20 speeding at horizontal curves and ramps to provide insights about critical times, specific locations, and situational contexts that require speed countermeasures or interventions.
•We investigate the impact of congestion (reflected in LOS) on speeding for these road elements, examining how traffic conditions may influence the odds of speeding.
•We demonstrate the application of probe data as a new data source to analyze speeding at horizontal curves and ramps.
•Given the availability of probe data, and a complete curve and ramp database in Maine, we consider the entire inventory of Interstate ramps and horizontal curves in the state in our analysis.
•We compare the odds of speeding in rural and urban areas. This analysis offers insights into whether speeding behaviors vary between these geographical regions.
•We provide recommendations to reduce speeding on these road elements to provide actionable strategies for policymakers or state agencies to enhance safety on horizontal curves and ramps.

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Session Number	**Poster Session 3039**
Session Title	Transportation Safety Management Systems from Start to Finish
Paper Number	TRBAM-25-05732
Paper Title	**Understanding the Association Between Transportation Safety and Quality of Life in Austin Using Bayesian Networks**
Abstract	Improving the quality of life is among the key focus of various jurisdictions. In doing so, various projects, including transportation-related projects, have been implemented each year to improve residents' lives. However, studies that evaluate the link between transportation attributes and quality of life are relatively scarce. Thus, this study used community survey data collected in 2018 and 2019 in Austin, Texas, to fill that gap by using the Bayesian Networks approach. The safety perception was measured using the resident's perception of walking in their neighborhood day and night and sharing the road with other road users. Results indicate that residents who feel safe walking in their neighborhood during that time are more likely to be satisfied with their quality of life. Other key indicators are safe walking downtown during the daytime and walking downtown during nighttime, while feeling safe walking in their neighborhood during nighttime was the least contributor to the quality of life. Furthermore, income was the key factor for safety perception, while street conditions and traffic flow on major streets were the key indicators of safety perception when sharing the road with other drivers. The findings suggest prioritizing transportation projects to improve residents' safety and quality of life. Keywords: Quality of Life; Traffic Safety; Residents' Perceptions

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Session Number	**Poster Session 3039**
Session Title	Transportation Safety Management Systems from Start to Finish
Paper Number	TRBAM-25-05800
Paper Title	**Understanding Pedestrian and Bicyclist Safety Trends in the Post-Pandemic Era**
Introduction	The COVID-19 pandemic significantly disrupted transportation patterns and behaviors, leading to changes that persist in the post-pandemic era. While some modes of travel, such as public transit and shared mobility, experienced dramatic declines, active transportation modes like walking and cycling exhibited mixed trends, with commuting-related declines offset by increases in recreational use (1-3). These shifts have brought renewed attention to long-standing issues of pedestrian and bicyclist safety, which have worsened in recent years. In 2021, pedestrian and bicyclist fatalities accounted for 17% and 2.2% of all U.S. traffic fatalities, respectively, with an alarming 18% and 12% increase between 2019 and 2021 (4; 5). These trends underscore the critical need to understand the pandemic's impact on pedestrian and bicyclist safety, particularly among disadvantaged communities that face systemic barriers to safe transportation infrastructure (6). Recent studies have examined factors influencing pedestrian and bicyclist safety, including socioeconomic disparities, infrastructure availability, and pandemic-induced changes in travel behavior. Research highlights disparities in safety outcomes, particularly for low-income and minority communities, which experience higher crash rates due to inadequate infrastructure and exposure to high-risk environments (6-8). However, gaps remain in understanding the pandemic's long-term effects on safety outcomes and variations across community settings. This study addresses these gaps by investigating pedestrian and bicyclist safety trends before and after the pandemic across the U.S. and California, with a particular focus on urban, rural, and disadvantaged communities. Descriptive statistics were applied to the data to explore fatality trends across the U.S. using data from the Fatality Analysis Reporting System (FARS) and fatality and serious injury (FSI) trends in California using the Statewide Integrated Traffic Records System (SWITRS). A random-effects negative binomial regression model with panel data further explores the factors contributing to the California FSI trends. The findings reveal a nationwide increase in pedestrian and bicyclist fatalities post-pandemic, with urban areas and disadvantaged communities experiencing a rise. In California, FSI rates rose with significant disparities between disadvantaged and non-disadvantaged communities. These statistically significant trends highlight the compounded risks for vulnerable populations and emphasize the need for 28 targeted interventions. This research advances the understanding of pedestrian and bicyclist safety by identifying critical disparities and their underlying causes. The findings provide valuable insights for policymakers and practitioners to develop equitable, region-specific interventions, ultimately contributing to safer transportation systems for vulnerable road users.

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Session Number	**Poster Session 3039**
Session Title	Transportation Safety Management Systems from Start to Finish
Paper Number	TRBAM-25-06096
Paper Title	**Two-wheelers trajectory prediction in complex crowded intersection scenarios considering driving style and vehicle interaction forces**
Abstract	Autonomous vehicles (AVs), driving in complex environments is a significant challenge, especially interacting with two-wheelers at intersections because the trajectories of two-wheelers are difficult to predict. Two-wheelers usually interact with multiple traffic participants at the same time in intersections, where conflicting interactions between two-wheelers and vehicles often lead to sudden changes in their trajectories. At the same time, cyclists with different driving styles will make different driving behaviors for the same interaction, resulting in different driving trajectories. In addition, due to the characteristics of "learning average behavior", the current deep learning model cannot learn the sudden behavior of two-wheelers during conflict interactions well.Based on these observations, this study proposes a random forest-based two-wheelers driving style identification model for identifying the driving styles of different two-wheelers. In addition, this study also proposes an interaction force model between two-wheelers and vehicles in the intersection area, which is used to represent the conflicting force of vehicles on two-wheelers. Finally, the driving style recognition model and the interaction force model were integrated into the edge set and weighted adjacency matrix of the space-time graph to construct a two-wheelers trajectory prediction model based on spatio-temporal graph convolutional network(ST-GCN). In the experiment, two-wheelers trajectory data at evening peak hours at multiple intersections in Nanjing were obtained to verify the rationality of the proposed model. Compared with the state-of-the-art models, the proposed model has lower errors, especially in conflict interaction scenarios. Keywords: Trajectory prediction,Two wheeler,Driving style,Graph convolutional network,Spatio-temporal feature extraction

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Session Number	**Poster Session 3039**
Session Title	Transportation Safety Management Systems from Start to Finish
Paper Number	TRBAM-25-06141
Paper Title	**Prioritization and Implementation of Safe Routes to School (SRTS) in Austin, Texas**
Abstract	In the early 2000s, various jurisdictions across the U.S. initiated safe routes to school projects (SRTS) to improve students' safety when walking or biking to school. In different areas, various criteria are considered when prioritizing such projects. In Austin, Texas, the main criteria are the project's overall benefit or the cost-benefit. However, less is known about what projects will likely have high benefits or high cost-benefits, as one project recommendation could have multiple improvement suggestions. Austin's SRTS data between 2016 and 2023 includes about 4,600 observed safety issues along school routes, ranked on a 5-Likert scale in terms of overall benefit and cost-benefit. Therefore, this study applied mixed-effects ordered and binary logit models to determine the likelihood of the recommendations being ranked as high benefit or high cost-benefit. In addition, the study identified the likelihood of the recommendations being reviewed and implemented after that. Results indicate that recommendations involving bike facilities, trails, and speed-related measures are more likely to be ranked with high overall benefits. Projects that mitigate difficult crossings improve faded crosswalk markings, and speed-related improvements will likely be ranked with high cost-benefits. The findings also indicate that recommendations likely to be ranked high in cost-benefit are likely to be reviewed and implemented, suggesting that cost-benefit might outweigh the overall benefits when it comes to prioritization. The practical applications of the findings are summarized and can be crucial to guide other SRTS projects in Texas and across the United States. Keywords: Safe Routes to School; Benefit; Cost-Benefit; Implementation; Safety

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Session Number	**Poster Session 3039**
Session Title	Transportation Safety Management Systems from Start to Finish
Paper Number	TRBAM-25-06278
Paper Title	**The Designation of School Zones Using a Mathematical Framework Based on a Simulated Annealing Algorithm**
Introduction	To enhance the safety of children who travel to and from their school, the authorities in charge of traffic management have tried to formulate plenty of policies in areas near schools. Their interest is to reduce traffic accidents involving children by decreasing the speed of vehicles. Therefore, designating school zones is one of the prioritized policies (1) because those include several regulations such as speed limitations, installing traffic signals or stop signs on crosswalks, and implementing traffic calming measures. Those measures within a school zone turn out to be effective in several pieces of research including (2–5). Previous studies on school zone safety are categorized into the behaviors of drivers (24, 6) or child pedestrians (7, 8). Also, (9–11) identified relationships between spatial features of school zones and social factors. Based on these varieties of studies, several countries developed manuals to designate school zones. Existing manuals in countries such as South Korea (12), New Jersey, U.S. (13), and Ontario, Canada (14) adopt different methods, including survey-based approaches or scoring systems. However, these methods often lack consistency, depend on subjective assessments, and overlook minor roads with high accident risks. This study proposes a framework for school zone designation that minimizes congestion and accident costs using a simulated annealing algorithm (SAA), inspired by methodologies in (15) and (16). By balancing travel time and collision risks, the method identifies optimal zones while addressing public concerns about excessive expansion and traffic inefficiency (17–20). Unlike previous studies (21–23) that focus on entire urban areas or theoretical models, this research applies advanced optimization techniques to real-world neighborhood networks with narrower roads and lower traffic volumes. The results demonstrate that this approach effectively reduces social costs, improves safety, and establishes an objective method for school zone designation.

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Sponsoring Committee Standing Committee on Transportation Safety Management Systems (ACS10)

Session Number **Poster Session 3039**

Session Title Transportation Safety Management Systems from Start to Finish

Paper Number TRBAM-25-06437

Paper Title **Investigating the Association of Post-Crash Medical Conditions and Human Factors with Motorcyclists Injuries: Insights from Fine Injury Data From Hospital Records**

Abstract This study investigates the factors influencing the Injury Severity Score (ISS) in motorcycle crashes, utilizing a comprehensive dataset from the Road Traffic Injury Research and Prevention Centre (RTIRPC) in Karachi, Pakistan. The analysis focuses on the post-crash medical conditions of crash victims as well as factors related to the roadway, environment, crash, and post-crash events. Specifically, the study examines the post-crash medical health conditions including Glasgow Coma Score (GCS), Systolic Blood Pressure (SBP), and Respiratory Rate (RR) and their association with the ISS. Based on the distribution of dependent variable (ISS), after addressing the issues related to missing or inappropriate values in the dataset with synthetic data generation, a Tobit regression model was employed in a corner solution setup. The findings indicate that decreased GCS and SBP levels have a significant impact on the ISS, signifying a more severe injury. Additionally, a positive association between prehospital time and ISS was established, underscoring the critical influence of emergency response times on injury outcomes. The study also highlights several significant characteristics contributing to the severity of injuries in motorcycle crashes, such as overspeeding, wrong-way driving, nighttime crashes, and crashes involving multiple vehicles. Furthermore, the study emphasizes the significance of specific actions, including focused interventions, improved enforcement of traffic laws, and enhanced emergency medical services, in mitigating injury severity in motorcycle crashes. It also calls for future research to consider real-time data collection at crash sites and account for socio-economic elements in formulating comprehensive safety measures. Kiyani, No Organization

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Sponsoring Committee Standing Committee on Transportation Safety Management Systems (ACS10)

Session Number **Poster Session 3039**

Session Title Transportation Safety Management Systems from Start to Finish

Paper Number TRBAM-25-06465

Paper Title **Characterizing Behavioral Differences and Adaptations of Automated Vehicles and Human Drivers at Unsignalized Intersections: Insights from Waymo and Lyft Open Datasets**

Abstract The integration of autonomous vehicles (AVs) into transportation systems presents an unprecedented opportunity to enhance road safety and efficiency. However, understanding the interactions between AVs and human-driven vehicles (HVs) at intersections remains an open research question. This study aims to bridge this gap by examining behavioral differences and adaptations of AVs and HVs at unsignalized intersections by utilizing two comprehensive AV datasets from Waymo and Lyft. Using a systematic methodology, the research identifies and analyzes merging and crossing conflicts by calculating key safety and efficiency metrics, including time to collision (TTC), post-encroachment time (PET), maximum required deceleration (MRD), time advantage (TA), and speed and acceleration profiles. The findings reveal a paradox in mixed traffic flow: while AVs maintain larger safety margins, their conservative approach can lead to unexpected situations for human drivers, potentially causing unsafe conditions. From a performance point of view, human drivers exhibit more consistent behavior when interacting with AVs versus other HVs, suggesting AVs may contribute to harmonizing traffic flow patterns. Moreover, notable differences were observed between Waymo and Lyft vehicles, which highlights the importance of considering manufacturer-specific AV behavior in traffic modeling and management strategies for the safe integration of AVs. The processed dataset utilized in this study is openly published to foster the research on AV-HV interactions.

TRB 104th ANNUAL MEETING
January 5–9, 2025 • Washington, DC

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Session Number	**Poster Session 3109**
Session Title	Transportation Research Board Minority Student Fellows
Paper Number	TRBAM-25-02082
Paper Title	**Analyzing Driver Behavior in Response to Traffic Safety Messages Broadcast by Roadside Units in Connected and Autonomous Environments**
Abstract	The safety of vulnerable road users (VRUs) at signalized intersections is a significant concern in urban traffic management. This study aims to enhance VRUs safety through the deployment of advanced communication and machine learning technologies. Using a Connected and Autonomous Vehicle (CAV) testbed, the research explores real-time communication between LiDAR sensors, Roadside Units (RSUs), On-Board Units (OBUs), and traffic controllers. This integration allows for the timely dissemination of safety messages, and it enables drivers to adjust their behavior to prevent potential crashes. The CAV testbed offers a controlled environment for studying these interactions, facilitating precise data collection and analysis. By collecting driving data from 32 participants under three scenarios and with two different sets of safety messages broadcasted by RSUs on the testbed, the study investigated the participants' driving behavior in 1nteractions with pedestrians and bicyclists. The study utilized machine learning models, including Logistic Regression, Random Forest, and Support Vector Machine (SVM), to predict driver behavior under various scenarios. The SVM model demonstrated the highest accuracy, particularly in predicting lateral distance, with an accuracy rate of 0.88 in response to the "Keep to the Right Lane" message. Key findings emphasize the importance of factors such as driver demographics, experience, and familiarity with CAV technology in shaping responses to safety messages. Additionally, the male drivers showed significant adjustments in speed and acceleration, while female drivers exhibited a more consistent, cautious approach, with minimal changes in speed, acceleration, and lateral distance. Keywords: Vulnerable Road Users (VRUs), Signalized Intersections, CAV Testbed, Safety Messages, Driving Behavior Analysis

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Sponsoring Committee Standing Committee on Transportation Safety Management Systems (ACS10)
Standing Committee on Safety Performance and Analysis (ACS20)

Session Number **Poster Session 3109**

Session Title Transportation Research Board Minority Student Fellows

Paper Number TRBAM-25-02346

Paper Title **Understanding the Importance of Safe Routes to School: Observing School Safety in Lower-Income and Underserved Communities**

Abstract Over the past decades, studies have shown that fewer children walk to school and are dropped off by their caregivers. Many researchers attribute this to parents' fears that the walking environment is unsafe for children (1). Traffic safety around elementary schools is a pressing concern, particularly in cities like Dallas where traffic congestion intersects with safety hazards. This study explores historical insights, contemporary research, and proposed strategies tailored to address these dangers, emphasizing the need for effective traffic safety to protect schoolchildren and create safer environments. As a result, federal and state programs were created to provide safe routes to school for all students (2). This research examines narratives surrounding pedestrian safety and transportation planning, with a particular focus on urban environments. By examining historical insights, policy interventions, and societal attitudes toward pedestrian safety, this study aims to provide a comprehensive understanding of the evolution of transportation planning strategies. This paper explores the multifaceted approaches employed to address pedestrian safety concerns amidst increasing automobile traffic and urbanization. By presenting insights gleaned from historical narratives, this research paper aims to inform evidence-based solutions and advocate for the integration of historical perspectives in modern transportation planning efforts. Our study consisted of four schools in three counties in the North Central Texas Council of Government (NCTCOG) planning area. Through insights from a diverse body of literature focusing on transportation safety, with an emphasis on pedestrian safety, community-based interventions, and safe routes to school programs, this review contributes to a deeper understanding of transportation safety literature, highlighting the interconnectedness of various factors influencing safety outcomes and underscoring the need for multidisciplinary approaches to address evolving challenges in transportation safety. Keywords: Dallas, pedestrian, urban and nonurban, accessibility, inclusivity

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Session Number **Poster Session 3109**

Session Title Transportation Research Board Minority Student Fellows

Paper Number TRBAM-25-05226

Paper Title **Developing New Robotic and Human-Data Interfaces to Collect Accident Site Critical Data for Emergency Preparation and Response**

Abstract Rural communities are at a disadvantage when it comes to emergency response and management. They do not have as many resources and personnel as urban communities do. This can cause higher fatalities in car crashes, longer burn times in wildfires and intense flooding. This paper investigates the use of UAVs combined with Augmented Reality (AR) as a potential solution to assist rural communities in disaster management and emergency response time. This paper's main contribution is exploring the development of UAV-AR interface to assist in emergency situations. This technology aims to improve the efficiency and speed at which responders can access disaster sites. Under this proposed design, crucial information about the scene could be gathered and sent to first responders. AR would be used so that the first responders can see the site in real time. This paper describes three protocols for developing and implementing an AR interface to assist emergency responders in rural environments. Draft protocols are created for scenarios involving flooding, wildfires, and crashes. These three protocols include protocol for identifying the scene and area of disaster, identifying infrastructure and hazards, and identification of points of flooding, hotspots, and patients. This means the first responders can prepare and be more equipped to act when arriving on scene. This proposed technology can identify safe evacuation routes and specify areas to target wildfires. Testing methodologies and validation methods are discussed that could be used for the UAV with AR.

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Sponsoring Committee Standing Committee on Transportation Safety Management Systems (ACS10)

Session Number **Poster Session 4081**

Session Title Advancements in Emergency Response, Incident Management, and Post-Crash Care: Innovative Approaches to Enhancing First Responder Safety and Efficiency

Paper Number TRBAM-25-00241

Paper Title **A Metric for Assessing Emergency Medical Service (EMS) Crash Response Time Reliability**

Abstract In emergency medical services (EMS), rapid response times are critical for patient outcomes, particularly in trauma cases. This study investigates the reliability of EMS transfer times from crash scenes to hospitals using the integration of EMS runs and the Google Maps Directions API. We used EMS runs related to traffic crash incidents from 2021 and 2022. For each EMS run, the corresponding estimated travel time between the scene and hospital location in driving mode was obtained from the Google Maps Directions API using the same O-D GPS coordinates and date and time of travel. Cumulative distribution function graphs were employed to illustrate the variations in EMS time reliability across different variables. Additionally, common reliability metrics, including percentiles, percent variation, buffer index (BI), and misery index (MI), were utilized to evaluate and pinpoint the factors influencing the reliability of EMS transfer times. Results revealed significant variability in EMS performance, with improved reliability observed in cases involving enhanced traffic patterns and the use of lights and sirens. Fire department agencies demonstrated more reliable EMS services, and regional comparisons indicated that Fayette County exhibited more efficient EMS performance compared to Jefferson County. The analysis also showed that patient acuity level impacts EMS response reliability. This research contributes to understanding EMS efficiency and can inform policy decisions to enhance emergency response systems, ultimately improving patient care and survival rates.
Keywords: 20 Travel Time Reliability, Emergency Medical Services, Real-time Travel Data

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Sponsoring Committee Standing Committee on Transportation Safety Management Systems (ACS10)

Session Number **Poster Session 4081**

Session Title Advancements in Emergency Response, Incident Management, and Post-Crash Care: Innovative Approaches to Enhancing First Responder Safety and Efficiency

Paper Number TRBAM-25-00478

Paper Title **Advancing Vision Zero and the Safe System Approach Through Cross-Agency Coordination in Florida**

Abstract The Safe System Approach and Vision Zero depend on interagency coordination and a culture of safety for their overall success. Among the six principles of the Safe System Approach, shared responsibility for roadway safety encapsulates the need for coordination between various stakeholders. Vision Zero, at its foundation, focuses on removing silos for improved safety outcomes. To this end, effective cross-agency coordination and data sharing are essential for the success of both initiatives. This paper describes a literature review and screening survey that explores how counties and first responder agencies work together and share data to enhance road safety. A survey was sent to the 24 largest counties in Florida to identify which counties coordinate with first responder agencies. It documents their coordination strategies and data-sharing practices, as well as the obstacles and lessons learned for cross-agency coordination on roadway safety. Using the survey findings, a set of suggestions for improved coordination and data sharing between counties and local first responder agencies was developed. This study represents a key step in understanding the broader network of interagency relationships that support the principles of the Safe System Approach and Vision Zero, with a specific focus on data sharing. Although this study was conducted in Florida, the findings and suggestions of this study contribute to a broader understanding of interagency coordination on transportation safety both nationally and internationally.

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Session Number	**Poster Session 4081**
Session Title	Advancements in Emergency Response, Incident Management, and Post-Crash Care: Innovative Approaches to Enhancing First Responder Safety and Efficiency
Paper Number	TRBAM-25-00712
Paper Title	**How Do Motorists' Pre-Crash Behaviors Contribute to the Injury Severity of Police Officers? Using Interpretable Machine Learning to Untangle the Behavioral Pathways in Police-Involved Crashes**
Introduction	Police officers play a vital role in traffic safety by enforcing laws, assisting motorists, and managing traffic incidents. However, they face significant risks on the road, often due to drivers' negligent or inappropriate behaviors. To enhance their safety and improve traffic enforcement and incident management, it is crucial to examine the factors influencing injury severity in police-involved traffic crashes. Despite extensive research on general road users' injury severity, this area remains underexplored (1, 2). Previous studies highlight that driver behaviors, especially pre-crash behaviors, significantly impact crash outcomes (1, 3, 4). Understanding the behavioral pathways linking contributing factors, pre-crash behaviors, and injury severity is essential to uncover these relationships. This study addresses the gap by exploring the roles of motorists' pre-crash behaviors in police-involved crashes, focusing on: • How various factors contribute to unsafe pre-crash behaviors? • How pre-crash behaviors influence police officers' injury severity? • Direct and indirect contributions of these factors to injury severity. Traditionally, statistical models have been used to study crash severity and driver behaviors (5–15 8). While effective for interpretation, these models often lack predictive power and struggle with nonlinear relationships. To address these limitations, this study employs machine learning methods, offering improved predictive capabilities and deeper insights into the factors and behaviors shaping police-involved crash outcomes. This study analyzes police-involved crash data (2017–2021, Alabama) using a path analysis framework and machine learning techniques to explore factors influencing motorists' pre-crash behaviors and police injury severity. To minimize model bias, classifiers like Random Forest, AdaBoost, Naïve Bayes, Artificial Neural Networks, and Linear Discriminant Analysis are applied. Marginal effects quantify how contributing factors impact pre-crash behaviors and injury outcomes. Path analysis identifies direct and indirect contributors to police injury severity, with indirect effects linked to pre-crash behaviors. Findings aim to inform targeted interventions, addressing key risk factors to enhance road 26 safety for police officers.

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Session Number	**Poster Session 4081**
Session Title	Advancements in Emergency Response, Incident Management, and Post-Crash Care: Innovative Approaches to Enhancing First Responder Safety and Efficiency
Paper Number	TRBAM-25-01564
Paper Title	**A Deep Reinforcement Learning Approach for Combined Solution of Ambulance Dispatch and Relocation Problems**
Introduction	Emergency Medical Service (EMS) systems are vital components of healthcare systems, providing urgent care and transporting patients to appropriate facilities. Ambulances are essential resources in pre-hospital care, and their efficient use is critical to reducing EMS response times. Ambulance operations involve two main decision-making tasks: dispatch and relocation (1). While dispatch optimally matches ambulances with emergency calls and hospitals, relocation repositions idle vehicles to better prepare for future calls. Existing research commonly applies mathematical optimization to these tasks but often struggles to balance accurate operational modeling with the scalability required for large, real-world systems (2). Moreover, most studies address each decision task in isolation, overlooking their interdependencies. Advancements in artificial intelligence, particularly in Markov Decision Process (MDP) modeling and Deep Reinforcement Learning (DRL), offer promising tools to address these limitations (3). This paper presents a DRL-based approach that integrates ambulance dispatch and relocation into a unified framework to minimize EMS response times. By employing a dynamic action masking technique, the model effectively manages distinct feasible action sets for dispatch and relocation. Using real emergency call data from Huangpu District, Shanghai, the proposed approach significantly reduces average EMS response times and adapts effectively to varying temporal and spatial demand patterns.

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Sponsoring Committee Standing Committee on Transportation Safety Management Systems (ACS10)

Session Number **Poster Session 4081**

Session Title Advancements in Emergency Response, Incident Management, and Post-Crash Care: Innovative Approaches to Enhancing First Responder Safety and Efficiency

Paper Number TRBAM-25-01597

Paper Title **Exploring the Non-Linear Relationship between Highway Emergency Services and Travel Satisfaction: Insights from Hong Kong-Zhuhai-Macao Bridge**

Introduction

• Problem Statement, Scope, and Objective: This research addresses the urgent need for improved emergency management in highway operation and maintenance (O&M), amidst increasing emergencies such as traffic accidents, vehicle breakdowns, and environmental pollution, which often lead to congestion and challenge O&M capabilities. The scope focuses on emergency demand disposal in highway O&M, particularly enhancing emergency response services from a traveler's perspective. The objective is to improve O&M management efficiency and quality by examining emergency response service satisfaction surveys and analyzing factors affecting service quality.

• Literature Review: Previous studies on highway management have concentrated on accident safety, analyzing frequency and severity. However, there's a notable gap in addressing highway O&M management, especially in emergency accident management. The importance of multi-faceted O&M services is increasingly recognized, emphasizing customer-focused services to improve efficiency and reduce risks. Although studies exist on emergency services from a medical perspective, the exploration of the correlation between emergency operations and service quality in highway O&M is limited.

• Methods: The research employs an advanced Gradient Boosting Decision Tree (GBDT) model to analyze comprehensive emergency management records and after-action surveys from the Hong Kong-Zhuhai-Macao Bridge (HZMB). The analysis focuses on identifying factors related to emergency handling services from the O&M management perspective, involving variables from both emergency handling and accident characteristics.

• Main Findings and Significance: The study contributes significantly to both academic research and industry practice. It provides insights into emergency handling practices from a complex highway O&M site, offering a multidimensional perspective involving multiple contexts. By comparing and analyzing factors affecting service satisfaction, the research offers valuable information on achieving different ratings in O&M management, facilitating practical business enhancements and improving road management and operational decision-making. It fosters cross-disciplinary insights and supports targeted policy formulation in O&M management, enhancing the practical effectiveness of highway administration strategies.

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Session Number	**Poster Session 4081**
Session Title	Advancements in Emergency Response, Incident Management, and Post-Crash Care: Innovative Approaches to Enhancing First Responder Safety and Efficiency
Paper Number	TRBAM-25-01894
Paper Title	**An Optimization Method for Forecasting and Scheduling the Demand for Emergency Medical Supplies in Sudden Public Health Events**
Abstract	To address the prediction and allocation challenges of emergency medical supplies during the middle and late stages of major outbreaks, we proposed an end-to-end ICSL deep learning algorithm architecture. This approach takes into account the characteristics of infectious diseases and the impact of government quarantine measures on their spread, enabling the prediction of the maximum demand for emergency medical supplies. Based on this, a multi-objective scheduling and allocation model was constructed, considering urgency, scheduling time, and cost. We designed a multi-objective particle swarm optimization algorithm to solve this model. Finally, we validated the algorithm using data from the Wuhan pandemic control measures. The results showed that the parameter update method improved the prediction accuracy of the LSTM model, increasing accuracy by 29.37% compared to the traditional LSTM algorithm and by 8.63% compared to the improved BP neural network algorithm. The proposed scheduling and allocation model optimizes delivery timeliness while also considering the urgency and cost-effectiveness of the resource allocation. The research findings can provide decision-making insights for the allocation of emergency medical supplies during public health emergencies. Keywords: Logistics Engineering; Emergency Medical Supplies; Parameter Update; ICSL 16 Algorithm; Particle Swarm Optimization Algorithm

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Session Number	**Poster Session 4081**
Session Title	Advancements in Emergency Response, Incident Management, and Post-Crash Care: Innovative Approaches to Enhancing First Responder Safety and Efficiency
Paper Number	TRBAM-25-02136
Paper Title	**Move Over or Slow Down? A Simulation-Based Evaluation of the Safety Impact of Motorist Actions in Compliance with Move Over Laws**
Introduction	The efforts of roadside responders such as law enforcement, fire crews, and tow operators are crucial for the smooth operation and safety of transportation networks [1], though they are exposed to risks from surrounding traffic environments while working [2]. To protect roadside responders, all states in the United States have Move-Over laws which requires drivers to either change lanes (Move Over) or significantly reduce their speed (Slow Down) when approaching roadside responders. However, determining whether drivers should slow down or move over involves significant complexity, as roadside situations are often unpredictable. This research seeks to explore the influence of different driver actions on roadside responder safety and to develop clear safety recommendations for drivers. Existing research on compliance with the Move-Over Law largely relies on field observations conducted at a few specific sites, often neglecting the broader spectrum of traffic scenarios that could be analyzed through simulation. Additionally, limited studies offer drivers actionable guidance on when and how to properly move over or reduce speed near roadside responders. To address these gaps, this study develops a traffic simulation tool capable of modeling a wide range of traffic conditions. The simulator integrates customizable input parameters to replicate real-world traffic situations and examines interactions between roadside responders and passing vehicles. By analyzing outputs such as speed, following distances, and other dynamics, the study quantifies risks to both responders and motorists. Through extensive simulations, this research identifies how varying conditions and driver behaviors influence roadside safety. The result shows that three primary factors --- sight distance to roadside responders, vehicle platoon length, and move-over success rate, greatly affects roadside responder's safety: shorten sight distance, longer vehicle platoons and low move-over success rate significantly lower drivers' reaction time and brake time, thus leading to actions dangerous (no move over, no slow down) to roadside responders. This study also provides practical recommendations for motorists to avoid mitigating risks or threats to roadside responders and enhance safety.

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Session Number **Poster Session 4081**

Session Title Advancements in Emergency Response, Incident Management, and Post-Crash Care: Innovative Approaches to Enhancing First Responder Safety and Efficiency

Paper Number TRBAM-25-02288

Paper Title **Move-Over Laws and Incident Response Personnel Safety in the United States**

Abstract As the number of vehicles on U.S. roads continues to grow, there is an increasing risk for all road users to be involved in a traffic incident. Although congestion and traveler delay are the most common problems in traffic incidents, workplace-related injury or fatality among incident response personnel are also a serious problem. The injuries may be alleviated with the help of effective laws about incident response personnel safety standards, including state move-over laws. This paper provides an overview, as of July 2024, of existing incident response personnel ("move-over") laws for all fifty states. This study finds that there is a great variation in such laws among states, which may lead to challenges with comprehension and compliance. States that offer the least amount of protection to their incident response personnel were identified. Recommendations were provided on specific elements of the legislation to offer greater protection to the incident response personnel while working on the side of the roads. The nuances and the variation in move-over laws can make it difficult for drivers to understand what the law requires of them. The findings of this paper will be of interest to researchers, stakeholders, and policymakers working in the field of transportation and occupational safety.

Keywords: incident response personnel, move-over laws, policy, safety, traffic crash, traffic incident.

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Session Number **Poster Session 4081**

Session Title Advancements in Emergency Response, Incident Management, and Post-Crash Care: Innovative Approaches to Enhancing First Responder Safety and Efficiency

Paper Number TRBAM-25-02405

Paper Title **Real-Time Incident Detection Through Predictive Modeling of Crowdsourced Waze Data**

Abstract Effective incident detection is essential for emergency response and transportation management. Traditional methods relying on stationary technologies are often costly and provide limited coverage, prompting the exploration of crowdsourced data such as Waze. While Waze offers extensive coverage, its data can be unverified and unreliable. This study aims to identify factors affecting the reliability of Waze alerts and develop a predictive model to distinguish true incidents from false alerts using real-time Waze data, thereby improving emergency response times. Real crash data from the New Jersey Department of Transportation (NJDOT) and crowdsourced data from Waze were matched using the DBSCAN algorithm to differentiate true and false alerts. A binary logit model was constructed to reveal significant predictors such as time categories around peak hours, road type, report ratings, and crash type. Findings indicate that the likelihood of accurate Waze alerts increases during peak hours, on streets, and with higher report ratings and major crashes. Moreover, two predictive models based on the XGBoost algorithm were developed: one using significant factors and the other incorporating all attributes. The model based on significant factors achieved an accuracy of 86.23%, while the model with all factors had an accuracy of 86.10%. Despite minimal differences in performance metrics, the significant factors model is computationally more efficient and suitable for real-time applications. The findings underscore the importance of user engagement and contextual factors in improving the reliability of crowdsourced traffic alerts, offering valuable insights for real-time traffic management and emergency response systems.

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Session Number	**Poster Session 4081**
Session Title	Advancements in Emergency Response, Incident Management, and Post-Crash Care: Innovative Approaches to Enhancing First Responder Safety and Efficiency
Paper Number	TRBAM-25-02541
Paper Title	**Identifying High Risk Roadway Segments for Dynamic First Responder Allocation**
Abstract	Motor Vehicle Crashes (MVCs) are a leading cause of unintentional injury and mortality in the U.S., with 36,500 fatalities and 4.5 million injuries reported in 2019, leading to a $340 billion societal burden. Fatalities increased by 10% the following year. This study utilizes advanced machine learning techniques and optimization algorithms, integrating data on weather, traffic volume, and road conditions to identify high-risk roadway segments. This approach aims to enhance emergency response deployment, improving public safety and reducing the economic impact of MVCs. As part of an NSF-funded project, we analyzed 2017 MVC data over a 1,000-mile corridor from Dallas, TX to Chicago, IL. Using an XGBoost Classifier model, refined with SMOTE and Tomek Links, we identified MVC predictors such as time of day, traffic flow, and weather conditions. The DBSCAN algorithm was then applied to locate MVC hotspots. Relocating EMS services closer to these hotspots led to a 33.5% reduction in median response distances (from 3.79 miles to 2.52 miles) and a 31.7% improvement in median response times (from 6.66 minutes to 4.55 minutes). This demonstrates the benefits of dynamic EMS positioning to high-risk areas. Our methodology aims to reduce MVC response times, optimize Traffic Incident Management (TIM), and Emergency Medical Services (EMS) deployment, thus lowering operational costs and enhancing MVC impact mitigation. This approach supports dynamic planning for TIM/EMS resource allocation.

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Session Number	**Poster Session 4081**
Session Title	Advancements in Emergency Response, Incident Management, and Post-Crash Care: Innovative Approaches to Enhancing First Responder Safety and Efficiency
Paper Number	TRBAM-25-02845
Paper Title	**Examining the Spatially Varying Correlates of Police Injury Severity: A Study of Pennsylvania**
Introduction	Police officers are integral to maintaining traffic safety, enforcing laws, and responding to incidents. However, these responsibilities place them at significant risk on roadways, particularly during high-stress situations such as emergency responses or routine traffic stops. National statistics reveal that motor vehicle-related accidents have accounted for a substantial portion of line-of-duty deaths, underscoring the occupational hazards faced by law enforcement. From 2011 to 2020, traffic crashes contributed to 33% of officer fatalities, highlighting the need for targeted interventions to enhance officer safety. 8 Despite the critical importance of this issue, research on police-involved traffic crashes remains limited compared to studies focusing on other road users. Existing studies primarily emphasize general crash dynamics or injuries among civilians, leaving significant gaps in understanding the unique risks faced by police officers. Furthermore, most traditional analyses overlook the geographic and socioeconomic contexts influencing crash severity, potentially underestimating the role of spatial heterogeneity in shaping crash outcomes. This study addresses these gaps by examining the factors contributing to police injury severity in traffic crashes across Pennsylvania. Using ten years of crash data involving police vehicles, this research employs a Geographically Weighted Ordered Logistic Regression (GWOLR) model to uncover spatial variations in the relationships between injury severity and explanatory variables. Unlike global models that assume uniform relationships, GWOLR accounts for non-stationarity, revealing how local conditions and risk factors vary across geographic regions. By identifying these localized patterns, the study provides insights into region-specific risks and strategies for improving police safety. Through this spatial lens, the research seeks to answer critical questions: What factors most significantly impact police injury severity, and how do these relationships vary across Pennsylvania? How can law enforcement agencies use these insights to develop tailored safety measures? By addressing these questions, this study not only enhances our understanding of police-involved crashes but also lays the groundwork for data-driven interventions that protect officers and promote safer roadways for all.

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Session Number	**Poster Session 4081**
Session Title	Advancements in Emergency Response, Incident Management, and Post-Crash Care: Innovative Approaches to Enhancing First Responder Safety and Efficiency
Paper Number	TRBAM-25-04169
Paper Title	**Emergency Vehicle Lighting Applications for Safety Service Patrols: A Synthesis Study**
Introduction	Emergency responders play a fundamental role in traffic incident management (TIM) and roadway safety, making them vulnerable to secondary crashes and struck-by incidents. Although laws such as Florida's "Move Over" law promote safety for responders, their fatality and injury rates remain unacceptable. This study used a systematic literature review to synthesize the documented factors related to emergency vehicle lighting that affect the safety of roadside emergency responders. A nationwide expert survey augments past research, providing context with current safety service patrol vehicle lighting configurations across the United States. One hundred ninety-eight relevant research publications were reviewed, of which 39 were synthesized. Observations showed that lighting color, flash pattern, flash rate, and placement encouraged move-over behavior. In addition, a national survey of experts from 44 different agencies was conducted across 30 states in the U.S. which supplemented information from the literature review. The survey highlighted the diversity in lighting systems across safety service patrol (SSP) programs. Respondents emphasized the need for national standards and automated technologies to enhance safety, efficiency, and reduce operator burden. Future research could explore qualitative data methods, the impact of field variables, geometric design, weather, driver demographics, and human factors to guide future policies and standards in emergency vehicle lighting for improved safety. Keywords: Warning lights, Visibility, Conspicuity, TIM, Service patrol, Emergency vehicle, Incident, Road ranger, Police.

104th ANNUAL MEETING
January 5–9, 2025 • Washington, DC

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Session Number	**Poster Session 4081**
Session Title	Advancements in Emergency Response, Incident Management, and Post-Crash Care: Innovative Approaches to Enhancing First Responder Safety and Efficiency
Paper Number	TRBAM-25-04759
Paper Title	**Enhancing Alternative Fuel Vehicle Emergency Response Through the Integration of Retrieval-Augmented Generation Enabled Large Language Model and Extended Reality**
Introduction	The rising number of alternative fuel vehicles (AFVs), such as electric vehicles (EVs), presents unique challenges in emergency situations, necessitating advanced tools for first responders due to operational differences from traditional combustion engines. This paper introduces a framework that integrates retrieval-augmented generation (RAG) enabled large language models (LLMs) with extended reality (XR) technology to enhance the effectiveness and accessibility of AFV emergency response guides. Traditional LLMs, while powerful, often face limitations in handling context relevance and factual accuracy when dealing with specialized content such as emergency response guides. The proposed system begins by extracting content from these guides, indexing the data for retrieval, and contextualizing it through the RAG 1omponent to ensure accurate, real-time guidance visualized through XR technology. The application of artificial intelligence in emergency response, specifically through the advancements in LLMs and XR, has redefined traditional approaches. Our methodology is supported by current research that highlights the improvements in emergency response capabilities facilitated by technological advancements. Notably, RAG techniques have been crucial in enhancing the accuracy and relevance of information delivered in urgent contexts typical of emergency situations. Our methodology involves a novel system architecture that combines real-time data retrieval with XR interfaces to provide dynamic, contextually relevant information overlays. The emergency response guides are processed digitally, extracting and indexing crucial information, which is then retrieved and synthesized in response to user queries, and displayed via XR devices like the Microsoft Hololens2. The main findings of this study demonstrate that the integration of RAG-enabled LLMs with XR can considerably improve the accessibility and applicability of emergency response guides, enhancing decision-making processes and reducing response times for first responders. These enhancements not only contribute practically by improving operational efficiency but also theoretically enrich the understanding of how integrated technologies can be leveraged to address complex challenges in emergency management for AFVs. This research highlights how advanced AI and XR technologies can improve emergency response strategies, contributing to both practical applications and theoretical understanding.

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Sponsoring Committee Standing Committee on Transportation Safety Management Systems (ACS10)

Session Number **Poster Session 4081**

Session Title Advancements in Emergency Response, Incident Management, and Post-Crash Care: Innovative Approaches to Enhancing First Responder Safety and Efficiency

Paper Number TRBAM-25-04781

Paper Title **Data Driven Analysis to Inform National Strategies on Improving Post-Crash Care**

Abstract Reducing prehospital emergency medical service (EMS) time is essential for decreasing the severity of crash outcomes. Recently, South Korea has faced prolonged prehospital EMS time, prompting the Korea National Fire Agency (KFA) to announce strategies to reduce prehospital EMS time. This study aimed to provide a methodological process and quantitative basis for implementing the KFA's strategies. To achieve this, the study employed an XGBoost approach with SHAP value analysis to identify key factors influencing crash severity and to examine their global and local impacts. The resultant key factors included spatiotemporal attributes, including on-scene time, freeway mainline, and nighttime, which were used to quantitatively validate the KFA's strategies. This research is the first attempt to apply an interpretable machine learning algorithm to improve post-crash care, using crash data and EMS infrastructure information from an entire country. The methodology employed can be applied to quantitatively support decision-making on similar issues in various regions and countries.
Keywords: Emergency medical service, Crash severity, XGBoost, SHAP value, Decision-making

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Sponsoring Committee Standing Committee on Safety Performance and Analysis (ACS20)

Session Number **Poster Session 2206**

Session Title Safety Performance and Analysis with Crash Predictions

Paper Number TRBAM-25-00395

Paper Title **Crash Risk Prediction and Analysis from the Perspective of Alignment and Environment Features: A Study on Expressway in Hilly Area**

Abstract Expressways in hilly areas feature complex alignment and environments constrained by terrain conditions, significantly threatening life and property safety. This study aims to investigate crash risk prediction of expressways in hilly areas through alignment and environment features and identify determinants of the high risk for safety improvement. Based on five years of crash data on casualties and property damage of an expressway in southwestern China, the TOPSIS and five clustering algorithms were employed to determine and classify risk levels. Environment features were extracted by semantic segmentation with a DeepLabv3 model. The study established four ensemble learning models to predict crash risks, and the SHAP approach was adopted to interpret contributing features. XGBoost achieved the best overall performance, with the accuracy and F1 score reaching 0.9259 and 0.8886. The proportion and variation rate of trucks and cars, and the proportions of constructions and the road positively affected high risks, while the proportions of the vegetation and road had negative effects. The horizontal and vertical alignments, including long steep slopes, smaller curve radii, shorter transition curves, and smaller convex and concave curves radii, were linked to high risks. This study provides an approach to predict risk sections without passive historical crash data and understand high risks from underlying mechanisms. The findings can benefit researchers and decision-makers from expressway design and management departments by proactively screening high-risk sections, improving operation safety, and promoting sustainable management of road infrastructures. 19 Keywords: road safety; hilly expressway; risk analysis; ensemble learning; SHAP

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Sponsoring Committee	Standing Committee on Safety Performance and Analysis (ACS20)
Session Number	**Poster Session 2206**
Session Title	Safety Performance and Analysis with Crash Predictions
Paper Number	TRBAM-25-01271
Paper Title	**Collision Risk Prediction in the First Phase of Overtaking on Two-lane Highway Based on Nearest Distance Risk Indicator**
Abstract	Overtaking on two-lane highway is a complex and hazardous task particularly in the first phase. In order to make up for the shortcomings of earlier studies on the risk prediction of the first phase on two-lane highway, this study presented a two-dimensional risk indicator considering the nearest distance between vehicles during overtaking and built short-time risk prediction models by non-parametric methods. Firstly, based on the overtaking trajectory obtained by the dual UAV observation method, this study analyzed the behaviors in the first phase of overtaking in various scenarios. Secondly the risk indicator dis_TTC was proposed which had been proved the superiority in the task of collision risk assessment by comparing it with TTC. Finally, the top five most important characteristic variables which were screened by Random Forest were selected to construct the non-parametric short-term risk prediction model. The findings 1demonstrate that overtaking behavior was quite variable in different conditions and the potential psychological cost to drivers is larger when there were a reversing car and overtaking trucks. According to the results of risk assessment, the 85% quantile risk threshold of dis_TTC was 2.00s. With the average R2 values of 0.97 and 0.82, respectively, the non-parametric model represented by Extra Trees and K-Nearest Neighbors performs best on the time scales of 0.5s, 1.0s, and 1.5s compared with parametric model. The research's conclusions show promise for proactive risk aversion on two-lane highways. Keywords: Overtaking collisions; non-parametric model; short-time risk prediction; two 20 dimensional conflict indicator

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Sponsoring Committee	Standing Committee on Safety Performance and Analysis (ACS20)
Session Number	**Poster Session 2206**
Session Title	Safety Performance and Analysis with Crash Predictions
Paper Number	TRBAM-25-01768
Paper Title	**Time-Varying Causality Analysis of Successive Secondary Conflicts Using Hazard-Based Duration Models**
Introduction	Secondary crashes within chain collisions represent a significant yet underexplored area in traffic safety (1). According to the U.S. Department of Transportation, secondary crashes account for approximately 20% of traffic-related fatalities (2-3). These crashes are generally categorized into two types: those caused by queuing effects following a primary crash and those occurring within the influence zone of a primary crash due to successive vehicle conflicts (4-5). This study emphasizes the latter type, as chain collisions are increasingly common in modern traffic systems (6). Since traditional crash databases often lack sufficient or unbiased records, secondary conflicts are examined as proxies to understand the spread of secondary crashes (7-9). The primary challenges lie in identifying secondary conflicts, quantifying their risks, and accounting for uncertainties. Existing studies have recognized secondary conflicts in various road conditions but have not fully explored the factors influencing their propagation or considered unobserved heterogeneity (10-18). This research employs a high-precision vehicle trajectory dataset to construct a chain conflict identification model that detects mutually influential conflicts. Secondary conflicts are then extracted and analyzed through a multi-level variable system encompassing macro-level factors (road segment type, traffic status), meso-level factors (front chain conflict patterns), and micro-level factors (vehicle statuses). Using Kaplan-Meier analysis and the Log-Rank test, significant factors influencing secondary conflicts are identified. Additionally, a Weibull Accelerated Failure Time model with random parameters is developed to analyze the combined effects of multiple factors on secondary conflict occurrences, accounting for unobserved heterogeneity. This approach yields a survival probability curve that highlights key risks during chain conflict propagation. The study introduces four innovations: (1) proposing a multi-level variable framework for quantifying factors influencing successive secondary conflicts; (2) developing a Kaplan-Meier model to compare the heterogeneous effects of different segment types, traffic statuses, and front chain conflict types on secondary conflicts; (3) constructing a hazard-based duration model with random parameters to determine the survival probability curve and influencing factors during chain conflict propagation; and (4) introducing the concept of a critical post-supervision period, emphasizing the need for close monitoring shortly after a conflict to prevent further chain conflicts.

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Session Number	**Poster Session 2206**
Session Title	Safety Performance and Analysis with Crash Predictions
Paper Number	TRBAM-25-01960
Paper Title	**Study on Regional Risk Evaluation Model of Mountainous Secondary Highway Based on BN-DS**
Abstract	This study investigates driving safety on mountainous secondary highways, focusing on sections, intersections, sharp curves, and slopes. Risk levels are quantitatively assessed by analyzing traffic characteristics and constructing evaluation indexes based on conflict rates and serious conflicts per vehicle-kilometer. A risk evaluation model is introduced, combining Bayesian Network (BN) and Dempster-Shafer (DS) theory, and considers factors from vehicle conditions, road environment, and weather. First, UAV aerial photography data is processed using optical flow methods, identifying eight key causal risk factors through correlation analysis. The risk evaluation model is then developed using machine learning to construct the Bayesian Network and integrate DS theory. Next, the highway is segmented using ArcGIS, with traffic risk levels and conflict locations visualized through a risk level map. When applied to practical scenarios, the model demonstrates its effectiveness in assessing traffic risk distribution across various road environments. It accurately identifies high-risk points, enabling targeted adjustments and laying a foundation for future risk prevention and control. Keywords: Traffic Safety, Mountainous Secondary Highway, Risk Evaluation, Visualization

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Sponsoring Committee	Standing Committee on Safety Performance and Analysis (ACS20)
Session Number	**Poster Session 2206**
Session Title	Safety Performance and Analysis with Crash Predictions
Paper Number	TRBAM-25-03242
Paper Title	**Predicting Crash Frequency at Upstream Diverging Section of Toll Plaza in Heterogenous Traffic**
Abstract	The presence of Electronic Toll Collection (ETC) lanes at toll plazas can increase crash risks, particularly in upstream diverging sections, due to the frequency of lane-changing maneuvers in heterogeneous traffic. The study aims to predict crash probabilities of mixed lane-changing traffic conflicts using extreme value theory (EVT) at the upstream toll plaza region. High-resolution (4K) video data were acquired using Unmanned Aerial Vehicle (UAV) technology, covering a 240-meter road segment to capture morning rush hour traffic (8 to 9 a.m.) at the Jewar Toll Plaza on the Yamuna Expressway (YE) in India. Vehicle trajectories and surrogate measures such as Time to Collision (TTC) were extracted using advanced AI-driven video analysis via DataFromSky platform. Furthermore, the proposed Lane Changing Time-to-Collision (LTTC) was analyzed using the Peak Over Threshold (POT) approach. The Mean Residual Life (MRL) plot, along with the scale and shape parameter stability plots of the Generalized Pareto Distribution (GPD), identified the threshold as -1.25 sec. The results indicate that the collision risk (R) for Cars, Two Wheelers (2W), Trucks, Buses, and Light Commercial Vehicles (LCV) are 0.0084, 0.0068, 0.0073, 0.0057, and 0.0034, respectively. The annual crash frequency (N) for all vehicle types at the section was calculated to be 41 incidents. The correlation heatmap between vehicle type, collision risk, sample size, and mean vehicle speed indicates that smaller vehicle types should be prioritized in traffic safety measures, as they are associated with higher collision risks and travel speeds. Keywords: Lane-changing traffic, Collision risk, Extreme value theory, Diverging section, Toll Plaza.

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Sponsoring Committee	Standing Committee on Safety Performance and Analysis (ACS20)
Session Number	**Poster Session 2206**
Session Title	Safety Performance and Analysis with Crash Predictions
Paper Number	TRBAM-25-03631
Paper Title	**Quantifying Road Network Structure and Its Impact on Traffic Crashes: A Bayesian Hierarchical Approach**
Abstract	Road traffic crashes (RTCs) are a major cause of fatalities worldwide. Recent studies indicate that the influence of road network structure on RTCs has not been adequately explored, and the results from the limited previous studies are inconsistent. This inconsistency can be attributed to the methodologies employed in earlier studies, which often relied on visual inspection to quantify road network structure. This approach is both subjective and impractical. Additionally, the failure to account for spatial autocorrelation and overdispersion in modelling can also lead to inconsistent results. This study aims to address these gaps by (1) using graph theory metrics to quantify road network structure and (2) developing a statistical model to understand how network characteristics like connectivity, density, complexity and centrality correlate with RTCs, accounting for overdispersion, unobserved heterogeneity and spatial autocorrelation. Using a Bayesian hierarchical model, the study conducts a spatial analysis of fatal RTCs at ward level for Delhi, India. The findings reveal a significant association between higher road network connectivity and increased fatal RTC risk. Areas with a higher density of intersections involving major roads also experience more fatal crashes. Intersections deviating from the typical 90-degree angle (higher skewness) are linked to higher fatal RTCs. Conversely, an efficient network structure (less circuity) is associated with lower fatal RTCs, while network centrality shows a negative correlation with fatal RTCs. These results should not be interpreted in isolation, as road network characteristics also interact with factors like traffic volumes, speeds, and environmental conditions impacting safety. Keywords: Road Network Structure, Bayesian Hierarchical model, Skewness, Crashes, Fatal Crashes

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Sponsoring Committee	Standing Committee on Safety Performance and Analysis (ACS20)
Session Number	**Poster Session 2206**
Session Title	Safety Performance and Analysis with Crash Predictions
Paper Number	TRBAM-25-04756
Paper Title	**Time-Dependent Negative Binomial-Lindley Model for Addressing Temporal Variations and Excess Zeros in Crash Data**
Introduction	Crash data usually exhibits unique characteristics, such as excess zero observations that the NB distribution cannot adequately model. The negative binomial-Lindley (NBL) has been proposed to address this limitation. Despite addressing the issues of excess zero observations, the NB-L model may not fully account for unobserved heterogeneity resulting from temporal variations in crash data. As crashes are sometimes counted over more extended periods, some explanatory variables such as speed, traffic volume, economic indicators, pavement skid number, and weather patterns may change significantly over time (1–4). Failing to account for this within-period variation in the explanatory variables may result in a loss of relevant information, also called unobserved heterogeneity (5–7) . To address these challenges, we propose and develop the NBL model with time-dependent parameters (NBL-TiDP) using the group random parameters strategy. The derivations and characteristics of the model and its power to account for both temporal variations and excess zeros in panel data are documented. Then, the model is illustrated using a simulation study and two empirical datasets from Texas having time-dependent variables. The results of several goodness-of-fit measures indicate that using the NBL model with time-dependent parameters enhances the model fit compared to the NB, NBL, and the NB model with timedependent parameters. Findings derived from crash data collected from both rural minor and principal arterial roads in Texas suggest that the variables denoting the median presence and wider shoulder width are associated with a potential decrease in crash occurrences. Moreover, higher variations in speed and wider road surfaces are linked to a potential increase in crash frequency. Similarly, a higher monthly average daily traffic (Monthly ADT) positively correlates with crash frequency. We also found that it is important to account for temporal variations using timedependent parameters.

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Session Number	**Poster Session 2206**
Session Title	Safety Performance and Analysis with Crash Predictions
Paper Number	TRBAM-25-04831
Paper Title	**A Joint Count and Generalized Ordered Fractional Split Approach for Addressing Temporal Instability in Road Safety Analysis**
Abstract	This study addresses temporal instability in multivariate crash frequency models using data from the Greater Orlando Region (2011-2019). We compare the performance of the Joint Negative Binomial-Generalized Ordered Probit Fractional Split (NB-GOPFS) Model with the performance of the Mixed Negative Binomial Model with a specific emphasis on parameter temporal variability. The dataset includes four injury severity categories: no injury, minor injury, non-incapacitating injury, and serious injury. The independent variables considered include sociodemographic, land use, and transportation infrastructure variables. Performance assessments using root mean square error (RMSE) values show that the NB-GOPFS model consistently outperforms the Mixed Negative Binomial model in accuracy and parsimony. The NB-GOPFS approach enhances prediction accuracy and model simplicity, making it effective for crash frequency modeling with temporal instability in exogenous variables. This study supports the integration of advanced multivariate models in transportation safety analysis to improve intervention strategies and policymaking. Keyword: Crash severity, Crash frequency, Temporal instability, Unobserved effects, Negative 16 Binomial Generalized Ordered Probit Fractional Split Model.

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Sponsoring Committee	Standing Committee on Safety Performance and Analysis (ACS20)
Session Number	**Poster Session 2206**
Session Title	Safety Performance and Analysis with Crash Predictions
Paper Number	TRBAM-25-04901
Paper Title	**Applying Extreme Value Theory to Road Safety Evaluation using Safety Pilot Model Deployment (SPMD) Data**
Introduction	Road safety assessment faces a critical challenge: traditional measures based on crash frequency and injury severity are often limited by data availability and quality issues. These limitations manifest in two key ways: (1) small sample sizes and underreporting due to predetermined reporting thresholds or voluntary non-reporting, and (2) insufficient detail to fully understand crash mechanisms, leading to inconclusive or conflicting analyses. To address these challenges, researchers have developed surrogate safety measures that evaluate traffic safety without relying on crash data. These measures identify traffic conflicts, defined as situations where two or more road users approach each other in space and time with a crash risk unless they alter their movements. Surrogate measures offer several advantages over traditional crash-based analysis: they enable proactive safety assessment, allow rapid evaluation of innovative intersection designs and traffic control strategies, and can effectively measure safety improvements for rare crash types such as pedestrian or bicycle incidents. While traditional collection methods for surrogate safety measures relied on field observations—which are time-consuming, labor-intensive, and potentially inaccurate—recent technological advances have revolutionized data collection approaches. Automated techniques, traffic simulations, and emerging data sources such as naturalistic driving studies and the Safety Pilot Model Deployment (SPMD) study now provide more efficient and accurate means of gathering surrogate safety data. Of particular interest is the SPMD study, which collected comprehensive vehicle-to-vehicle and vehicle-to-infrastructure communication data from approximately 3,000 vehicles across 73 lane-miles in Ann Arbor, Michigan. The goal of this study was to 1) provide a framework on utilizing the in-vehicle SPMD data to extract surrogate safety measures and evaluate road safety; 2) apply extreme value theory models in the road safety evaluation and illustrate possible application using the in-vehicle data. The findings contribute both theoretical and practical value: theoretically, they extend the application of extreme value theory to in-vehicle connected vehicle data analysis; practically, they provide transportation agencies with a more robust methodology for proactive safety assessment using in-vehicle data.

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Session Number	**Poster Session 2206**
Session Title	Safety Performance and Analysis with Crash Predictions
Paper Number	TRBAM-25-05657
Paper Title	**Analyzing Crash Frequency and Crash Type Dynamics in Sweden from 2017 to 2022 Using a Hierarchical Modeling Approach**
Introduction	Traffic crashes represent a persistent global challenge, significantly impacting public health, economics, and societal well-being. In Sweden, which experiences diverse environmental and traffic conditions, understanding and predicting crash frequency and types are vital for developing effective policies. This study builds upon the existing body of traffic crash research by employing a hierarchical modeling framework to analyze crash data across national-level roads in Sweden from 2017 to 2022. Past studies on traffic crashes often focus on single-level models (1-2), limited to intersections or specific crash types. Models like the multinomial logit and negative binomial have been used to examine crash categories or frequencies but often fail to capture nested structures, such as road segments within counties. Hierarchical models address these gaps by accounting for unobserved heterogeneity across data levels (3-5). Previous research in traffic safety has emphasized the need to incorporate regional variations and environmental factors (6). Some studies indicate that traffic volume, road width, and environmental factors, like weather conditions, significantly influence crash risks. However, relatively few studies have explored these dynamics on a national scale in countries with varying regional characteristics, such as Sweden. Moreover, the COVID-19 pandemic has introduced additional complexity in crash analysis, as changes in mobility patterns have impacted crash frequency and severity worldwide (7). This study addresses these gaps by applying a multi-level model that integrates both segment-level and county-level variables. The objectives are to model crash frequency and identify distinct crash types, while assessing the effects of various factors, including road design, socio-demographics, and time-varying conditions such as the COVID-19 pandemic. In our previous research, we conducted a macroscopic analysis, of changes in crash frequency across Sweden during the pandemic (8). Building on those findings, this study delves into a more detailed micro-level examination. This research offers a comprehensive approach to understanding traffic crash dynamics and provides insights essential for policy development and safety improvements.

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Sponsoring Committee	Standing Committee on Safety Performance and Analysis (ACS20)
Session Number	**Poster Session 2206**
Session Title	Safety Performance and Analysis with Crash Predictions
Paper Number	TRBAM-25-00996
Paper Title	**Investigating the Impact of Recommended Fragment Size to Improve Crash Count Prediction Models**
Introduction	Numerous traffic crash studies acknowledge the influence of a consistent fragment size (FS) on their results due to the traffic data aggregation impacts. A previous study proposed an innovative method using the Laplacian score joined by a distance-based entropy measure (LSDBEM) and K-means clustering to avoid the arbitrary selection of a FS and provide a recommended fragment size (RFS) for data aggregation. The study investigates the impact of changes in FS on the crash count prediction modeling process under four different scenarios for forming crash group definitions while evaluating the value and suitability of the RFS rather than exhaustively testing or arbitrarily selecting a FS. The study results show that the minimum multicollinearity among the explanatory variables occurs when using the RFS. The training model performances reached their minimum Akaike Information Criterion (AIC) at RFS of 0.24 and 0.20 mile under scenarios 1, 2, and 3 for IH 20 EB and IH 20 WB, respectively while the minimum AIC values for scenario 4 inconsistently appear at different fragment sizes. For scenarios 1, 2, and 3. the results show that the $RMSE$ from the testing data occurred at the RFS for some crash groups and the remaining crash groups show that the RMSE at the RFS, $RMSE$, remains within 20% of the $RMSE$. Scenario 3 provides high granularity and consistent modeling performance across all crash groups. This shows that the RFS represents a reasonable strategy to simplify fragment selection and modeling for all scenarios and crash groups with sufficient non-zero observations.

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Session Number	**Poster Session 2206**
Session Title	Safety Performance and Analysis with Crash Predictions
Paper Number	TRBAM-25-02751
Paper Title	**Out-Of-Sample Prediction for Random Parameter Generalized Linear Models**
Introduction	The use of random parameters in generalized linear models (GLMs) is a well-documented approach that captures unobserved heterogeneity and non-constant effects of independent variables on the dependent variable (1, 2). The unobserved heterogeneity is often due to important factors that are not available or are unobservable, measurement error, missing important interactions, or incorrect functional forms (3, 4). Failure to account for this unobserved heterogeneity can lead to biased and inefficient parameter estimates, inaccurate predictions, and incorrect conclusions (3, 5-7). However, applying models with RPs to make predictions for observations outside the sample used to estimate the model is not straightforward. Several studies have recently proposed various methods to incorporate RPs in out-of-sample predictions, but these tend to provide biased estimates or are computationally intensive (17, 20, 54). To alleviate these drawbacks, this paper applies fundamental statistical theory to leverage properties of the distributions of underlying RPs incorporated into GLMs to provide more direct and accurate predictions for out-of-sample observations. The proposed method applies fundamental statistical theory to directly use the characteristics of the random paramete distributions for generating out-of-sample predictions with GLMs, focusing on applications to GLMs that use a log-link function. By using the properties of the distributions directly, simulation error and approximation issues from simulation-based methods are removed from the predictions. The theory is applied to random parameter count regression models to illustrate their use for out-of-sample predictions. Methods are provided for several common RP distributions—including the normal/Gaussian, lognormal, triangular, uniform, and gamma distributions—combined within log link GLM framework. The proposed methods are tested using crash frequency prediction models developed using data from the Highway Safety Information System (HSIS). The results suggest that the proposed exact method provides more accurate predictions than the computational-intensive simulation-based approximation approaches while also being simple to apply. The method is suitable for the widespread use of RPs in research and in practical applications of GLMs.

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Sponsoring Committee Standing Committee on Safety Performance and Analysis (ACS20)

Session Number **Poster Session 2206**

Session Title Safety Performance and Analysis with Crash Predictions

Paper Number TRBAM-25-01145

Paper Title **Evaluating the Accuracy of Vehicle Tracking Data from UAV Videos and Identifying Traffic Conflict Points to Develop a Conflict Frequency Predictive Model for Roundabout Safety Assessment under Mixed Traffic**

Introduction Road safety is a critical concern globally, with low- and middle-income countries (LMICs) accounting for over 90% of road traffic crash (RTC) fatalities. According to crash statistics provided by the Ministry of Road Transport and Highways, Government of India, 461,312 road crashes happened in India in the year 2022 (1). These road traffic crashes have resulted in 443,366 injuries and 168,491 fatalities. 11,410 crashes at Indian roundabouts happened in the same year, resulting in 10,636 injuries and 4,051 fatalities (1), indicating that the roundabouts, which are considered to be safer intersections, are not that safe in the non-lane-based highly mixed traffic scenarios (2). The traffic in LMICs is characterized by a dense mix of bicycles, cars, motorcycles, auto-rickshaws, trucks, buses, etc., plying on the same road, maintaining no lane discipline (3). Consequently, roundabouts have turned into junctions of confusion, leading to unsafe interactions (4, 5). The advent of Unmanned Aerial Vehicles (UAVs) provides a transformative solution for traffic monitoring and safety analysis. UAVs enable high-resolution aerial imagery, capturing dynamic traffic interactions over large areas (6–8). Unlike traditional fixed sensors or manual observations, UAVs can observe complex traffic scenarios from multiple angles, enhancing data accuracy (9). However, the reliability of UAV-derived vehicle tracking data under non-lane-based traffic conditions requires rigorous validation to ensure its applicability in safety evaluations. The objectives of this research were threefold. First, the authors aimed to validate the accuracy of speed measurements derived from UAV footage by comparing them against GPS data and data from a reliable automated data extraction platform. This validation was crucial for establishing the reliability of UAV-based vehicle tracking in traffic analysis. Second, the authors sought to identify and visualize the conflict points in the case of roundabouts under mixed traffic scenarios. This analysis employed Surrogate safety measures (SSMs) such as Modified Time to Collision (MTTC) and Deceleration Rate to Avoid Collision (DRAC) to identify conflict points. Lastly, a conflict frequency predictive model was developed to investigate the conflict causal factors at roundabouts. SSMs are becoming increasingly important for analyzing road safety as they utilize advanced technologies such as video recording by UAVs, image processing, and vehicle tracking (10, 11). Some of the studies employed UAVs, object detection, and tracking algorithms to generate trajectory data for the safety assessment of roundabouts (6, 7). The SSMs were employed on the trajectory data to identify the conflict points by setting suitable threshold values (12–15). The traffic conflicts are advantageous due to their higher event frequency, observability, and strong conceptual and actual correlation with collisions (16, 17). Numerous studies examined the variables impacting the frequency of roundabout crashes. A variety of modeling techniques were employed by researchers, including multiple logistic regression (18), zero-inflated Poisson regression (19), zero-inflated negative binomial regression (20), Poisson regression (21, 22), and negative binomial (NB) regression (23–25). Average annual daily traffic (AADT), number of legs, number of circulatory lanes, circulating lane width, entry width, flare length, flare width, inscribed circle diameter, number of entry lanes, entry width, entry radius, and weaving width were some of the factors found responsible for roundabout crash occurrence (4, 5, 20, 26–28). The literature survey revealed that utilization of vehicle trajectory data from UAV videos for roundabout safety assessment under mixed traffic conditions was very limited. Furthermore, there are a very limited number of roundabout safety studies in which conflict frequency prediction models have been developed considering the lane indiscipline prevailing in the traffic environments of LMICs.

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Session Number	**Poster Session 2206**
Session Title	Safety Performance and Analysis with Crash Predictions
Paper Number	TRBAM-25-02287
Paper Title	**Validation Analysis of Traffic Simulation Safety Metrics with Real-World Crash Data**
Abstract	Assessing safety using traffic simulation is becoming increasingly feasible with advancements in methodological frameworks and tools, emphasizing the critical importance of accuracy and reliability. This study aims to bridge the gap between simulation models and real-world safety observations, contributing to the advancement of more robust safety assessment methodologies. It presents a comprehensive comparative analysis of traffic safety metrics derived from both simulated and real-world data, employing clustering technique to identify safety patterns. Using Aimsun Next, simulation data was analyzed in the Safety Assessment Model (SSAM) to extract traffic conflicts, which were then converted into crash risk levels. Real-world crash data from the Hellenic Statistical Authority (ELSTAT) encompassed various crash types involving at least one slightly injured individual between 2017 and 2019. Specifically, observational data encompassed speed limits, road lengths, injuries, vehicles involved, and crash counts, while simulation metrics included flow, capacity, and crash risk. The analysis of simulation and observational data revealed two distinct clusters: roads with low and high crash risks, clearly distinguished with minimal overlap. Comparison of clustering results demonstrated approximately 87.7% accuracy in predicting road crash risk classifications through traffic simulation, confirming its reliability for safety assessment. The study also highlights the importance of thorough calibration; roads inaccurately predicted lacked sufficient traffic data, underscoring the need for robust calibration to enhance safety assessment. This study validates a framework ready for future research applications in scenarios where direct observation is impractical, enhancing road safety and guiding interventions amid evolving traffic conditions and technologies. Keywords: Road safety, Traffic simulation, Crash data, Comparative analysis, Simulation validation

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Sponsoring Committee Standing Committee on Safety Performance and Analysis (ACS20)

Session Number **Poster Session 2240**

Session Title Safety Performance and Analysis for Safe Roads

Paper Number TRBAM-25-00148

Paper Title **Identification and Characterization of Wrong Way Driving Crashes on Virginia's Interstate Highways**

Introduction Wrong-way driving (WWD) on interstate highways occurs when a vehicle enters on the wrong side at a ramp or an interchange and travels in the direction of oncoming traffic. WWD incidents present an immediate and significant operational impact and carry a severe risk, as relative vehicle speeds are high due to the opposite directions of colliding vehicles. Previous studies showed that WWD crashes are a small portion of overall crashes, however they are much more likely to be fatal or severe injury crashes than other crash types (1, 2). The literature also shows that many WWD crashes share similar characteristics. WWD crashes frequently occur at night or when it is dark (1-4). The WW driver is often under the influence of drugs or alcohol (2, 3, 4). Research (2, 3, 4) also shows that WW drivers are more frequently male than female. Older drivers are overrepresented in the WW driver pool in some studies (2, 3) but not in others (4). Many recent WWD crash studies focused on characteristics of the collected WWD crash sample, with few describing the methodology for discerning WWD crashes from a larger crash dataset. Kadeha et al. (5) did describe a methodology in which 926 WWD crashes in Florida were obtained by reviewing 2,879 WWD coded crashes from five years of police reports (2012-2016). This study also excluded "rear-end" crash type from among those WWD coded crashes. Since the Virginia crash report form does not have a WWD crash code, collecting WWD crashes is difficult using typical crash evaluation methods. This study aimed to perform identification and evaluation of WWD crashes on interstates highways in Virginia. This included collecting potential WWD crashes using key words of crash description and assessing the characteristics of WWD crashes in Virginia.

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Sponsoring Committee Standing Committee on Safety Performance and Analysis (ACS20)

Session Number **Poster Session 2240**

Session Title Safety Performance and Analysis for Safe Roads

Paper Number TRBAM-25-00170

Paper Title **Insights into Texas Barrier Crashes: A Cluster Correspondence Approach**

Abstract Roadside and median barriers have been effective in preventing crashes, yet a considerable number of crashes involving these barriers still occur in the United States. This paper examines the factors contributing to barrier crashes in Texas. The dataset comprises 63,475 crashes involving road barriers over a six-year period (2017-2022). Utilizing the Cluster Correspondence Analysis (CCA) data mining approach, the study identifies six distinct crash clusters, each highlighting specific factors contributing to barrier-related crashes. Prior to employing CCA, a variable importance analysis was conducted to determine the significance of the variables. The results indicate that dry road surfaces and clear weather conditions are strongly linked to high-speed crashes, while driver distraction and the lack of traffic control devices are associated with crashes on lower-speed roads. Additionally, adverse weather conditions were found to influence crash frequency and types. The paper concludes with policy recommendations aimed at assisting transportation planners in reducing the frequency and severity of barrier-related crashes.
Keywords: barrier crashes, correspondence analysis, clustering, clustering, pattern recognition.

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Sponsoring Committee Standing Committee on Safety Performance and Analysis (ACS20)

Session Number **Poster Session 2240**

Session Title Safety Performance and Analysis for Safe Roads

Paper Number TRBAM-25-02613

Paper Title **Evaluating the Impact of Pavement Conditions on Road Safety by Analyzing Crash Frequency and Severity**

Abstract Road safety is impacted by a range of factors that can be categorized into human, vehicle, and roadway/environmental elements. This research explores the connection between pavement performance and road safety, particularly in relation to crash frequency and severity, using data from the Iowa Department of Transportation (DOT) for 2022. By merging crash data with pavement inventory data, we conduct a spatial analysis that incorporates the geographical coordinates of crash sites with the conditions of road segments. Statistical methods are applied to compare crash rates and severities across various pavement condition categories. To pinpoint the most influential factors affecting crash rates and severity, we use machine learning models along with negative binomial and ordered probit regression models. The study's key findings reveal that higher speed limits, well-maintained roads, and improved friction scores correlate with lower crash rates, whereas rougher roads and adverse weather conditions are linked to higher crash severity. This analysis emphasizes the critical need for prioritizing pavement maintenance and integrating safety-focused design principles to boost road safety. Additionally, the study underscores the ongoing need for research to better understand and address the intricate relationship between pavement performance and road safety.

Keywords: Highway Safety, Pavement Condition, International Roughness Index, Friction, Rut Depth

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Sponsoring Committee Standing Committee on Safety Performance and Analysis (ACS20)

Session Number **Poster Session 2240**

Session Title Safety Performance and Analysis for Safe Roads

Paper Number TRBAM-25-03138

Paper Title **Analysis of Highway Traffic Crashes Risk Considering Traffic States in Merging and Diverging Areas**

Abstract Highway collisions are influenced by numerous factors. To reduce crash risk and enhance traffic safety, it is essential to understand how traffic conditions and road geometry impact road traffic crashes. While the relationship between traffic conditions and collision risk in highway sections has been explored, road geometry, particularly merging and diverging areas has not been thoroughly examined. Road section types significantly affect vehicle movement and, consequently, collision risk. This study analyzes the impact of traffic states on crash risk, with a focus on merging and diverging sections. Key aspects include analyzing the effect of the speed difference between upstream and downstream traffic and the influence of ramp flow on crash risk across different road sections. The results of this research provide valuable insights for evaluating highway crash risk and enhancing traffic safety by considering road section types.

Keywords: traffic safety, road traffic crash, traffic state, merging, diverging

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Sponsoring Committee	Standing Committee on Safety Performance and Analysis (ACS20)
Session Number	**Poster Session 2240**
Session Title	Safety Performance and Analysis for Safe Roads
Paper Number	TRBAM-25-04393
Paper Title	**Safety-focused Median Treatment Selection For A Suburban Arterial**
Abstract	Suburban arterial roadways must serve two conflicting road functions: mobility and accessibility. The high potential for conflicts between traffic passing through and traffic from neighboring areas raises safety concerns. Among design alternatives that traffic engineers consider, the median treatment is one of the important design decisions. As the access control level increases, alternative median treatment choices include undivided cross-section, two-way-left-turn-lane, and non-traversable median. Although it is known that a higher control level of traffic usually leads to better safety performance, the quantitative relationship between these median treatments and their safety outcomes was not well investigated, especially when other operational conditions vary from segment to segment. There is a multiway causal relationship (endogeneity) between the operational conditions, speed limits, and traffic safety which was seldom considered in previous studies. To properly compare the safety performance of different median treatments on suburban arterial roads, this study collected geometry, traffic and operational conditions along 200 road segments across Indiana and applied simultaneous equations to address the endogeneity problem. In the conclusion of the presented research, a comprehensive crash cost-oriented evaluation framework for selecting median treatments was proposed. Traffic volume, density of access points, speed limit, and median treatments on the studied road segments were found to significantly affect safety. It was confirmed that the operational conditions also affect the crash cost and, consequently, the choice of the median treatment. The research generated convenient tables to support traffic engineers' selection of median treatment among the three considered in the study. Keywords: Median Treatment, Suburban Arterial, Simultaneous Equations, Crash Cost

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Sponsoring Committee	Standing Committee on Safety Performance and Analysis (ACS20)
Session Number	**Poster Session 2240**
Session Title	Safety Performance and Analysis for Safe Roads
Paper Number	TRBAM-25-04510
Paper Title	**Mash Crashworthiness of Breakaway Luminaire Poles Supported By TRANSFORMERBASE**
Abstract	Extensive research funded by the National Cooperative Highway Research Program (NCHRP) have been devoted to examining the crashworthiness of breakaway luminaire poles. The present study evaluates the crash performance of breakaway luminaire poles supported by TB1-17 transformer base. This effort aimed at reducing costs and time of crash testing and facilitating MASH certifying, given that current MASH guidelines require three full-scale crash tests for the evaluation of each variation of a device, leading to significant testing costs. Two full-scale crash tests and extensive numerical simulations were conducted to provide insights to identify critical test matrices under MASH 2016. Two critical pole configurations were crash tested under MASH test designation no. 3-60 impact conditions, with a vehicle center impact point and 0-degree impact angle selected to maximize the likelihood of roof crush. Based on the test results and observed pole fracture mechanism, finite element models of the poles and TB1-17 transformer bases were developed and refined. This model was then validated against the two pendulum tests and two full-scale crash tests previously completed under an earlier project (i.e., NCHRP Project no. 03-119), while further validation against MASH test nos. 3-61 and 3-62 impact conditions is still required. The validated FE model was then utilized to simulate various pole configurations and impact conditions. Next, simulation and available crash testing results were used to provide insights on MASH testing guidelines for luminaire poles. Continued research will further refine these guidelines, as additional full-scale crash testing and numerical simulations are required. Keywords: MASH, Finite Element Simulation, LS-DYNA, Breakaway Luminaire Poles, 21 Transformer Base TB1-17, Pendulum Test, and Full-Scale Crash Test.

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Session Number	**Poster Session 2240**
Session Title	Safety Performance and Analysis for Safe Roads
Paper Number	TRBAM-25-04668
Paper Title	**Performance Evaluation of Equivalent Property Damage Only (EPDO) Weight Sets: A Case Study Using Traffic Crash Data from Korean Expressways**
Abstract	In this study, we aim to evaluate Equivalent Property Damage Only (EPDO) weight sets about how effectively they identify high crash-risk segments, known as hotspots, on Korean expressways as potential sites for safety improvement. An EPDO weight set represents the importance ratios among the four types of crash severities: fatal crashes, severe injury crashes, minor injury crashes, and Property Damage Only (PDO) crashes. For multiple EPDO weight sets, we identify the top 1% to 10% of hotspots for each set using expressway traffic crash data from Korea. The performance of the EPDO weight sets is evaluated by examining the numbers of (i) fatal, (ii) non-PDO (i.e., including fatal and injury crashes), and (iii) total crashes that occurred for the top 1% to 10% of identified hotspots for the subsequent year. Based on these three criteria, we derived Pareto EPDO weight sets. The results indicated that assigning higher weights to non-PDO crashes than to PDO crashes resulted in more accurate identification of hotspots with a high number of casualty crashes that actually happened in the subsequent year. Conversely, assigning identical weight to all severity-type crashes best predicted the total crashes of the subsequent year. Among the multiple Pareto sets, we propose 1:1:1:1 and 2:1:1:1 as practically usable weight sets for Korean expressways, which consistently showed high performance in identifying hotspots for three criteria. Keywords: Equivalent Property Damage Only, High Crash-Risk Segments, Expressways in Korea, 16 Pareto Sets, Safety, Crash Severity

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Session Number	**Poster Session 2240**
Session Title	Safety Performance and Analysis for Safe Roads
Paper Number	TRBAM-25-04787
Paper Title	**Examining the Impact of Centerline Rumble Strips on Reducing Rural Two-Lane Head-On Collisions in Maine**
Introduction	Rumble strips are a common and relatively low-cost countermeasure (1–3) used to alert drivers about a possible lane departure through noise and vibration (4, 5). Centerline rumble strips are commonly used on undivided roadways to prevent head-on and opposite-direction sideswipe collisions (4). In Maine, 511 miles of centerline rumble strips were installed on bidirectional and undivided rural two-lane roadways. Additionally, two types of rumble strips were installed: conventional and sinusoidal. Evaluations showed that the sinusoidal rumble strips generate lower noise levels compared to the conventional ones (6, 7). Maine experiences the highest crash fatality rate among New England states (8) and the majority of these crash fatalities result from lane-departure crashes. In fact, according to crash records from 2010 to 2022, lane departure crashes resulted in approximately twice as many (or more) fatalities as all other types of crashes combined. Additionally, Maine's lane-departure crashes accounted for approximately 73% of the fatalities, even though only 30% of the total number of crashes in the state were lane departure crashes. Head-on and opposite sideswipe collisions represented approximately 20% of the total lane departure crashes in the state. Moreover, the fatality rate per 100 million vehicle miles traveled (VMT) was 1.7 times higher in rural compared to urban areas (9), and Maine is mainly a rural state where approximately 80% of its roadways are in rural areas (10). Therefore, this study aims to assess the effectiveness of centerline rumble strips installed in Maine on preventing total and fatal injury (KABC) head-on and opposite sideswipe collisions on rural two-lane roadways. The terms fatal and injury crashes and KABC crashes are used interchangeably referring to the following crash severities defined by the Highway Safety Manual (HSM) (11). The effectiveness of the centerline rumble strips is assessed using before-and-after studies with two methods: comparison group, and empirical Bayes (EB) comparison group. Crash modification factors (CMFs) and the percentage of change in crash frequency are computed. Also, safety performance functions (SPFs) are estimated for the rural two-lane roadways. In addition, economic analysis is performed to determine the economic benefits of installing centerline rumble strip for the same roadway type. The installations of centerline rumble strips are associated with reductions of 28%-48% of head-on and opposite sideswipe collisions on rural two-lane roads, and the benefits of the rumble strips are at least 14 times the cost. The centerline rumble strips are cost-effective countermeasures to reduce head-on collisions on rural two-lane roadways in Maine.

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Sponsoring Committee Standing Committee on Safety Performance and Analysis (ACS20)

Session Number **Poster Session 2240**

Session Title Safety Performance and Analysis for Safe Roads

Paper Number TRBAM-25-05031

Paper Title **From Pandemic to Present: A Data-Driven Examination of Factors Influencing Deer-Vehicle Crashes**

Abstract The deer population in the United States has been rising significantly, with current estimates exceeding 25 million nationwide. This increase has led to a corresponding rise in deer-vehicle crashes (DVCs), presenting challenges for road safety and wildlife management. This study investigates the factors influencing DVCs in Lewis County, New York, focusing on the periods before, during, and after COVID-19. Using Principal Component Analysis (PCA) and multinomial logistic regression, the research identifies key environmental, infrastructural, and socioeconomic variables affecting DVCs. The PCA results highlight that activity density, speed limit, road surface conditions, and light conditions are significant contributing factors to DVCs. The logistic regression analysis reveals an increased odds ratio for speed limits after COVID-19, indicating that higher speed limits are increasingly associated with a greater likelihood of deer-vehicle crashes after COVID. Additionally, the study observed a notable decrease in DVCs in areas with high-density of multimodal infrastructure networks, before and after the pandemic, suggesting that increased human activity and lower speed in such areas reduced the likelihood of DVCs. This research contributes to a deeper understanding of DVCs and provides a foundation for targeted strategies in urban planning and transportation policies. By focusing on a rural area, this study addresses a critical gap in the literature, offering new data and perspectives often overlooked in urban-focused research. The study findings underscore the need for adaptive management strategies that account for varying traffic and environmental conditions, especially in rural settings where wildlife-vehicle interactions can differ significantly from those in urban areas.

Keywords: 23 Deer-Vehicle Crash, Principal Component Analysis, Driving Behavior, Wildlife Management

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Session Number	**Poster Session 2240**
Session Title	Safety Performance and Analysis for Safe Roads
Paper Number	TRBAM-25-05277
Paper Title	**Analyze Impacts of Lane-change on Highway Safety Risk with Safety Risk Potential Field and Multi-State Survival Analysis**
Introduction	The effect of vehicles' lane changes on the de-escalation of safety risks, by which vehicles' safety conditions return to normal, merits a thorough investigation but was overlooked by the literature. A detailed investigation into the impact of underlying factors, such as vehicles' lane changes, on the de-escalation process of safety risks will help us better understand the complete process of traffic risk evolution and provide new insights for improving highway safety. Survival analysis is well-suited for examining the influence of lane-changing behaviors on the recurrent transitions of vehicle safety risks. Nonetheless, existing survival models for vehicle safety exhibit certain drawbacks, posing challenges in lane-change risk analysis: • Oversimplified risk transition: Existing survival models for vehicle safety often use single-transition models that oversimplify the risk transition process by using binary states such as "no-conflict" against "conflict" (1) or "crash" against "no-crash" (2). These models cannot effectively capture the complexity of traffic risks. (3). • Missing recurrent risk nature: Some models consider multi-state transitions but overlook the recurrent nature of risks by assuming a one-directional risk progression and hence cannot model the de-escalation process of traffic risks. • Limited incorporation of multi-directional risks: Existing models often rely on surrogate safety measures biased toward longitudinal risks in risk identification, such as minimum gap (1), time-to-collision (4), and modified time-to-collision (MTTC) (5). To address the aforementioned problems, we propose multi-state survival models combined with an innovative surrogate safety measure namely the potential field risk index (PFRI) based on safety potential field theory (6). Building on our previous framework (5), the proposed multi-state survival models discretize safety risks into four hierarchical states of severity: "crash," "near crash," "risky," and "safe," based on PFRI values. We refer to our proposed multi-state survival models combined with PFRI risk states as PFRI-survival models. Comparing survival analysis regarding PFRI and MTTC, we identified which type of risk (multi-directional or longitudinal) was predominantly affected by vehicles' lane-change and other risk factors in different driving conditions.

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Session Number	**Poster Session 2240**
Session Title	Safety Performance and Analysis for Safe Roads
Paper Number	TRBAM-25-05301
Paper Title	**Interactive Crash Risk Mechanism of Vehicle-Group and Road Segment for the Expressway**
Introduction	Expressway facilities serve as the core of the transportation system, characterized by high speed and large volume. Thus, a crash in such facilities can significantly reduce the road capacity. Active Traffic Management (ATM) is an efficient method of smoothing traffic flow on expressways. However, existing crash risk patterns are inadequate for supporting rapid ATM. Therefore, more refined crash risk mechanisms need to be explored. There have been plenty of studies on crash risk for expressways, but most studies have relied on data from segment detectors, focusing only on the contributing variables of road segment. In terms of mechanistic analysis, there is a tendency to construct statistical models. The spatial unit division of road segment is mainly divided into the fixed-length method and the segment detector method. However, the length of the divided road units is usually greater than 400 meters and it is difficult to ensure the consistency of geometric and traffic characteristics. For the temporal unit, most of the data used in previous studies come from segment detectors, including loop detector (1), radar (2), and electronic license plates (3). Consequently, most studies have used 5-minute time units. However, aggregated traffic data cannot provide high-resolution pre-crash information. In terms of crash risk contributing variables, previous studies primarily use road segment as study unit, considering geometric(4) and traffic features(5-7). These studies typically attribute the cause of a crash to the road segment. In 2019, Wang et al. (8) proposed that the trajectory of vehicle-group can influence the vehicles to crash. Zhu et al. (9) further found that crash risk is not only formed within a vehicle-group but also propagated between vehicle-groups. Consequently, the impact of the crash risk of the vehicle-group and the influence of high-risk vehicle-group appearing downstream for road segment and the influence of high-risk vehicle-group appearing downstream for road segment need to be taken into account. The key to analyzing crash risk mechanisms is to establish accurate models. Early studies predominantly utilized statistical models(10,11). However, statistical models often struggle with correlations among independent variables and typically have lower prediction accuracy. Many studies have adopted machine learning (12-14)and deep learning (15-19), which offer significantly higher accuracy. However, these methods are often considered black-boxes, limiting their use to prediction. Since some studies have proposed methods to reveal the internal relationships of black-boxes (20-22), there is a need to take into account the accuracy and interpretability of crash analysis. The literature review above shows that the existing crash risk study is mainly based on aggregated traffic data, ignoring the interaction between vehicle-group and road segment. They do not combine high prediction accuracy with mechanistic analysis at same time. This study tends to answer these three questions, (1) How to analyze the relationship between contributing variables and crash risk with high accuracy? (2) How can downstream road segment affect the crash risk of the vehicle-group? (3) How can downstream high-risk vehicle-groups affect the crash risk on the road segment?

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Sponsoring Committee Standing Committee on Safety Performance and Analysis (ACS20)

Session Number **Poster Session 2240**

Session Title Safety Performance and Analysis for Safe Roads

Paper Number TRBAM-25-05589

Paper Title **Analyzing Head-On Crash Severity on Rural Two-Lane Roads**

Abstract
Although head-on collisions are relatively fewer with respect to total traffic crashes, they account for a high percentage of fatalities and serious injuries. This study employed Ordinal Logistic Regression (OLR) to investigate the contributing factors that affect the injury severity of head-on crashes on rural two-lane roads in North Carolina. Utilizing data from the Highway Safety Information System (HSIS), this analysis categorizes injury severity into three levels and correlates it with various roadway, temporal, and environmental factors. The model's predictors include lighting condition, road surface type, and intersection traffic control, with the outcome variable reflecting increasing injury severity from no injury to fatality. The results indicate severe injuries are less likely at intersections and more common on arterials and collectors, with wider shoulders correlating with higher injury severity. This study contributes to traffic safety by identifying key factors influencing head-on crash outcomes on rural two-lane roads, which could guide infrastructure improvements and policy revisions.
Keywords: HSIS data, crash severity, head-on crashes, rural two-lane roadways, ordinal logistic 15 regression

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Sponsoring Committee Standing Committee on Safety Performance and Analysis (ACS20)

Session Number **Poster Session 2240**

Session Title Safety Performance and Analysis for Safe Roads

Paper Number TRBAM-25-05600

Paper Title **Evaluating the Safety Effects of Right-Turn Yielding Measures for Large Vehicles: Evidence from Suzhou, China**

Introduction
Large vehicles including large trucks and buses have blind spots and the inner wheel differential leading a high fatality of vulnerable road users. The large vehicle right-turn crash is an urgent problem within the commercial transportation industry safety. To reduce large vehicle right-turn crashes, some cities in China (i.e., Shanghai, Nanjing, Xi'an, Suzhou) implemented right-turn yielding measures including rules and safety facilities for large vehicles. A naïve before-and-after method was used in each city to assess changes in large vehicle right-turn crashes after the implementation of the measures. However, this method didn't consider secular trends, seasonal fluctuations, and confounding. Therefore, the effect of these measures on crashes is yet to be revealed. Randomized controlled trials are regarded as the gold standard design to estimate a causal effect between a treatment and related outcomes. In reality, most policy interventions are non-random, whereas quasi-experimental designs replace random assignment with deterministic assignment requiring the cost of additional assumptions. Quasi-experimental designs have given rise to methods including matching method, difference-in-difference, synthetic control method, instrumental variable method and regression discontinuity design, and interrupted time series design. They differ in terms of model design, result validity and scope of application. To comprehensively examine the effect of right-turn yielding measures on large vehicle crashes, this study aimed to utilize an interrupted time-series design, which is a powerful tool for evaluating the impact of time dependent interventions. The counterfactual framework is a method used for causal inference to understand the causal relationships between treatment and outcome. The counterfactual framework was further introduced to construct causal segmented Poisson regression and Bayesian causal models measuring the causal impact.

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Sponsoring Committee Standing Committee on Safety Performance and Analysis (ACS20)

Session Number **Poster Session 2240**

Session Title Safety Performance and Analysis for Safe Roads

Paper Number TRBAM-25-05914

Paper Title **Safety Impact Assessment of Median Cable Barriers on Four and Six-Lane Interstates: Utilizing Safety Performance Functions and the Empirical Bayes Method**

Abstract This paper estimates the impacts of median cable barriers in Louisiana by developing Safety Performance Functions (SPFs) for rural 4-lane, urban 4-lane, and urban 6-lane interstates. The SPFs were developed for both total and median-related crashes, considering variables such as segment length, Average Annual Daily Traffic (AADT), median width, lane width, and shoulder width. Empirical Bayes (EB) estimates of Crash Modification Factors (CMFs) strongly support the installation of median cable barriers, particularly for reducing visible injury crashes (KAB). The CMFs derived from EB results indicate a 54% reduction in total KAB crashes overall, with large reductions of 48% for rural 4-lane, 64% for urban 4-lane, and 35% for urban 6-lane interstates. Median-related KAB crashes experienced substantial reductions, with reductions of 55% for rural 4-lane, 77% for urban 4-lane, and 69% for urban 6-lane interstates, leading to an overall reduction of 65%. Besides developing SPFs that should facilitate future analyses of the safety impacts of median cable barriers and similar interventions, this study demonstrates the effectiveness of median cable barriers in reducing visible injury crashes, potentially aiding in the strategic implementation of such interventions on interstates.

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Sponsoring Committee Standing Committee on Safety Performance and Analysis (ACS20)

Session Number **Poster Session 2240**

Session Title Safety Performance and Analysis for Safe Roads

Paper Number TRBAM-25-06211

Paper Title **Comparative Analysis of Single Vehicle Run-off Crashes in Rural vs. Urban Freeways**

Abstract Lane departure crashes present a critical challenge to road safety. In the State of Florida, these crashes have emerged with the highest proportion of fatal crashes and the second highest proportion of serious injury crashes among the state's identified emphasis areas. Run-off crashes constitute a significant percentage of lane departure crashes, necessitating a focused examination of their contributing factors in both rural and urban freeways. This study conducted a comparative examination of single vehicle run-off crashes in rural and urban freeways in Florida, employing Ordered Logistic Regression (OLR) analysis. The crash data, sourced from the Signal Four Analytics database, encompasses a comprehensive array of variables related to roadway conditions, vehicle attributes, crash characteristics, environmental factors, and driver characteristics and behaviors. Results from the OLR analysis indicate that twelve variables were found to be significant at a 95% confidence level. Specifically, six variables, weather conditions, total number of lanes, vehicle type, driver's gender, driver's age, and restraint use, were significant in both rural and urban freeway models. Furthermore, six other variables, light condition, vehicle age, posted speed limit, roadway alignment, vehicle maneuver, and driving under the influence, were significant exclusively in the rural freeway model. In contrast, no additional variable was found to be significant solely in urban freeways. Understanding the factors contributing to these crashes is paramount to developing targeted and effective interventions and policies to mitigate the frequency and severity of single vehicle run-off crashes, fostering safer roadways for all users.

Keywords: Single Vehicle Run-off Crashes, Lane Departure Crashes, Rural Freeway, Urban 22 Freeway, Ordered Logistic Regression

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Session Number	**Poster Session 2240**
Session Title	Safety Performance and Analysis for Safe Roads
Paper Number	TRBAM-25-05753
Paper Title	**Identification of Hazardous Locations Based on Unsafe Driving Event Detection Using Telematics Data**
Abstract	Road safety is a crucial aspect of transportation systems worldwide, with the primary goal of preventing accidents, injuries, and fatalities on the road. Identifying hazardous driving locations is essential to ensure road safety. Hazardous locations are spots where unsafe driving events are frequently observed, and the transportation infrastructure can significantly contribute to such behaviors. Therefore, this study proposes a framework for identifying hazardous driving locations by analyzing the spatial distribution of recurring unsafe driving events that are detected from naturalistic driving data without requiring any predefined thresholds, reference patterns, or rules. Telematics data involving different vehicles and drivers is used in this study to demonstrate the robustness of the framework. Our motivation is to develop a proactive measure to identify hazardous locations before unsafe driving occurs. This could aid in developing an automated real-time driver warning system for cautious driving or an automated sensor bar for safety audits. Keywords: Acceleration, Clustering, Hazardous location, Telematics data, Unsafe driving event

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Session Number	**Poster Session 2240**
Session Title	Safety Performance and Analysis for Safe Roads
Paper Number	TRBAM-25-05859
Paper Title	**Understanding GPS-related Crashes Using A Matched Case-Control Approach**
Abstract	Global Positioning Systems (GPS) have revolutionized transportation by providing real-time location and navigation information. While GPS technology has significantly enhanced mobility and efficiency, its potential role in traffic crashes remains understudied. The current study aims to address this gap by examining the factors associated with GPS-related crashes. Using crash data from Ohio between 2017 and 2022, this study utilized a logistic regression model by developing a case-control study to identify patterns, contributing factors, and their influences on GPS involvement in crashes. Results indicate that GPS-related crashes are disproportionately concentrated at intersections, interchanges, and complex road geometries, particularly under adverse weather conditions. Driver age and weather conditions significantly impact crash risk, with younger drivers and commercial vehicles more involved. These findings highlight the need for targeted interventions, such as improved GPS technology, disruptive technologies such as augmented reality, infrastructure enhancements, and driver education, to mitigate the risks associated with GPS use while driving and improve overall road safety. Keywords: Traffic safety, GPS, GPS related hazards, Logistic regression.

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Session Number	**Poster Session 2240**
Session Title	Safety Performance and Analysis for Safe Roads
Paper Number	TRBAM-25-03039
Paper Title	**A Hybrid Data Mining Framework to Investigate Roadway Departure Crashes on Rural Two-lane Highways: Applying Fast and Frugal Tree with Association Rules Mining**
Abstract	The complexity of factors contributing to roadway departure (RwD) crashes on rural highways necessitates advanced analytical approaches to enhance traffic safety. This study presents a hybrid data mining framework that combines the Fast and Frugal Tree (FFT) and Association Rules Mining (ARM) algorithms to identify the patterns of RwD crashes on rural 2-lane highways in Louisiana state. The research is focused on addressing two critical research questions (RQ), RQ1: Which variable features contribute to the fatal-severe RwD crashes? RQ2: Focusing on the identified top factors contributing to fatal-severe RwD crashes, how co-occurrence of different crash-contributing factors increase the likelihood of RwD crashes? For the analysis, this research team collected crash data from the Louisiana Department of Transportation and Development, encompassing a total of 22,988 unique RwD crashes on rural 2-lane highways. Based on the findings, the FFT model identified the top variable features contributing to fatal-severe RwD crashes, including no use of seatbelts, alcohol-impaired driver condition, male gender, 12 am – 6 am, dark-no-streetlight, 45-54 years age group, light truck, on-grade vertical alignment, and so on. Subsequently, ARM explored how these factors interact and associate, revealing intricate drivers' behavioral patterns related to RwD crashes. This comprehensive analysis uncovers not only the individual impact of these factors but also their combined effects, offering a deeper understanding of the dynamics of RwD crashes. This research contributes valuable insights into evidence-based, data-driven strategies to reduce the frequency and severity of RwD crashes on rural highways, advancing traffic safety initiatives and improving safety on rural 2-lane roadways. Keywords: Fast and Frugal Tree, Association Rules Mining, Seatbelt, Impairment, Nighttime

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Session Number	**Poster Session 2240**
Session Title	Safety Performance and Analysis for Safe Roads
Paper Number	TRBAM-25-03536
Paper Title	**Heterogeneous and Differential Treatment Effect Analysis of Freeway Exit Ramp Improvements Using Causal Inference**
Introduction	Freeway safety is a significant concern due to high crash rates at interchanges, which often result from weaving and varying travel speeds caused by vehicles entering and exiting the freeway (2, 3). In China, rapid freeway expansion from 15,000 km to 150,000 km over three decades has intensified safety challenges, particularly at exit ramps (5, 6). This study evaluates effectiveness of exit ramp modifications on crash reduction, addressing the challenge of isolating causal impacts from confounding factors. Traditional safety evaluation methods, such as Empirical Bayes (EB), negative binomial regression, and generalized linear models, have been widely used to assess interventions (7, 9, 11). However, these methods often face limitations in identifying causal relationships. Emerging approaches, including the Neyman-Rubin Causal Model (14), Propensity Score Matching (17), and Inverse Propensity Weighting (16), address confounding but assume observable factors are sufficient. Recent studies combine machine learning (ML) with causal inference to manage high-dimensional data and reduce bias, enhancing accuracy of treatment effect estimation (21, 22, 23). This study employs a Causal Forest (CF) model to estimate Heterogeneous Treatment Effects (HTE) and Differential Treatment Effects (DTE) of exit ramp improvements on traffic crashes. Data from Suzhou, China, spanning 2018–2023, was used to analyze ramps upgraded between 2019 and 2022. The CF mode6 ranks predictors by their influence on HTE and DTE using a Variable Importance Plot, while Average Treatment Effects (ATE) are compared with EB and Naïve Before-and-After approaches. The CF model successfully reduced confounding bias and revealed complex causal relationships between ramp improvements and crash reductions. Traffic operation and geometric design features emerged as significant predictors of HTE and DTE. This research advances ML-based causal inference in transportation safety, providing a robust framework for evaluating interventions. The findings contribute to theory by refining causal analysis techniques and to practice by offering actionable insights for prioritizing freeway safety measures.

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Sponsoring Committee Standing Committee on Safety Performance and Analysis (ACS20)

Session Number **Poster Session 2240**

Session Title Safety Performance and Analysis for Safe Roads

Paper Number TRBAM-25-04696

Paper Title **Analyzing Contributing Factors to Crashes Involving Mobile and Stationary Work Zones**

Abstract While work zones are crucial for infrastructure sustainability, they pose significant public safety challenges. Nationally, work zone fatalities have been increasing, with Ohio observing a similar trend. This study analyzed crash severity factors involving mobile and stationary work zones using Ohio crash data from 2019 to 2023. Bayesian binary and hierarchical models were developed and compared, with the hierarchical model performing better. The hierarchical model significantly accounted for the unexplained variation in crash severity which would have been ignored in the binary model. Factors contributing to higher fatal injury likelihoods in both work zones included alcohol or drug use, speeding, vehicle damage, higher posted speed limits, and multi-vehicle crashes. Contrary, safety equipment use and divided roadways decreased the risks in both types. Mobile work zones on curved segments decreased crash severity, while stationary work zones saw increased severity with older and out-of-state drivers, specific collision types, and pre-crash actions. The study recommends using intelligent transportation systems, such as dynamic speed display and advanced traveler information systems, to reduce work zone crashes. The Bayesian hierarchical model's performance highlights its ability to capture complex interactions and variability in crash data. These findings are expected to inform the development of countermeasures for reducing work zone severity.

Keywords: Work zone, mobile, stationary, hierarchical Bayesian.

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Sponsoring Committee Standing Committee on Safety Performance and Analysis (ACS20)

Session Number **Poster Session 2240**

Session Title Safety Performance and Analysis for Safe Roads

Paper Number TRBAM-25-02956

Paper Title **Framework for Applying Highway Safety Manual Methods During Project Alternatives Analysis**

Abstract The Highway Safety Manual (HSM) provides methods for transportation agencies to quantify and compare safety performance of project alternatives in terms of estimated average crash frequency. When applicable, the HSM promotes the use of the empirical Bayes (EB) method to combine predicted average crash frequency and observed crash frequency to obtain a more reliable estimate of expected average crash frequency. In cases where the EB method does not apply to one or more alternatives, the HSM recommends not using the EB method within the Part C predictive method and relying solely on predicted crashes for comparing alternatives. This has led agencies to avoid using the EB method, including for "future no-build" scenarios. The objective of this research was to consolidate best practices and research findings to develop a reliable and consistent approach supporting project alternatives analysis using HSM-recommended methodologies. This paper provides a five step alternatives analysis approach prioritizing methods based on reliability and consistency. This approach establishes an estimated baseline average annual crash frequency for the no-build condition in the design year. This approach then recommends identifying appropriate crash modification factors (CMFs), including pseudo-CMFs determined based on the HSM predictive method. The results of this research highlight the importance of calibrating national SPFs or developing jurisdiction-specific SPFs. Additionally, this research demonstrated a need for consistency when applying the EB method based on external CMFs and pseudo-CMFs, particularly when evaluating whether historic crash data are applicable to project alternatives that do not change HSM facility type.

Keywords: Highway Safety Manual; predictive method; alternatives analysis

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Sponsoring Committee Standing Committee on Safety Performance and Analysis (ACS20)

Session Number **Poster Session 2240**

Session Title Safety Performance and Analysis for Safe Roads

Paper Number TRBAM-25-00155

Paper Title **Impact of Access Management on Arterial Road Crashes: A Case Study of Albuquerque, New Mexico**

Introduction Arterial roads play a crucial role in urban mobility, accommodating high traffic volumes and allowing unrestricted access for all users, including bicyclists and pedestrians. Previous studies have identified features such as access points and speed as contributing factors to higher crash frequency and severity on arterial roads, due to increased user conflicts. (1–4). Consequently, there is a need to study further and understand the impact of arterial road features on the safety of all road users, specifically Vulnerable Road Users (VRUs). The analysis examines the relationship between access management on arterial roads and crash types in Albuquerque, New Mexico—a state with notably high rates of crash fatalities, particularly among bicyclists (5) and pedestrians (6, 7), making it a compelling case for a safety study. The first research question aims to disentangle whether high-speed, high-access arterial roads are more likely to experience crashes than roads with better access management. The findings from that inquiry informed the subsequent question: Do more driveway access and intersections per mile in arterials correlate to more non-motorized crashes? Using data from the Mid-Region Council of Governments, the City of Albuquerque, and the New Mexico Department of Transportation, the study applies ANOVA and negative binomial regression on crash data from 2018 and 2019 for 845 arterial roads. This research contributes by introducing a novel methodology for evaluating access management across arterial road networks, considering the effects of access and speed management on crash frequency. The method can be customized to focus on VRU crashes when data permits. Additionally, this study fills a gap in previous research by analyzing the influence of access and speed on crash frequency on primary arterial roads (2, 8) and in Albuquerque, a location different than those previously studied (9). Thus, this research may serve as a point of reference for other metropolitan areas in the country, given the safety statistics concerning all road users in this region.

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Sponsoring Committee Standing Committee on Safety Performance and Analysis (ACS20)

Session Number **Poster Session 2240**

Session Title Safety Performance and Analysis for Safe Roads

Paper Number TRBAM-25-01386

Paper Title **Intersection Crash Frequency Analysis Considering Drivers' Visual Environment Features**

Abstract Existing intersection crash analysis studies primarily consider macro infrastructure and traffic conditions. However, drivers' micro-level visual perception of the surrounding environment might impact also their driving behavior and thus safety, which has not been investigated yet. Therefore, this study developed a deep learning model to extract drivers' visual environment features from Google Street View (GSV) images. Eight-angle GSV images were collected to capture the entire intersection environment, and six types of objects in the images were segmented: sky, road, buildings, vegetation, vehicle, and walk area. Their pixel proportions were then aggregated as the drivers' visual environment's features. These features, along with geometric design, traffic, and socioeconomic features, were combined into a Negative Binomial model to analyze their impact on intersection crashes. Data from 501 signalized intersections in Florida were used for the empirical study. Results show that: 1) The inclusion of visual environment features results in better model fit than the traditional approach, as reflected by lower AIC and BIC values and a higher R2. 2) For total crashes, intersections near more underserved communities would suffer more crashes. Two visual environment features (i.e., buildings and vegetation) are significantly negative correlated with crash frequency. 3) The contributing factors vary for different crash types. Overall, a high proportion of buildings and vegetation at intersections can reduce rear-end, sideswipe, and severe crashes. However, the proportions of road and vehicle increase visual complexity, thus being significantly positive with the frequency of rear-end and vulnerable road user crashes.
Keywords: Intersection Crash Frequency, Drivers' Visual Environment, Google Street View, Image 20 Segmentation, Computer Vision

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Sponsoring Committee Standing Committee on Safety Performance and Analysis (ACS20)

Session Number **Poster Session 2240**

Session Title Safety Performance and Analysis for Safe Roads

Paper Number TRBAM-25-02358

Paper Title **A Comprehensive Multi-Criteria Decision Analysis Tool for Assessing Traffic Danger at Urban Intersections**

Abstract Intersections are critical points in urban transport networks where traffic danger is at its peak: traffic flows converge, involving a complex interplay of factors and giving rise to potential collisions. Ensuring intersection safety is particularly critical in densely populated cities, where vulnerable groups such as children are at heightened risk. As variables contributing to traffic danger do not have an equal or linear impact on traffic danger, a sophisticated approach to assess it is needed. Further, input from diverse stakeholders, such as urban planners, traffic engineers, community groups, and policymakers, is necessary to get a holistic perspective. The purpose of this study is to develop a comprehensive tool to assess traffic danger at intersections using a Multi-Criteria Decision Analysis (MCDA) method integrating diverse stakeholder perspectives. Our MCDA method involves input from children, parents, and experts who identified key factors of traffic danger. These factors were then systematically analyzed by experts, leading to the construction of evaluation criteria, both qualitative and quantitative. The traffic danger assessment tool was implemented in a geographic information system, applied to intersections in Montreal with special consideration to children as a vulnerable group, and validated by experts as a final step. The findings provide actionable insights for urban planners and policymakers aiming to achieve zero traffic fatalities and severe injuries. The tool is meant to be used as a decision support system to help implement traffic danger 16 mitigation measures.

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Session Number	**Poster Session 2240**
Session Title	Safety Performance and Analysis for Safe Roads
Paper Number	TRBAM-25-02415
Paper Title	**A Transformer-GAN framework for Advanced Crash Likelihood Prediction at Intersections**
Abstract	Intersections in major cities are often hotspots for road crashes, resulting in significant human casualties. We propose real-time crash likelihood prediction to proactively prevent these crashes and save lives. Existing algorithms are ineffective for predicting real-time crash likelihood at intersections, struggling with data imbalance and failing to address different crash types or provide granular cycle-level prediction. To address these gaps, we develop an anomaly detection framework integrating Generative Adversarial Networks (GANs) and Transformers to predict cycle-level crashes at intersections. Our framework achieves 76% sensitivity in predicting crash events using highly imbalanced real-world Signal Phasing and Timing (SPaT) and traffic data, highlighting its deployment potential in smart intersections. Key factors in predicting crash likelihood include yellow time, red clearance time for left-turning vehicles, and occupancy of through-moving vehicles during green. Overall, the results of this study offer a roadmap for city-wide application at smart intersections, enabling real-time solutions such as signal timing adjustments, driver warnings, and efficient emergency response, thus enhancing urban safety and livability. Keywords: Anomaly Detection, GANs, Transformers, Crash Likelihood Prediction, Proactive 17 Safety Measures

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Session Number	**Poster Session 2240**
Session Title	Safety Performance and Analysis for Safe Roads
Paper Number	TRBAM-25-05015
Paper Title	**Leveraging Naturalistic Trajectory Data for Safety Analysis of All-Way Stop Control Intersections: Exploration Speed Limit and Stop Violations Patterns**
Abstract	All-Way Stop Control (AWSC) is a widely used traffic control strategy at unsignalized intersections in the United States. However, safety concerns persist as drivers 1) often disobey speed limits and 2) fail to come to a complete stop at designated signs. This paper offers one of the few studies analyzing safety associated with both 1) speed limit adherence and 2) full-stop behavior at AWSC intersections. A specialized tool is constructed for this purpose allowing the use of large amounts of probe vehicle trajectory data. In particular, the Strategic Highway Research Program 2 naturalistic driving dataset is mined over extended periods of time and over multiple states. 1) Regarding speed violations, the study finds that older drivers are more likely to adhere to speed limits compared to adults, and females have a lower probability of speeding than males. SUV drivers tend to exceed speed limits more frequently than automobile drivers, while truck drivers comply better with speed limits. Left turn maneuvers correlate with higher compliance, and an increase in intersection legs reduces the likelihood of speed violations. 2) In terms of full-stop behavior, The paper reveals that both younger and older drivers are less inclined to perform full stops. SUVs and Vans are less likely to make full stops compared to automobiles. Left turns are more likely to be accompanied by full stops, while right turns show lesser compliance. These findings align with existing literature and reinforces the reliability of the data extraction tool for future behavioral analyses. Keywords: All Way Stop Control Intersections, Multinomial Logistic Model, Safety Analysis

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Session Number	**Poster Session 2240**
Session Title	Safety Performance and Analysis for Safe Roads
Paper Number	TRBAM-25-05030
Paper Title	**Safety Evaluation of Dilemma Zone Protection System for Rural, High-Speed Signalized Intersections Using Empirical Bayes Method**
Abstract	This study employed the Empirical Bayes (EB) method to conduct a before-and-after safety analysis of a radar sensor-based dilemma zone protection (DZP) system deployed at rural, high-speed signalized intersections in Alabama. Six intersections treated with the DZP system were selected as the treatment group, while 33 untreated intersections with similar characteristics in terms of traffic, geometric, and speed-limit conditions were selected as the reference group. Safety performance functions (SPFs) and crash modification factors (CMFs) were developed using police-reported crash data. Red-light running (RLR) crashes were chosen and categorized into two groups (strict definition (SD-RLR) and extended definition (ED-RLR) crashes) for a comprehensive safety analysis. The analysis results showed that SD-RLR and ED-RLR crashes would decrease by 35% (CMF = 0.65, SE = 0.06) and 24% (CMF = 0.76, SE = 0.05), respectively if a rural high-speed intersection is treated with the radar sensor-based DZP system. Keywords: Dilemma zone protection (DZP), Dynamic green extension (DGE), Empirical Bayes (EB), Safety performance function (SPF), Continuous-wide-area (CWA) detector.

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Sponsoring Committee	Standing Committee on Safety Performance and Analysis (ACS20)
Session Number	**Poster Session 2240**
Session Title	Safety Performance and Analysis for Safe Roads
Paper Number	TRBAM-25-03617
Paper Title	**Segmentation of Risk Factors for Fatal Crashes at Urban Signalized Intersections: A Hybrid Approach**
Abstract	Signalized intersections are frequently installed in developing countries to facilitate efficient traffic flow and seldom to increase traffic safety. As a result, fatal collisions still occur at intersections with signals. The purpose of this study is to gain a better understanding of signalized intersection safety by identifying and segmenting traffic and geometric risk factors associated with fatal crashes. For this purpose, a thorough road inventory survey—primary crash data—was used to analyze crashes at 67 signalized intersections in Hyderabad, an Indian metropolitan city. This paper proposes a hybrid segmentation strategy that classifies a group of important crash factors determining crash fatality at urban signalized intersections by combining machine learning, data mining, and statistical modeling results. The proposed segmentation divided the crash parameters into four distinct categories: very high, high, moderate, and low-risk factors. The key findings show that major road width, number of lanes, lack of right turn protection, all-red time, and clear road markings are the most influential factors contributing to fatal crashes at signalized intersections. Based on the findings, several policy recommendations were proposed. The segmentation of signalized intersection features would provide useful insights into the level of their influence and the impact of signalized intersection design on safety in developing countries. The study's findings and proposed policy insights may assist transportation officials in developing, prioritizing, and implementing specialized safety ountermeasures for signalized intersections. Keywords: signalized intersections, fatal crashes, Hybrid, statistical, machine learning, data mining.

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Sponsoring Committee Standing Committee on Safety Performance and Analysis (ACS20)

Session Number **Poster Session 2240**

Session Title Safety Performance and Analysis for Safe Roads

Paper Number TRBAM-25-01324

Paper Title **Analysis of the Safety Influence Areas for Signalized Intersections: An Integrated Spatial-Statistical Analysis**

Abstract Intersections are the most crash-prone areas, accounting for more than half of all traffic crashes, making their safety a critical concern. One of the significant challenges in intersection safety is the identification of Intersection Influence Areas (IIAs), a crucial step toward implementing targeted safety improvements. While previous studies have explored IIAs based on vehicle operational characteristics, empirical approaches, surveys, and simulation analysis, examining IIAs using traffic crash data has been largely overlooked. This study investigates IIAs for 118 four-legged signalized intersections using 11 years of crash data in North Dakota. The study employed spatial and statistical analysis techniques and predicted the probability of total, upstream, and downstream crashes being intersection-related to estimate IIAs. The analysis considered crash distance from the intersection center, posted speed limits, and road surface conditions. The study evaluated the models using the Area Under the Receiver Operating Characteristic Curve (ROC-AUC), Akaike Information Criterion, Deviance, and the absolute false frequency difference. The results show that the classification of crashes based on traffic direction, posted speed limit, and road surface condition improved the prediction accuracy. Moreover, the models demonstrated robust predictive capability, with ROC-AUC values ranging from 0.7 to 0.94. The findings indicate that IIAs were longer under adverse road and low-speed limit conditions and ranged from 82 ft to 335 ft. The findings will assist researchers, transportation engineers, and policymakers by offering methods and models for identifying IIAs to improve crash prediction accuracy and enhance intersection safety.
Keywords: Signalized Intersection, Intersection Influence Area, Logistic Regression Model, Spatial Analysis.

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Sponsoring Committee Standing Committee on Safety Performance and Analysis (ACS20)

Session Number **Poster Session 2240**

Session Title Safety Performance and Analysis for Safe Roads

Paper Number TRBAM-25-05661

Paper Title **A Spatial Typology Analysis of Crash Characteristics across 2480 Census Tracts**

Abstract Roadway safety is a critical concern globally, with motor vehicle crashes resulting in significant fatalities and injuries each year. This study aims to develop a data-driven spatial crash typology to enhance our understanding of crash characteristics and improve road safety interventions. Using crash data from Massachusetts and Connecticut, we integrated and standardized datasets, employing Uniform Manifold Approximation and Projection (UMAP) for dimensionality reduction and Gaussian Mixture Modeling (GMM) for clustering. Our analysis identified distinct crash types based on spatial and temporal patterns, vehicle types, and environmental conditions. We validated our typology using a Random Forest classifier, achieving an accuracy of 94%, demonstrating the0 robustness of our approach. The resulting typology offers valuable insights into crash dynamics, enabling targeted safety measures for different geographic areas in New England. Future research will expand the dataset to include additional states and refine the typology for broader applicability.
Keywords: Roadway safety, typology analysis, UMAP dimensionality reduction, GaussianMixture Modeling, Random Forests, crash characteristics

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Sponsoring Committee	Standing Committee on Safety Performance and Analysis (ACS20)
Session Number	**Poster Session 3147**
Session Title	Safety Performance and Analysis Using Machine Learning or Artificial Intelligence
Paper Number	TRBAM-25-00443
Paper Title	**Ensemble-based Machine Learning Approach to Prioritize Driving Safety Indicators Using Connected Vehicle System Data for Proactive Safety Analytics**
Introduction	The advancement of vehicle detection technology has enabled the collection of individual vehicle trajectory data, which is invaluable for identifying safety-related events of traffic conditions in real time. Based on driving trajectory data, it is possible to derive a variety of driving safety indicators that can be used to quantitatively estimate the potential for crash occurrence. Real-time traffic safety evaluation, which enables the immediate identification of hazardous road sections, can be performed by analyzing driving safety indicators. This can contribute to the development of proactive accident prevention measures for hazardous sections. To implement an effective model for identifying hazardous road sections, driving safety indicators that have the greatest impact on determining the presence of hazardous sections should be selected from a variety of available indicator candidates. The use of the selected salient driving safety indicators is expected to reduce model's complexity and maximize its efficiency. Many studies have aimed to derive the prioritization of indicators to implement effective models. The literature related to the prioritization of indicators has derived results using only one model. However, the importance of variables can be derived differently even with the same dataset (1, 2, 3, 4) because of the inherent algorithmic differences in machine learning models. The purpose of this study is to prioritize driving safety indicators that can be used to identify hazardous road sections effectively by combining multiple models. Three well-known machine learning methods, support vector machine (SVM), artificial neural network (ANN), and K-nearest neighbor (KNN), are adopted to implement the hazardous section identification model. Here, driving safety indicators are used as input variables, and hazardous and normal road sections are defined as output variables. Then, the performance of the ensemble learning model is compared to those of the aforementioned individual models. This study adopted permutation importance, which is a model-agnostic feature importance method, to determine the priority of indicators in terms of identifying hazardous segments.

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Sponsoring Committee	Standing Committee on Safety Performance and Analysis (ACS20)
Session Number	**Poster Session 3147**
Session Title	Safety Performance and Analysis Using Machine Learning or Artificial Intelligence
Paper Number	TRBAM-25-01011
Paper Title	**Investigating Resilience Features in Driving Safety: A Quantitative and Interpretable Machine Learning Approach**
Introduction	Despite the widespread application of the resilience concept across diverse traffic systems, there remain notable research gaps in its application to micro-driving safety: (1) Driving behavior consists of a series of discrete fragments, making it inherently challenging to delineate the resilience process to general driving behavior; (2) Although there has been considerable research on the application of machine learning interpretability tools, they mostly remain at a basial analysis of feature impact direction and magnitude, without fully exploring their nonlinear interpretive potential. The tradition resilience process contains the decline and recover process of the system's performance (1). Referencing the definition of the resilience, the risk evolution of the high-risk car-following process can be conceptualized as a special resilience process. As shown in the Fig. 1, we divide the resilience process of driving risk avoidance into decay and recovery stage, which describe the safety decline from the safe status to dangerous and then recovery. It is assumed that the normal status of driving safety is maintained around Q0. Due to the inherent instability of driving operations, there are normal disturbances in the car-following process. Safety decay stage: The incidence of driving risk escalates in the wake of dangerous driving behaviors and maneuvers, such as distraction, high-velocity following, and sudden braking of the leading vehicle. These risk factors are equivalent to abnormal disturbance events in resilience process. Subsequently, the driving safety declines over a period to a safety minimum value, resembling the worst state of system performance in the traditional resilience process. Safety recovery stage: Subsequent to the driver's recognition of the driving risk, appropriate countermeasures are implemented, thereby facilitating the restoration of driving safety. To comprehensively characterize the driving safety evolution during resilience process, five resilience factors were selected: (1) D_SMR: The average decay rate of SM in the decay stage; (2) D_Dur: The duration of the decay stage; (3) Min: The minimum safety value in the resilience process; (4) R_SMR: The average recovery rate in the recovery stage; (5) R_Dur: The duration of the recovery stage. After model fitting, interpretability techniques can be used to quantify the impact of car-following features on resilience features. This study has made three significant contributions: (1) The resilience process of car-following is decomposed into the decay and recovery stage, proposing five resilience features to characterize the driving resilience process; (2) The safety resilience contributing factors are analyzed and explained using the ML model and SHAP. A novel low-rank polynomial SHAP fitting technique is proposed to accurately delineate the intricate functional interplay between car-following variables and resilience features. (3) Through the analysis of car-following variables and resilience features, we elucidate the risk perception and behavioral response mechanisms involved in car-following risk avoidance.

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Session Number	**Poster Session 3147**
Session Title	Safety Performance and Analysis Using Machine Learning or Artificial Intelligence
Paper Number	TRBAM-25-01181
Paper Title	**Generating Risky and Realistic Scenarios for Autonomous Vehicle Tests Involving Powered Two-Wheelers: A Novel Reinforcement Learning Framework**
Abstract	Emerging technologies have the potential to revolutionize transportation, with Autonomous Vehicles (AVs) enhancing traffic safety, improving efficiency, and reducing emissions by optimizing driving patterns and minimizing idling time. However, despite their great potential, the actual utility and functionality of AVs have yet to be fully realized. Testing remains a critical method for advancing AV adoption, and given that Powered Two-Wheelers (PTWs) are a major contributor to crashes, this paper proposes a novel scenario generation method for PTWs interactions with AVs. First, we extracted 314 car-to-PTWs crashes from the China In-depth. Mobility Safety Study-Traffic Accident (CIMSS-TA) database as the initial state of the test scenarios. Subsequently, Reinforcement Learning (RL) was employed to control PTWs, using a reward function guided by a potential energy function that mirrors human driving characteristics to enhance the risk and realism of the generated scenarios. Finally, the effectiveness and scientific validity of the generated scenarios are verified by comparing and analyzing the risk, realism, and crash severity through multiple indicators. The results demonstrate that our proposed method increases riskiness while maintaining a high level of realism. It is hoped that this process will be applied in the future to not only test AV functions but also encourage AVs to be more mindful of crash severity. Keywords: Traffic safety, Autonomous vehicles, Safety testing

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Session Number	**Poster Session 3147**
Session Title	Safety Performance and Analysis Using Machine Learning or Artificial Intelligence
Paper Number	TRBAM-25-01335
Paper Title	**Integrating Road Network Characteristics in Traffic Crashes Analysis Based on Heterogeneous Graph Neural Networks**
Introduction	Safety considerations are fundamental in transportation planning, with macro-level safety analysis playing a crucial role in understanding crash patterns across large zones such as census blocks or Traffic Analysis Zones (TAZs). Previous studies have demonstrated that factors such as traffic flow, road network characteristics, land use, and socioeconomic indicators significantly impact safety outcomes (1, 2). However, quantifying road network characteristics has posed considerable challenges, as traditional metrics like road density fail to fully represent variations in roadway patterns, which in turn affect safety differently (3). Thus, it is essential to incorporate more comprehensive metrics to better understand the relationship between road networks and safety outcomes. Over the years, researchers have introduced several approaches to enhance our understanding of road network characteristics and their impact on crashes. While early studies focused on visual inspections of network patterns (4), more objective metrics such as closeness centrality, betweenness centrality, and the meshedness coefficient have been proposed to classify network structures (5, 6). Although these methods offer rapid assessments, they still fall short in capturing the complexities of heterogeneous network structures, prompting the need for more advanced modeling techniques. Recent advances in deep learning, particularly Heterogeneous Graph Neural Networks (HGN), have shown significant promise in modeling complex network structures (7–9). By representing road networks as topological graphs with intersections as nodes and roads as edges, HGN provides a more nuanced understanding of road network configurations. This method allows for the integration of additional factors such as traffic flow, road types, and speed limits, offering a more comprehensive exploration of how different network structures influence crashes. The primary objective of this study is to explore the relationship between road network structures and aggregated crashes using HGN. To the best of our knowledge, this is the first study to integrate road network structures with urban traffic safety analysis using HGN. Our contributions are threefold: • We introduce a novel framework utilizing HGN to analyze the spatial factors influencing crash occurrences. • We employ post-hoc explanation methods to quantify road network characteristics and reveal the heterogeneous impact of network structures on crashes. • Our approach offers insights into both theory and practice, providing a new avenue for improving transportation safety through advanced network analysis.

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Session Number	**Poster Session 3147**
Session Title	Safety Performance and Analysis Using Machine Learning or Artificial Intelligence
Paper Number	TRBAM-25-01767
Paper Title	**Evolution Pattern Analysis Using a Rule-Based Road Chain Conflict Identification Algorithm**
Introduction	Recently, chain traffic crashes have occurred frequently on continuous flow facilities such as expressways and highways. Chain traffic crashes involve multiple vehicles and typically occur on high-capacity and high-speed roads. These crashes often result in high fatality rates and difficulties in rescue, seriously endangering the reliability of road transportation system (1). Existing studies on multi-vehicle collisions mainly explore the identification method (2), influencing factors (3-6), and risk control strategies (7-9) of chain conflicts or chain crashes. However, current research is not sufficient to understand the risk pattern of multi-vehicle chain conflicts under diverse road segments or traffic conditions, and it is difficult to effectively break the chain conflicts. Therefore, it is of great significance for traffic managers to identify and analyze the development patterns of chain crashes before they occur, as this can help predict the risks and control the risk conditions of chain crashes, highlighting the potential benefits in the era of connected and automated vehicles. This study firstly identifies conflicts of vehicle pairs based on a large-scale and multi-period vehicle trajectory dataset. Secondly, this study matches conflicts between different vehicle pairs to identify chain conflicts, taking into account the randomness of the moment of conflict occurrence and the fluctuation of the duration of conflict impact. Thirdly, a series of chain conflict risk quantification indicators are constructed, including risk intensity, risk volatility, risk trend, propagation speed, propagation direction, and propagation length. Then, the chain conflict risk pattern recognition is carried out, and three patterns of chain conflict patterns are finally identified, i.e., Longitudinal Risk Decrease Pattern, Longitudinal Risk Increase Pattern, and Comprehensive High-risk Persistent Pattern. Furthermore, the analysis of transition probabilities of different chain conflict patterns yields a series of meaningful inferences that are crucial in improving traffic system safety. This study proposes three innovations: (1) It proposes a nonlinear mapping relationship between modified time-to-collision (MTTC) and potential conflict risks, and constructs chain conflict risk quantification indicators; (2) It constructs a rule-based chain conflict extraction algorithm by matching conflicts between different vehicle pairs, further identifies different patterns of chain conflicts, and calculates the probability of pattern transition in the chain conflict micro system; (3) It compares the performance of different chain conflict patterns and transition probability under different traffic conditions and road segments based on a vehicle trajectory dataset.

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Session Number	**Poster Session 3147**
Session Title	Safety Performance and Analysis Using Machine Learning or Artificial Intelligence
Paper Number	TRBAM-25-02687
Paper Title	**Elaborate AI-Driven Methods for Imputing Missing Data from Vehicle Detection Systems: Considering Safety Aspects with Hard-Braking Records**
Abstract	High-quality traffic data are essential for efficient highway traffic management and the successful operation of intelligent transportation systems. Currently, data collected from various detectors are widely used; however, data loss due to external factors can hinder the establishment of accurate and reliable traffic management systems. This presents a major challenge in accurately identifying traffic conditions and preventing crash risks. Therefore, effective processing methodologies are required to address the missing values. In particular, reflecting the crash risk characteristics when imputing missing values is important for capturing the crash risk under rapidly changing traffic conditions. This study uses dangerous driving event data, specifically hard-braking events, to impute missing values from vehicle detection systems. Both statistical and machine learning techniques, such as a K-nearest neighbor, generative adversarial neural network, long short-term memory network (LSTM), and bidirectional LSTM, were applied to compare the imputation performance. Moreover, the performance of traffic data prediction in unexpected situations was evaluated by applying hard-braking event data collected from navigation to missing-value imputation. The missing-value imputation using hard-braking event data was found to be more accurate than existing methods. The impact of navigation data on the prediction performance was also evaluated through a case analysis of traffic flow characteristics. This study solves the problem of data loss in highway traffic management, even in crash risk situations. Keywords: Traffic Data Imputation, Navigation Data, Hard-Braking Event, Intelligent Transportation System, Highway

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Session Number	**Poster Session 3147**
Session Title	Safety Performance and Analysis Using Machine Learning or Artificial Intelligence
Paper Number	TRBAM-25-03124
Paper Title	**Analysis and Prediction of Traffic Accidents Based on Interpretable Spatial Machine Learning: A Case Study in California**
Abstract	Traffic accidents are not only the leading cause of fatalities and disabilities but also impose substantial economic losses on society. However, understanding the nonlinear and heterogeneous relationship between environmental factors and traffic accidents remains challenging. This study establishes an interpretable spatial machine learning framework to address the nonlinearity, spatial heterogeneity, and interpretability of this issue through the geographically weighted support vector machine (GW-SVM) model. Utilizing a large-scale traffic accident dataset and leveraging multi-source big data, this study provides both global and local interpretations of the nonlinear associations in California, United States. Our findings highlight that: (1) the Visibility factor plays a more significant role in the relationship between environmental factors and traffic accident severity. (2) All environmental variables, encompassing both natural and socio-economic factors, exhibit nonlinear and threshold effects on traffic accidents. (3) Compared to existing models, the GW-SVM model demonstrates improved performance in predicting the severity of urban road traffic accidents. These findings are of great significance for reducing the risk of traffic accidents. Keywords : Traffic Accidents, Geographically Weighted Regression (GWR), Support Vector Machine (SVM), Nonlinear Associations

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Sponsoring Committee	Standing Committee on Safety Performance and Analysis (ACS20)
Session Number	**Poster Session 3147**
Session Title	Safety Performance and Analysis Using Machine Learning or Artificial Intelligence
Paper Number	TRBAM-25-03146
Paper Title	**Beyond the Conventional: Exploring Pedestrian Safety on Interstates with Bayesian and Machine Learning Models**
Introduction	Pedestrian safety on interstate highways has emerged as a critical issue in the United States, despite regulations restricting pedestrian access to these high-speed roadways (1). Recent statistics reveal a troubling rise in pedestrian fatalities, particularly on freeways. Between 2009 and 2018, pedestrian fatalities increased by 53%, with 17% of all roadway fatalities involving pedestrians (2). From 2015 to 2018, freeway pedestrian fatalities averaged over 800 annually, with 941 fatalities reported in 2021, accounting for 12.7% of total pedestrian deaths that year (3). These figures underscore the urgency of improving pedestrian safety on interstates. Research on pedestrian crashes on interstates remains limited, particularly for "unintended pedestrians" who access freeways due to vehicle breakdowns or other emergencies (4). These individuals face significant risks from high-speed traffic and challenging conditions such as inadequate lighting (5). Demographic trends indicate that young to middle-aged males with elevated blood alcohol levels are disproportionately affected (6). Key contributing factors include pedestrian and driver alcohol impairment and poor visibility, especially in rural areas with inadequate road lighting (7). This study addresses these gaps by analyzing pedestrian crash data from North Carolina (2007–2022) using statistical and machine learning models. It focuses on pedestrian actions, roadway conditions, and vehicle characteristics to identify determinants of injury severity. Aligned with the Safe Systems approach, this research aims to provide actionable insights for policymakers and practitioners. The findings can potentially guide the development of safety measures such as improved infrastructure and public awareness campaigns. The study findings can be instrumental in supporting efforts to reduce pedestrian fatalities on interstates and advancing Vision Zero goals. The conceptual framework of the study is shown in Figure 1.

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Sponsoring Committee	Standing Committee on Safety Performance and Analysis (ACS20)
Session Number	**Poster Session 3147**
Session Title	Safety Performance and Analysis Using Machine Learning or Artificial Intelligence
Paper Number	TRBAM-25-03514
Paper Title	**To Balance or Not to Balance? Applying a Machine Learning Technique to Oversample Severe Injury Crashes in Work Zones**
Introduction	Road work zones (WZs) are critical components of highway infrastructure maintenance and rehabilitation, ensuring mobility and economic progress. However, they present significant safety risks due to factors like variable traffic flow, lane closures, and reduced visibility. These challenges are exacerbated during active traffic hours, demanding robust safety measures. In the United States, work zone crashes continue to be a pressing concern, with 956 fatalities and over 42,000 injuries reported in 2021, as per national statistics (1). Tennessee highways are no exception, with over 3,855 WZ crashes recorded in 2022 (2), predominantly caused by distracted and reckless driving. While past studies have analyzed WZ crash severity using frequentist and machine learning methods, many aspects, including behavioral factors influencing injury severity, remain underexplored (3-7). Furthermore, crash datasets often exhibit an imbalance in injury severity categories, with fatal and serious injury crashes being underrepresented despite their high societal costs. Addressing this imbalance is crucial for enhancing predictive accuracy and policy relevance. This study utilize a unique dataset of Tennessee WZ crashes (2018–2022) and employs a novel approach combining the Random Forest (RF) algorithm and Synthetic Minority Over-sampling Technique (SMOTE) (8-11). This method effectively balances minority categories and identifies critical behavioral factors such as speeding, aggressive driving, and alcohol impairment. The findings provide actionable insights for enhancing WZ safety, emphasizing targeted interventions like speed limit enforcement and better signage. By addressing data imbalance and integrating emerging machine learning methods, this research bridges gaps in the literature and contributes to safer WZ design and management practices.

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Sponsoring Committee Standing Committee on Safety Performance and Analysis (ACS20)

Session Number **Poster Session 3147**

Session Title Safety Performance and Analysis Using Machine Learning or Artificial Intelligence

Paper Number TRBAM-25-04823

Paper Title **Comparative Geospatial Analysis of Weather-Related Impacts on Crash Frequency With Explainable Machine Learning: A Case for Kansas Census Tracts**

Abstract Predictive crash modeling enables researchers to identify correlations between safety performance and various explanatory factors. Traffic crash prediction models are handy tools for transportation safety as they can help predict crash frequencies and the contributing factors. Previously, traffic safety analysis at spatially aggregated levels has drawn the interest of safety researchers to meet the needs of region-level safety inspection and emerging safety planning. Weather is a significant contributing factor to traffic crashes, and its effect is not identical across all regions. Similarly, traffic and demographic characteristics also contribute to crashes, and their effect varies across different geographical regions. In this work, we study the impact of these contributing factors at the census tract level in Kansas. We use an explainable Machine Learning (ML) approach to train a crash frequency prediction model, and the SHapley Additive exPlanations (SHAP) algorithm is established on the classification model to investigate the possible associations between weather, socio-demographic factors, and traffic characteristics. Our findings suggest that Daily Vehicle Miles Traveled (DVMT) is the most significant traffic-related contributing factor to crash frequency prediction across all census tracts. Among weather-related factors, snow, relative humidity, and precipitation are the most critical. Additionally, our study compares these weather variables across all census tracts and analyzes all contributing factors in detail for two specific census tracts. Our approach enables us to compare both global and local contributing factors for the entire state of Kansas and for individual census tracts.

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Sponsoring Committee Standing Committee on Safety Performance and Analysis (ACS20)

Session Number **Poster Session 3147**

Session Title Safety Performance and Analysis Using Machine Learning or Artificial Intelligence

Paper Number TRBAM-25-05032

Paper Title **Analyzing the Factors Behind Heavy Vehicle Crashes: A Deep Learning Approach**

Abstract The trucking industry is integral to the U.S. economy, handling 73.1% by value, 71.1% by cargo, and 42.0% by ton-miles of all commodities transported. Despite its importance, truck crashes, which caused 3,903 fatalities in 2014, have a higher fatality rate per vehicle mile compared to passenger cars and lead to significant economic disruptions. This paper aims to identify the most critical factors regarding heavy vehicle crashes in New Jersey. This study aims to address this research deficiency by employing three advanced machine learning models— Artificial Neural Network (ANN), Random Forest (RF), and Support Vector Machine (SVM)— to explore the complex factors influencing crash severity in heavy vehicles. Our findings reveal that ANN offers superior predictive ability in comparison to Random Forest and Support Vector Machine for assessing crash severity. Additionally, we identify run off the road as the most significant factor affecting crash severity. By bridging this gap, our research not only provides valuable insights for improving safety measures for large vehicles but also lays the groundwork for future studies in freight transportation. Future research directions include enhancing prediction models, developing real-time monitoring systems, and exploring interventions to reduce the incidence and impact of "Run off the road" crashes. This study thus contributes to addressing urgent safety concerns and advancing the field of heavy vehicle safety and transportation research.

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Sponsoring Committee Standing Committee on Safety Performance and Analysis (ACS20)

Session Number **Poster Session 3147**

Session Title Safety Performance and Analysis Using Machine Learning or Artificial Intelligence

Paper Number TRBAM-25-05368

Paper Title **CrashLLM: Modeling Traffic Crash Patterns and Discovering Causal Factors with Multimodal Data and Foundation Models**

Abstract Current research in traffic crash frequency modeling and analysis has predominantly approached the problem as classification tasks, focusing mainly on classification or ensemble learning methods. These approaches often overlook the intricate relationships among the complex infrastructure, environmental, human and contextual factors related to traffic crashes and risky situations. In contrast, we initially propose a large-scale traffic crash language dataset, named Crash Event, summarizing 19,340 real-world crash reports and incorporating infrastructure data, environmental and traffic textual and visual information in Washington State. Leveraging this rich dataset, we further formulate the crash event feature learning as a novel text reasoning problem and further fine-tune various large language models (LLMs) to predict detailed accident outcomes, such as crash types, severity and number of injuries, based on contextual and environmental factors. The proposed model, Crash LLM, distinguishes itself from existing solutions by leveraging the inherent text reasoning capabilities of LLMs to parse and learn from complex, unstructured data, thereby enabling a more nuanced analysis of contributing factors. Our experiments results show that the proposed Crash LLM not only predicts the severity of accidents but also classifies different types of accidents and predicts injury outcomes, all with averaged F1 score boosted over 54.15% comparing with the state-of-the-art model. Furthermore, Crash LLM can provide valuable insights for numerous open world what-if situational-awareness traffic safety analyses with learned reasoning features, which existing models cannot offer. We make our benchmark, datasets, and model publicly available for further exploration based on the manuscript's acceptance.
Keywords: traffic safety, large language models, multimodal data, casual analysis

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Sponsoring Committee Standing Committee on Safety Performance and Analysis (ACS20)

Session Number **Poster Session 3147**

Session Title Safety Performance and Analysis Using Machine Learning or Artificial Intelligence

Paper Number TRBAM-25-05485

Paper Title **Spatial-Proximity Integration in Transformer Based Models for County-Level Collision Prediction**

Abstract Understanding the impact of spatial proximity on traffic crash prediction is crucial for effective traffic safety and management. This study leverages Transformer based models to evaluate spatial-proximity effects by incorporating adjacency and distance data from 58 counties in California. By integrating collision, victim, demographic, and spatial variables, we use three dimensions of comparison to explore the significance of spatial components in enhancing predictive accuracy. These dimensions include the effect of different variables, the impact of varying model layers, and the number of epochs used in training. Our findings demonstrate that models incorporating spatial features such as adjacency and distance data consistently outperform baseline models that rely solely on collision data. The optimal performance was achieved with models using two layers, while those trained for 150 epochs performed better than those trained for 300 epochs. The research provides a robust framework for future studies aimed at improving traffic safety through advanced machine learning techniques. Keywords: Transformer Encoder; Spatial Proximity; Traffic Collision Prediction; Adjacency Matrix; Distance Matrix; Multivariate Comparison.

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Sponsoring Committee	Standing Committee on Safety Performance and Analysis (ACS20)
Session Number	**Poster Session 3147**
Session Title	Safety Performance and Analysis Using Machine Learning or Artificial Intelligence
Paper Number	TRBAM-25-06160
Paper Title	**Causality Modeling and Analysis of Crash Risk during Interactions Between Motorized and Non-Motorized Vehicles Based on Double Machine Learning**
Abstract	The mixing of motorized and non-motorized vehicles in the central area of the intersection with a high density of interaction behavior leads to a high risk of collision that seriously end angers users. To devise effective control strategies for risky driving behavior, it is crucial to model how risk evolves during these interactions. This study presents a novel analytical framework grounded in causal inference theory to assess accident risk and uncover the causal links between driving behavior and risk. Initially, risk during the interaction between motorized and non-motorized vehicles is quantified using a modified measure known as Anticipated Collision Time (ACT). Next, a double machine learning model (DML) is employed to explore the relationship between vehicle motion characteristics, environmental conditions, and collision risk. The findings demonstrate that this causal analysis framework effectively examines micro-level interaction behavior and reveals that the impact of driving behavior on interaction risk varies significantly across different scenarios. These insights enhance our understanding of interaction processes and their potential to lead to accidents, offering valuable information for developing driver assistance systems. Keywords: Mixed traffic flow, Interaction between motorized and non-motorized vehicles, traffic conflicts, causal discovery, double machine learning

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Sponsoring Committee	Standing Committee on Safety Performance and Analysis (ACS20)
Session Number	**Poster Session 3147**
Session Title	Safety Performance and Analysis Using Machine Learning or Artificial Intelligence
Paper Number	TRBAM-25-06171
Paper Title	**Enhancing Crash Frequency Modeling with Mixed-Type Data Using a Hybrid VAE-Diffusion-Based Generative Approach**
Introduction	Crash frequency modeling is to predict the aggregated number of crashes occurred in a given time on certain location (1). Accurate prediction helps to identify risk factors that contribute to crashes, and guides tailored safety improvement. However, the excess zero problem in crash datasets, where the majority records have zero crash counts, can lead to poor model fit in crash frequency modeling (2; 3). Traditional model-driven statistical models, such as zero-inflated Poisson and zero-inflated negative binomial (4) are often constrained by assumptions of data distribution and may not fully capture the underlying patterns, especially in complex datasets (5). Data-driven methods is another solution to excess zero problem, which focus on enhancing the data by resampling techniques, including under-sampling and over-sampling (6). However, under-sampling methods which may lead to a loss of important information and potentially degrade model performance (7). In contrast, traditional over-sampling techniques often fails to capture the mixed structure of count, ordinal, and nominal discrete features, as well as real-valued continuous feature in mixed-type crash dataset, along with the complex correlations between them. This limitation can reduce the synthetic data quality and result in biased model predictions (8). Deep generative models offer a promising alternative for over-sampling and data-driven modeling(9). Several recent methods showed significant success in tabular data generation, such as Conditional Tabular Generative Adversarial Networks (CTGAN)(10), tabular variational autoencoder (TVAE) (10), and Generation of Realistic Tabular data (GReaT)(11). But a novel score-based generative model—Diffusion model—shows greater performance on generating synthetic data with high quality and diversity(12). Despite the impressive capabilities of diffusion-based tabular generative models, challenges remain when tailoring a diffusion model for tabular data(13). Existing models mostly adopted simple encoding techniques—transform discrete features into numerical ones using techniques like one-hot encoding (14; 15)and analog bit encoding (16).However, the crash dataset in this study is a highly-structured, mixed-type data, with high-cardinality variables, such as the count, ordinal discrete data. Simple encoding may aggravate the 'curse of dimensionality' problem(9), which means the tabular data might be transformed into a high-dimensional form. This makes it challenging for the model to learn and compute, thereby reduce the synthetic quality and accuracy (14; 15). To this end, this study introduces a data-driven crash frequency modelling approach based on the advanced VAE-Diffusion deep generative model—TabSyn (17). The major contributions of the study are summarized below: (1) A novel data generation approach based on TabSyn, which can handle mixed-type crash data. It transforms diverse input features into a unified embedding space, where the model can learn and extract various features at once. (2) The hybrid architecture of the generative model, combining a VAE structure with a Transformer encoder and decoder, can map all features to a lower-dimensional space, thereby mitigating the 'curse of dimensionality'. (3) A comprehensive study was conducted to evaluate the quality of the synthetic data, which is with complex mixed types features, using coverage similarity metrics like distribution plot and statistical metrics, as well as structural similarity metrics like Pair-wise Correlation Difference (PCD).

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Session Number **Poster Session 3147**

Session Title Safety Performance and Analysis Using Machine Learning or Artificial Intelligence

Paper Number TRBAM-25-04468

Paper Title **Enhancing Traffic Safety with Dense Video Captioning: A Parallel Framework for Comprehensive Event Analysis**

Abstract This paper presents an innovative solution for enhancing traffic safety through dense video captioning. The primary objective is to address traffic safety description and analysis using the Woven Traffic Safety (WTS) dataset, which provides a comprehensive Pedestrian-Centric Traffic Video Dataset for Fine-grained Spatial-Temporal Understanding. Our approach focuses on four main points: 1) To solve dense video captioning, we leverage the Parallel Dense Video Captioning (PDVC) framework, which models visual-language sequences and generates dense captions by chapters for videos. 2)We utilize CLIP (Contrastive Language–Image Pretraining) to extract visual features, enabling more efficient cross-modality training between visual and textual representations. 3)Domain-specific model adaptation is conducted to mitigate the domain shift problem, which poses significant recognition challenges in video understanding. 4) We implement know ledge transfer from BDD-5K captioned videos to enhance the understanding and captioning accuracy of WTS videos. Our empirical evaluations on the WTS and BDD-5K datasets demonstrate that our approach significantly improves dense video captioning performance. Specifically, our model achieves BLEU-4, ROUGE-L, METEOR, and CIDEr scores of 0.2005, 0.4416, 0.4115, and 0.5573, respectively, for the WTS dataset, and 0.2102, 705, 0.4435, and 0.8698, respectively, for the BDD-5K dataset.
Keywords: Dense Video Captioning, Traffic Safety, Parallel Decoding, Visual-Language Modeling, Domain-Specific Adaptation, CLIP, Knowledge Transfer

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Sponsoring Committee Standing Committee on Safety Performance and Analysis (ACS20)

Session Number **Poster Session 3147**

Session Title Safety Performance and Analysis Using Machine Learning or Artificial Intelligence

Paper Number TRBAM-25-05236

Paper Title **Advanced Crash Causation Analysis for Freeway Safety: A Large Language Model Approach to Identifying Key Contributing Factors**

Abstract Understanding the factors contributing to traffic crashes and developing strategies to mitigate their severity is essential. Traditional statistical methods and machine learning models often struggle to capture the complex interactions between various factors and the unique characteristics of each crash. This research leverages large language model (LLM) to analyze freeway crash data and provide crash causation analysis accordingly. By compiling 226 traffic safety studies related to freeway crashes, a training dataset encompassing environmental, driver, traffic, and geometric design factors was created. The Llama3 8B model was fine-tuned using QLoRA to enhance its understanding of freeway crashes and their contributing factors, as covered in these studies. The fine-tuned Llama3 8B model was then used to identify crash causation without pre-labeled data through zero-shot classification, providing comprehensive explanations to ensure that the identified causes were reasonable and aligned with existing research. Results demonstrate that LLMs effectively identify primary crash causes such as alcohol-impaired driving, speeding, aggressive driving, and driver inattention. Incorporating event data, such as road maintenance, offers more profound insights. The model's practical applicability and potential to improve traffic safety measures were validated by a high level of agreement among researchers in the field of traffic safety, as reflected in questionnaire results with 88.89%. This research highlights the complex nature of traffic crashes and how LLMs can be used for comprehensive analysis of crash causation and other contributing factors. Moreover, it provides valuable insights and potential countermeasures to aid planners and policymakers in developing more effective and efficient traffic safety practices.

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Sponsoring Committee	Standing Committee on Safety Performance and Analysis (ACS20)
Session Number	**Poster Session 3147**
Session Title	Safety Performance and Analysis Using Machine Learning or Artificial Intelligence
Paper Number	TRBAM-25-01359
Paper Title	**Relationship Exploration of Traffic Safety Risk Factors with Naturalistic Driving Data Via Unsupervised Learning Models**
Abstract	Understanding traffic risk factor interrelationships is crucial for developing strategies to reduce road accidents and enhance safety. Traditional methods focus on individual or multiple factors' impacts on crash risk, lacking systematic evaluation with real-world data. This study explores traffic safety risk factors using data from the Secondary Strategic Highway Research Program Naturalistic Driving Study (NDS). Twenty-four potential risk factors, including driver demographics, behavior, environmental conditions, road characteristics, traffic context, vehicle kinematics, and cell ban policy, were considered. Pair-wise associations were assessed using Cramer's V, and hierarchical agglomerative clustering grouped the 24 factors into five clusters. Probabilistic Structural Equation Modeling analyzed the interaction and joint effects of these factors. Results show consistent associations between factor pairs, with higher Cramer's V values clustering together. The tree structure reveals relationships among the five clusters: the distraction-dominated cluster (2) is connected to the driver demographics-dominated cluster (1), and the traffic-dominated cluster (3) is linked to the driver demographics-dominated cluster (1), road characteristics-dominated cluster (4), and environment-dominated cluster (5). Joint effect analysis indicates direct impacts of the distraction-dominated cluster (2), traffic-dominated cluster (3), and road-dominated cluster (4) on safety outcomes. In contrast, the driver demographics-dominated cluster (1) and environment-dominated cluster (5) indirectly influence safety outcomes through clusters 2 and 3. This study identifies underlying structures and associations among risk factors, highlighting their interactions and contributions to traffic safety. Keywords: Risk factors, relationship, unsupervised learning models, naturalistic driving data

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Sponsoring Committee	Standing Committee on Safety Performance and Analysis (ACS20)
Session Number	**Poster Session 3147**
Session Title	Safety Performance and Analysis Using Machine Learning or Artificial Intelligence
Paper Number	TRBAM-25-04855
Paper Title	**Investigating the Contributing Factors to Crashes with and without the Presence of Work Zone Workers Using Machine Learning Techniques**
Abstract	As the nation's roadways continue to deteriorate, the presence of work zones on US highways is anticipated to increase, highlighting the crucial need for the safety of both work zone workers and road users. This study combined descriptive statistics and SHapley feature important analysis to examine work zone crash data in Ohio from 2019 to 2023. The goal was to identify the factors contributing to crash severity with and without the presence of work zone workers. Various machine learning models, including k-nearest neighbors, random forest, eXtreme gradient boosting, and Light gradient boosting machines, were employed to predict crash outcomes across three datasets. Light gradient boosting machines emerged as the best-performing model. SHapley values were then utilized to interpret the contributing factors on crash injury severity. The analysis indicated that shoulder and lap belt use consistently reduced crash severity across all datasets. Multi-vehicle crashes, sideswipe, angle, and rear-end crashes were among the variables that had an increasing influence on crash severity across the three datasets. The partial dependence plot revealed that the mobile work zone type significantly influenced worker-present crash severity, while out-of-state drivers were a significant factor in non-worker-present crashes. The findings of this study are intended to guide transportation practitioners and policymakers in enhancing work zone safety. Keywords: Work zone, SHapley, contributing factors, workers, machine learning.

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Sponsoring Committee	Standing Committee on Safety Performance and Analysis (ACS20)
Session Number	**Poster Session 3147**
Session Title	Safety Performance and Analysis Using Machine Learning or Artificial Intelligence
Paper Number	TRBAM-25-05407
Paper Title	**Spatiotemporal Prediction of Secondary Crashes by Rebalancing Dynamic and Static Data with Generative Adversarial Networks**
Abstract	Secondary crashes tend to intensify traffic disruptions and lead to further casualties, underscoring the importance of predicting these events to enhance traffic safety. However, traffic crash data is often highly imbalanced, with normal crashes greatly outnumbering secondary ones. Such data imbalance issue poses a challenge for secondary crash modelling, especially for spatiotemporal prediction of secondary crash with limited samples. Existing rebalancing methods struggle to generate both dynamic and static crash data effectively. Considering those limitations, a secondary crash prediction framework is developed in this work. Firstly, this work incorporates a novel generative adversarial network, called DoppelGANger (DG), to augment the dataset, mitigating the data imbalance. DG replaces multilayer perceptron (MLP) with long short-term memory (LSTM) to improve the fidelity of generating dynamic data for multivariate and long time series. Meanwhile, DG proposes a batch generation approach to capture the complex dependencies between variables. In addition, a static data generator and an auxiliary discriminator are added to model the joint distribution between static and dynamic data for the generation of composite crash data. Secondly, we construct a Transformer-based predictive module to predict the probability and spatiotemporal distribution of secondary crashes. The results show that the DG model performs superior in generating multidimensional traffic crash data with high fidelity, compared with MC-GAN and TVAE. The prediction experimental results clearly indicate that the proposed generative model significantly improves the performance of the prediction module. Thus, the synthetic data from DG improves prediction accuracy for secondary crash occurrences and their spatiotemporal distribution. Keywords: Time Series Data, Imbalanced Data, Generative Adversarial Networks, Spatiotemporal Prediction, Secondary Crash

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Sponsoring Committee	Standing Committee on Safety Performance and Analysis (ACS20)
Session Number	**Poster Session 3147**
Session Title	Safety Performance and Analysis Using Machine Learning or Artificial Intelligence
Paper Number	TRBAM-25-02616
Paper Title	**Identifying Crucial Indicators of Task Complexity and Coping Capacity Associated with Crash Risk through Machine Learning Techniques: A Comparative Study using On-Road and Simulator Data**
Abstract	Task demand is the objective complexity of the task and arises out of a combination of features of the environment, the behavior of other road users, control and performance characteristics of the vehicle. On the other hand, coping capacity refers to the ability of drivers and road systems to manage and respond effectively to various challenges and stressful situations encountered while driving. The aim of this study was to identify crucial indicators of task complexity and coping capacity associated with crash risk through machine learning techniques. Towards that end, data from an on-road driving experiment (involving 135 drivers) along with data from a simulator experiment (involving 55 drivers) were collected and analysed. In order to fulfill these objectives, a feature importance algorithm extracted from Extreme Gradient Boosting (XGBoost) was used to evaluate the significance of variables on forecasting STZ. Additionally, a Neural Network model was implemented for real-time data prediction, taking into account the most important and significant risk indicators. Furthermore, a comprehensive assessment of the performance of three machine learning classifiers (i.e. Decision Trees, Random Forests and k-Nearest Neighbors) across two distinct datasets (i.e. on-road and simulator experiment dataset) was performed to predict STZ levels for headway. Results indicated that RF model outperformed the DT and kNN models across all metrics, making it the most effective for predicting headway with accuracy up to 90%. It was also revealed that Neural Networks demonstrated that the level of STZ can be predicted with an exceptional accuracy of up to 89.8%.

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Sponsoring Committee	Standing Committee on Safety Performance and Analysis (ACS20)
Session Number	**Poster Session 3213**
Session Title	Safety Performance and Analysis for Safe Road Users and Safe Speeds
Paper Number	TRBAM-25-03101
Paper Title	**Joint Analysis of E-bike Crash Types and Injury Severity at Different Locations Using a Copula-based Approach**
Introduction	E-bikes stand out as one of the most energy-efficient forms of motorized transport due to their light weight (1) and their environmental advantages over other motorized vehicles in terms of emissions. E-bikes represent a cost-effective, relatively low-tech, and low-carbon for urban transportation alternative. However, the rapid proliferation of e-bikes has been accompanied by a significant increase in traffic crashes, raising concerns about their safety and the factors influencing crash severity. In China, Vulnerable Road Users (VRU), including pedestrians, motorcyclists, and cyclists, make up over 70% of the fatal crashes in 2016 (2). In this case, ensuring road safety for e-bike cyclists has become an emerging public health issue in countries advocating for this environmentally friendly mode of transportation. A majority of the existing studies in safety literature have consistently shown that the crash type and the crash location are closely linked to the crash outcomes (3). Furthermore, certain locations of crashes, especially intersections and road segments had distinct patterns in terms of outcomes (4–6). Previous studies emphasize the need for targeted safety measures tailored to specific crash types and locations to effectively reduce injury risk and severity. However, the particular impacts on e-bikes remain unclear despite their rapid usage growth outpacing research on roadway facilities and safety regulations. Addressing this gap, our study conducts a comprehensive analysis of factors influencing e-bike crash severity, focusing on how crash locations (intersections vs. segments) and crash types differentially affect outcomes. We employ separate multinomial logistic regression models for crash type and severity and utilize a Copula-based model to jointly examine injury severity, incorporating interaction effects between crash type and location for a more efficient analysis. The remainder of this paper is organized as follows: In Section 2, we introduce the detailed framework used in the analysis and the data sources used in this study are presented. In Section 3, the performance of the models and the effects of the factors are analyzed and discussed. Finally, we conclude and discuss future research.

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Session Number	**Poster Session 3213**
Session Title	Safety Performance and Analysis for Safe Road Users and Safe Speeds
Paper Number	TRBAM-25-03664
Paper Title	**Exploring the Spatial Heterogeneity in Non-Motorized Vehicle Crashes on Urban Roads**
Introduction	As a cost-effective and easy transportation means, non-motorized vehicles (NMVs), such as bicycles and electric bicycles (e-bikes), have been widely used for commuting travels in more and more cities worldwide. However, it has been a critical safety concern with NMV crashes, and the number of NMV crashes on urban roads is high. Therefore, identifying key influencing factors of NMV crashes is essential for implementing countermeasures aimed at reducing NMV crashes on urban roads. Traffic crashes are related to geographical locations, and the frequency of NMV crash varies greatly between different roadways. However, few studies have explored the spatial heterogeneity in the effects of influencing factors on NMV crash frequency. Previous studies adopted various statistical approaches to consider the potential spatial heterogeneity and correlation issues in modeling data, such as random parameter models (1), and conditional autoregressive (CAR) models (2). These models have good interpretability but also have some limitations, such as predefined assumptions and low predictive capability (3). Machine learning (ML) approaches (e.g., random forest) are employed to explore different relations. These models have high prediction accuracy but lack interpretability and do not consider spatial factors (3,4). Nowadays, the geographically weighted random forest model (GWRF) has been adopted in studies, which has good predictive performance and can effectively explore spatial heterogeneity (5-7). Further, extensive studies have explored factors related to NMV crashes on urban roads. Previous studies mainly focused on road and traffic operation characteristics, including segment length, median, traffic volume, and speed (8-14). In terms of bicycle facility features, previous studies have only investigated the relationship between NMV crashes on urban roads and bike lanes and protected bike lanes (8,12,13,15,16), while neglecting some meaningful bicycle facilities. The spatial variation in the effects of these meaningful factors (e.g., bike lane width, the type of physical separation of bicyclists from motor vehicles) on NMV crash frequency has not been analyzed yet. Against this background, this study aims to explore the spatial heterogeneity in the effects of factors on the NMV crashes that occurred on urban roads using the GWRF model. In addition, the hierarchical negative binomial conditional autoregressive (HNB-CAR) model was used as a supplement to analyze the relationship between influencing factors and NMV crashes on urban roads. The results of this study can help traffic management departments develop and implement tailored safety measures to reduce the likelihood of NMV crashes on different urban roads.

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Sponsoring Committee Standing Committee on Safety Performance and Analysis (ACS20)

Session Number **Poster Session 3213**

Session Title Safety Performance and Analysis for Safe Road Users and Safe Speeds

Paper Number TRBAM-25-05580

Paper Title **Analysis of Crashes Involving Micromobility Devices**

Introduction

Shared micromobility systems have rapidly emerged as a popular transportation option for short distances, with 133 million trips made in the US alone in 2023, a 16% increase from 2022 (1). These systems have shown significant potential in alleviating traffic congestion by reducing the number of vehicle trips, facilitating short-distance travel, extending the reach to public transportation, and addressing first and last-mile travel challenges (2, 3). This potential to alleviate traffic congestion is a promising aspect of shared micromobility systems in urban areas. Micromobility devices are motorized transportation devices that are mainly designed not to exceed 20 miles per hour (mph) on level ground (4). These devices can be privately owned and operated or used as part of a shared system. Examples of micromobility devices include electric bikes (e-bikes), electric scooters (e-scooters), shared bicycles, and electric pedal-assisted bicycles.

The spread of micromobility use has brought about a rapid increase in micromobility crashes. In the United States, the number of crashes involving e-scooters increased from 8,016 in 2017 to 14,641 in 2018 (5). Transportation agencies have implemented diverse strategies to combat micromobility crash occurrences and severity, such as ensuring bike facilities such as installing bike lanes, bicycle boulevards, proper parking corrals, and reducing speed limits. However, the specific impact of such strategies on reducing micromobility-related crashes remains uncertain, highlighting the need for further research in this area.

This study aims to assess the safety implications of various on-street facilities on micromobility users by analyzing crash data and evaluating the effectiveness of different infrastructure elements. The study will utilize statistical models to identify significant factors contributing to micromobility-related crashes and estimate crash modification factors (CMFs) to quantify the impact of each variable. The findings of this study will provide valuable insights to urban planners and transportation engineers, assisting them design safer streets and implement effective strategies to reduce the risk of crashes involving micromobility users.

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Sponsoring Committee Standing Committee on Safety Performance and Analysis (ACS20)

Session Number **Poster Session 3213**

Session Title Safety Performance and Analysis for Safe Road Users and Safe Speeds

Paper Number TRBAM-25-05655

Paper Title **Bicycle Crash Incidents in San Francisco Before, During and After COVID-19**

Abstract

This study investigates bicycle crash incidents in San Francisco, focusing on the impact of population density before, during, and after the COVID-19 pandemic. Utilizing Interrupted Time Series analysis and negative binomial regression models calibrated for each year, and for various crash severity levels, the study captures the evolution of crash patterns over time. The analysis reveals a significant reduction in bicycle crash rates coinciding with the COVID-19 pandemic, aligning with the reported reduction in bicycle counts. This initial reduction has persisted post-pandemic, suggesting a quasi-permanent effect. The study finds that this reduction predominantly occurs in high-density areas, with minimal change at locations with medium and low density. The study also finds that crash rates on weekends remain largely unchanged, with most of the reduction occurring on weekdays. Overall, the research underscores the importance of considering population density in urban safety planning to better understand the impact of large-scale disruptions like the COVID-19 pandemic.

Keywords: Bicycle, Crashes, Population Density, Safety, COVID-19.

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Sponsoring Committee	Standing Committee on Safety Performance and Analysis (ACS20)
Session Number	**Poster Session 3213**
Session Title	Safety Performance and Analysis for Safe Road Users and Safe Speeds
Paper Number	TRBAM-25-03741
Paper Title	**Factors Influencing the Severity of Personal Mobility Device Accidents: A Decision-Tree Method**
Introduction	Personal Mobility Devices (PMDs), including electric scooters (e-scooters), electric bicycles (e-bikes), and self-balancing scooters, have emerged as a new mode of transportation designed for individual use (1). These devices are expected to reduce greenhouse gas emissions and provide an alternative to public transportation, especially during infectious disease outbreaks, such as COVID-19 (2). PMDs are particularly attractive in urban environments for first-mile and last-mile transportation, offering users greater mobility and freedom (3). The global PMD market is projected to grow at an average annual rate of 7%, with an increase from $256 billion in 2020 to $421 billion by 2029 (4). PMD registrations are expected to rise from 33 million to 41 million during this period. In Korea, the number of registered shared e-scooters reached approximately 290,000 in 2023, reflecting a 20% year-on-year increase and a more than four-fold growth since 2020 (5). However, this rapid growth has been accompanied by a rise in safety incidents. Between 2017 and 2022, 5,807 PMD accidents were reported in Korea, representing a 20-fold increase in 2022 compared to 2017 (6). While the overall average annual rate of traffic accidents, including those involving vehicles and bicycles, decreased by 1.6%, PMD accidents surged by 96.2%. Notably, accidents involving only PMDs resulted in approximately 4.7 times more fatalities than those involving vehicles. These findings suggest that PMD accidents are more severe than those involving other modes of transportation, highlighting the urgent need for a deeper understanding of the factors contributing to these accidents in order to implement effective safety measures and regulations. This study stands out due to its use of non-linear modeling based on the decision-tree method and its extended analysis period, which utilizes approximately six years of accident data from 2017 to 2022. Our method considers a wider range of factors, providing a more holistic understanding of the contributors to PMD accidents. By employing advanced modeling techniques and a comprehensive dataset, this study aims to deepen the understanding of the factors influencing the severity of PMD accidents, ultimately informing better safety measures and regulations.

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Session Number	**Poster Session 3213**
Session Title	Safety Performance and Analysis for Safe Road Users and Safe Speeds
Paper Number	TRBAM-25-05534
Paper Title	**Exploring the Effect of Speed on Crash Frequency: A Negative Binomial Lindley Approach**
Introduction	Vehicular speed stands as one of the key determinants in shaping the risk and consequences of highway crashes. Even with cursory observation of recent crash statistics, the relationship between speed and crashes is evident. In the U.S, 29% of the total traffic fatalities in 2021 were speeding-elated, which was an increase of 8% from the previous year (1). However, the Highway Safety Manual (HSM) has not yet incorporated speed metrics into its crash prediction methodology. There remains a lack of agreement regarding the impact of speed on crashes. Pei et al. (2) showed that speed is positively related with crash risk when controlling for the effect of time exposure, but is negatively related with crash risk when controlling for distance exposure. Imprialou et al. (3) aggregated crashes according to the similarity of their pre-crash traffic and geometric conditions (condition-based aggregation) and compared with the link-based aggregation. The condition-based model suggested a positive relation of speed with crash frequency, while the link-based model showed speed had a negative relationship with crash regardless of crash severity. While some studies (4) claim that in rural areas, lower average speeds correlate with higher crash frequency. The effect of speed variability is debated: some suggest it's positively related to crashes, emphasizing that speed variation may be more critical than speed itself (5-7); others find no significant effect (2) or even an inverse relationship (8). Studies (9) even suggest that differences in percentile speeds on roadways are more informative compared to individual percentile speed values and are positively associated with crashes. However, other studies have also identified higher speed differentials as a reason for lower severity (10). Few studies (11, 12) have claimed that models which include speed related parameters in combination with volume and geometry provided superior predictions compared to the ones without speed parameters. However, some studies have also observed a varying effect of speed across different speed ranges from low-speed to high-speed roads (13) and implied a subgroup effect of speed on crashes. Crashes being non-negative count data, from a methodological perspective, have been traditionally modeled using statistical count models such as Negative Binomial (NB), Poisson, and zero-inflated models. This study utilizes the Negative Binomial-Lindley (NB-L) model (14) for crash prediction. NB-L offers the benefit of being able to handle crash datasets with large number of zeros, while still maintaining characteristics similar to the traditional NB. Studies have demonstrated that NB-L provided superior model fit compared to NB, Poisson, as well as zero-inflated models (15, 16). By adopting the NB-L modeling approach, this study seeks to provide further insight into the relationship between speed differentials and crash frequency across varying severities and route types. We leverage a range of newly formulated speed differential metrics that capture deviations between observed driving speeds, roadway design and regulatory parameters. We analyze speed differentials by comparing observed average speeds, Inferred Design Speed (IDS)—inferred from roadway curvature and grade—and statutory speed limits. Specifically, we assess speed differentials that reveal discrepancies between the speeds suggested by road design (IDS) and the actual speeds driven. Furthermore, our study also delves into the 'deficiency condition', exploring how situations where the IDS is below the speed limit correlate with crash occurrences. We also delve into congestion by measuring if average driving speeds being lower than the statutory speed limits (indicating congested conditions) have any influence on crashes. Moreover, we employ the coefficient of variation of speed which provides a more comprehensive indication of variation in speed compared to just standard deviation. Furthermore, this research aims to determine if inclusion of these speed differentials in the NB-L model enhances its predictive accuracy.

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Session Number	**Poster Session 3213**
Session Title	Safety Performance and Analysis for Safe Road Users and Safe Speeds
Paper Number	TRBAM-25-00524
Paper Title	**Assessing Pedestrian Safety: Risk Factors in Georgia's Pedestrian-Vehicle Crashes**
Introduction	According to the World Health Organization, road safety is a major global health concern, especially for vulnerable road users such as pedestrians and cyclists, as their fatalities account for more than half of all road crashes. In the United States, the total number of pedestrian fatalities was 7,522 in 2022, almost a 60 percent increase from 2013 (2). In 2021, Georgia ranked 4th in pedestrian fatalities after California, Florida, and Texas, with one in four pedestrians in crashes sustaining a serious or fatal 6 injury. This study aims to identify risk factors associated with pedestrian injury severity between 2013-2022, the most recent decade available through the state-level data. Identifying these factors aids in comprehending the characteristics of the crashes in Georgia and provides valuable guidance for preventing crash occurrences and formulating effective countermeasures specific to the state. Our research underscores the effects of pedestrians' and drivers' ages on injury severity and especially highlights the importance of countermeasures such as appropriate lighting and speed limits. We also emphasize a targeted focus on vulnerable regions characterized by low socio-economic status, disadvantaged populations, and rural areas.

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Session Number	**Poster Session 3213**
Session Title	Safety Performance and Analysis for Safe Road Users and Safe Speeds
Paper Number	TRBAM-25-00613
Paper Title	**Freeway Crash Risk Prediction using Deep Forest with SHAP and Detailed Risky Driving Behavior Data**
Abstract	Crash risk prediction is essential for proactive traffic safety management. Previous studies have rarely considered risky driving behavior factors in crash risk prediction, neglected vehicle-motion parameters during risky driving, and have not quantified and interpreted the impact of these factors on crash risk based on interpretable machine learning models. This study considered the frequency of risky driving behaviors as well as vehicle-motion parameters during risky driving and introduced a novel algorithm, Deep Forest, to develop a crash risk prediction model driven by detailed risky driving behavior data. The experiment suggests that the hyperparameter-tuned Deep Forest model significantly outperforms the other models in terms of sensitivity (75.0%) and specificity (81.6%). Then, the SHapley Additive explanation method was adopted to quantify the importance and interaction effects of the risky driving behavior features in the Deep Forest model. The results indicate that the features related to sharp acceleration and deceleration have a more significant impact on crash risk than those related to sharp merges into another lane. The average maximum acceleration and the average maximum speed of all vehicles with risky driving behaviors are more influential than the frequency of risky driving behavior. Besides, the adversarial validation approach is used to divide the training and testing datasets to enhance the generalization ability of the model. The research results provide a valuable reference for implementing active traffic safety risk assessment from the perspective of risky driving behaviors. Keywords: Crash risk prediction; Risky driving behavior; Deep Forest; Interpretability; SHAP

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Sponsoring Committee Standing Committee on Safety Performance and Analysis (ACS20)

Session Number **Poster Session 3213**

Session Title Safety Performance and Analysis for Safe Road Users and Safe Speeds

Paper Number TRBAM-25-01266

Paper Title **Evaluating the Safety Impact of Mid-block Pedestrian Signals (MPS)**

Abstract The Florida Department of Transportation (FDOT) has recently started implementing a new signal system at mid-blocks called Mid-block Pedestrian Signals (MPS). This study aims to evaluate the effectiveness of these newly implemented MPSs. A total of 260 hours of video data were collected from five locations across Florida, with 130 hours recorded before MPS installation and 130 hours after installation. State-of-the-art computer vision technology was employed to detect and track various road users. A random parameters multinomial logit model with heterogeneity in the means was implemented to assess safety of vehicle-pedestrian interaction by three conflict categories: No Conflict, Moderate Conflict, and Serious Conflict. Relative-Time-to-Collision (RTTC) values were utilized to classify these level of conflicts. The analysis demonstrates that the presence of MPS significantly enhances safety outcomes by increasing the likelihood of avoiding conflicts and reducing the probabilities of both moderate and serious conflicts. Key factors influencing conflict probabilities were identified, including pedestrian and vehicle counts, average leading vehicle speed, standard deviation of leading vehicle speeds, and land-use mix, all of which increase the probability of serious conflicts. Interestingly, the analysis identified three significant interaction variables with MPS: average leading vehicle speed, standard deviation of leading vehicle speeds, and land-use mix. While these factors individually had a higher probability of leading to serious conflicts, the presence of MPS effectively mitigates these risks by moderating their adverse effects, increasing the likelihood of no conflicts. These results underscore the importance of MPS as an effective measure to improve safety at mid-block crossings.

Keywords: Mid-block Pedestrian Signals, Mixed Logit Model, Conflict, Relative time to collision, Computer Vision Data Collection.

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Sponsoring Committee	Standing Committee on Safety Performance and Analysis (ACS20)
Session Number	**Poster Session 3213**
Session Title	Safety Performance and Analysis for Safe Road Users and Safe Speeds
Paper Number	TRBAM-25-01286
Paper Title	**Unveiling the Determinants of Injury Severities in E-Scooter Crashes: A Latent Class Binary Logit Analysis of Single and Multiple-Vehicle Crashes**
Abstract	Electric scooters (e-scooters) have emerged as a transformative mode of urban transportation, providing 2 sustainable and convenient solution for short to medium-distance travel. Their popularity is driven by their affordability, accessibility, and ability to navigate congested urban areas. Despite these benefits, the rapid proliferation of e-scooters has raised significant safety concerns. Reports from the UK reveal a growing number of crashes involving e-scooters, many resulting in severe injuries, especially among riders (1). These trends align with global observations of increasing micromobility-related injuries, particularly among young and male users (2). Research into e-scooter safety has identified various contributing factors to crash severity, including rider demographics, behavioral tendencies such as speeding or risk-taking, environmental conditions like lighting and weather, and infrastructure characteristics such as road type or roundabouts (3-5). Previous studies have largely focused on either single-vehicle crashes, where e-scooters collide with stationary objects or lose control, or multiple-vehicle crashes involving interactions with other road users. This segmentation often overlooks the comparative dynamics and injury mechanisms across these two contexts, limiting the development of targeted safety measures. This study addresses these gaps by examining the determinants of injury severity in e-scooter crashes using crash data from the STATS19 database of the United Kingdom, covering incidents from 2021 to mid-2022. The study applies latent class binary logit models to identify unobserved subgroups within the crash data, allowing for a nuanced analysis of injury determinants accounting at the same time for unobserved heterogeneity. By distinguishing between single-vehicle and multiple-vehicle crashes, this study provides insights into the factors that exacerbate or mitigate injury severity in these contexts. Findings highlight the roles of socio-demographics, environmental conditions, and crash dynamics, offering actionable recommendations for policymakers and urban planners. This research contributes to a deeper theoretical understanding of micromobility safety and practical efforts to enhance operation and safety of urban transportation systems.

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Sponsoring Committee Standing Committee on Safety Performance and Analysis (ACS20)
Session Number **Poster Session 3213**
Session Title Safety Performance and Analysis for Safe Road Users and Safe Speeds
Paper Number TRBAM-25-02110
Paper Title **Assessing the Safety Nature of Pedestrian-Vehicle Interaction at Non-signalized Crosswalks**

Abstract Uncontrolled crosswalks frequently contribute to pedestrian crashes. Despite extensive studies on pedestrian crossing safety, the dynamic state of pedestrian-vehicle interactions (PVI) and its impact on collisions have received little attention. This study investigates how the dynamic behavior of PVI influences pedestrian crossing safety from a novel perspective. A methodology is put forth that leverages computer vision and clustering techniques to gain insight into pedestrian-vehicle interactions. This is accomplished by extracting trajectory data from unmanned aerial vehicle (UAV) videos and calculating the representation of PVI. The resultant pattern of interactions is then clustered. Additional, two novel interaction indicators are devised to evaluate the dynamic of the interaction state. A risk prediction test assesses the efficiency of the proposed indicators. Further analysis examines pedestrian crossing safety and decision-making from the perspective of interaction dynamics, considering differences among interaction clusters. While collision exposure might increase crash probability, it can also improve risk perception. Frequent changes in passing priority increase the possibility of serious conflicts. The risk prediction model incorporating the proposed dynamic interaction indicators outperforms other models. Our findings reveal that complex interaction experiences encourage vehicles to yield and influence potential conflict risks.
Keywords: Traffic safety; pedestrian-vehicle interaction; interaction dynamic; conflict severity; behavior analysis

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Sponsoring Committee Standing Committee on Safety Performance and Analysis (ACS20)
Session Number **Poster Session 3213**
Session Title Safety Performance and Analysis for Safe Road Users and Safe Speeds
Paper Number TRBAM-25-02123
Paper Title **Investigating the Association Between Bike Sharing Docks and Cyclist Crash Frequency in Greater London**

Abstract Bike sharing schemes are becoming an increasingly popular travel choice for road users because of their convenience. They are also a desirable choice for policy makers to encourage because they can help to reduce pollutants and congestion as well as improve human health. Due to the relative novelty of bike share schemes, less is known about the safety implications of their use as compared to other travel modes. The present research is a macro-level investigation into the factors associated with cyclist crash frequency, including the presence of bike share docking stations. To analyse this effectively, the confounding factors which are associated with both the propensity of a given area to feature a docking station and the expected crash frequency within that area need to be accounted for. This is achieved by adding an endogenous treatment element to a multilevel count model. The analysis found that the presence of a bike share dock initially appears to be associated with an increase in bicycle crash frequency, but once endogeneity is accounted for the presence of a bike sharing dock may have no significant association with cyclist safety. This finding indicates that the expansion of existing schemes as well as the addition of new ones need not necessarily be seen as detrimental to safety for cyclists as long as adequate mitigating measures are in place.
Key words: bike share; cycle hire; endogeneity; crash frequency; macro-level

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Sponsoring Committee	Standing Committee on Safety Performance and Analysis (ACS20)
Session Number	**Poster Session 3213**
Session Title	Safety Performance and Analysis for Safe Road Users and Safe Speeds
Paper Number	TRBAM-25-03697
Paper Title	**Developing Road-HFACS: A Novel Approach Quantifying Human Factors Analysis and Classification System with Bayesian Network for Road Traffic Incidents**
Introduction	The Global Status Report on Road Safety 2023 reveals 1.19 million annual road traffic deaths worldwide, with China reporting 62,763 fatalities in 2019 (1). Over 90% of road incidents involve human factors, but attributing them solely to human error oversimplifies the issue (2). Research shows a causal link between safety management and incident risks, underscoring the need for deeper incident analysis to uncover underlying causes and improve road safety (3). Despite advances in global traffic investigation technology, police investigations often prioritize blame over causation, neglecting systemic issues like company safety management, training, and regulatory enforcement. This limits opportunities to enhance safety culture and accountability (6). The Human Factors Analysis and Classification System (HFACS), based on Reason's "Swiss Cheese" model, offers a framework for understanding human factors by categorizing issues into four levels: Organizational Influences, Unsafe Supervision, Preconditions for Unsafe Acts, and Unsafe Acts (5). Combining HFACS with quantitative methods can enhance its depth analysis and application. For example, Feng et al. integrated HFACS with grey correlation analysis to identify key factors in coal mining casualties (7). However, similar application of quantitative techniques to HFACS in road traffic has been lacking (8). Bayesian network (BN) provides a framework for reasoning under uncertainty and is widely used to represent uncertain knowledge (9). Compared to other quantitative incident analysis methods, such as the analytic hierarchy process, event tree analysis, and fuzzy comprehensive evaluation, BN offers the significant advantage of probabilistic reasoning (10). Detailed countermeasures and recommendations to reduce road incident risks often fall short in depth and sufficiency. To addressing these limitations, the application of HFACS-BN models to road traffic incidents will be expanded and insightful countermeasures based on robust data analysis will be developed. In conclusion, the HFACS provides a valuable framework for understanding human factors in incidents. However, it has not yet been applied to road transport. Adapting HFACS to the context of road traffic incidents and integrating it with quantitative methods can significantly improve the analysis and prevention of these incidents. This study aims to develop a reliable and valid Human Factors Analysis and Classification System (HFACS) and Bayesian Network methodology to understand the causal factors of road traffic incidents.

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Sponsoring Committee Standing Committee on Safety Performance and Analysis (ACS20)

Session Number **Poster Session 3213**

Session Title Safety Performance and Analysis for Safe Road Users and Safe Speeds

Paper Number TRBAM-25-03750

Paper Title **Bayesian Networks in Identifying Patterns between Pedestrian and Driver Behavioral Interactions**

Abstract Walking, a mode of active and eco-friendly transportation, offers numerous health and environmental benefits. However, the rising incidence of pedestrian crashes has raised significant public health concerns. This study addresses the urgent need to examine the direct and indirect impacts of various contributing factors on pedestrian injury severity in pedestrian-motor vehicle crashes. Analyzing data from pedestrian-vehicle crashes in Louisiana from 2017 to 2021, this study investigates the association between contributing factors, pedestrian actions, driver and pedestrian characteristics, and injury severity. Employing Bayesian network (BN) analysis, a robust probabilistic graphical modeling technique, this study identified relationships among these variables. A unique aspect of this study is its comprehensive examination of both driver and pedestrian behavior, focusing on how their interactions critically influence pedestrian injury severity in crashes. The results reveal that crossing behaviors were a significant factor in injury crashes, with most crashes occurring away from intersections. Counterfactual analyses highlight the importance of driver attentiveness, crash location, pedestrian actions, and lighting conditions in influencing crash outcomes, offering insights for targeted interventions. Considering the critical importance of pedestrian safety and the global emphasis on sustainable transportation, the results hold significant implications for public health, urban planning, and transportation policy.
Keywords: pedestrian crash, traffic crashes, crash severity, Bayesian network.

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Sponsoring Committee Standing Committee on Safety Performance and Analysis (ACS20)

Session Number **Poster Session 3213**

Session Title Safety Performance and Analysis for Safe Road Users and Safe Speeds

Paper Number TRBAM-25-03910

Paper Title **Developing a Short-Term and Rapid Road Traffic Safety Assessment Indicator: Copula-Based Joint Modeling of Crash and Risky Driving Behavior Count**

Abstract Crash data is crucial for evaluating road safety, but its randomness limits the ability to conduct prompt road safety assessments. Additionally, property damage-only crashes may go unreported, leading to biased estimates. Alternative safety measures are used in road safety analysis since they can capture more frequent "near-miss" situations. However, concerns about their predictive accuracy persist. This study aims to jointly model crash and risky driving behavior count to develop a short-term, rapid road safety assessment indicator. Panel data, including crash and risky driving behaviors (such as sharp acceleration, deceleration, and turning) recorded at 1-hour intervals across 22 segments of the Yongtaiwen freeway, is utilized. Zero-inflated negative binomial (ZINB) models and negative binomial (NB) models are employed for the marginal regression modeling of crash and risky driving behavior frequency. A copula-based approach jointly models the marginal distributions, describing the nonlinear dependency structure between the variables. Comparing Gaussian and five one-parameter Archimedean copulas reveals that the Gumbel copula is the best fit. Finally, the joint cumulative distribution function (joint CDF) values of crash and risky driving behavior count were derived under the Gaussian copula joint distribution. The modified total rank differences test (TRDT) indicates that the ranks based on joint CDF values are more consistent with those based on risky driving behavior count than with those based on crash count alone. This demonstrates that the joint CDF values provide a more accurate and stable identification of high-risk freeway segments, showcasing the effectiveness of copula-based data fusion for road safety assessment.
Keywords: Traffic safety, Crash count, Risky driving behavior, Gaussian copula, Archimedean copula, 20 Multivariate modeling

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Sponsoring Committee	Standing Committee on Safety Performance and Analysis (ACS20)
Session Number	**Poster Session 3213**
Session Title	Safety Performance and Analysis for Safe Road Users and Safe Speeds
Paper Number	TRBAM-25-05286
Paper Title	**Comprehensive Safety Impacts Analyses of the Augmented Reality Warning and Navigation System**
Introduction	Due to the serious consequences of road crashes on property and human life, road safety has been widely studied by relevant researchers for decades. To improve driving behavior and safety, certain navigation companies like Amap and Sogou have developed Augmented Reality Warning and Navigation System (ARWNS) and put it into real-world use. The fundamental function of ARWNS is to offer drivers audiovisual interactive driving assistance by analyzing the surrounding external environment in real time. Though previous experiment suggests that AR navigation will reduce driver’s load and improve driving behavior, real-world evidence that characterizes the safety impacts of ARWNS is still limited. Most of the studies conducted driving simulator experiments and identified optimal AR navigation designs in terms of specific aspects such as display mode (audio, visual, audio-visual, etc.), stereoscopic display, interface symbols, and so on. Driving simulator experiments were also conducted to compare AR navigation and conventional navigation and explore whether it would distract drivers' attention or increase the driving load. The research results show that AR navigation systems can benefit driving performance, reduce uncertainty and hesitation in unfamiliar areas. Furthermore, some studies have investigated the effects of AR navigation integrated with pedestrian conflict warnings on driver behavior and performance. Based on the above literature review, previous research primarily focuses on either ADAS or AR navigation. While the ARWNS, as a deployed alternative ADAS, has received limited attention in the literature. There is a notable research gap regarding the safety impacts of ARWNS under the new "navigation+warning" assistance form. However, the safety effects of ARWNS have not been thoroughly investigated, particularly in diverse scenarios of real road environments.

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Session Number	**Poster Session 3213**
Session Title	Safety Performance and Analysis for Safe Road Users and Safe Speeds
Paper Number	TRBAM-25-05322
Paper Title	**<u>Unveiling the Speeding Behavior: Assessing the Speeding Risks and Driver Injury Severities in Single-Heavy Truck Crashes</u>**
Introduction	Large trucks play a key role in the national economy, facilitating the transport of goods and materials across vast distances (long-haul), ensuring supply chain efficiency, and supporting various industries. However, despite their economic role, these vehicles pose serious safety risks, particularly due to their size, weight, and potential for high-speed impacts. Although large trucks comprise less than 5% of registered vehicles in the United States, large trucks are involved in over 10% of all fatal crashes annually (1). Speeding, especially "driving too fast for conditions," is a prominent factor in these incidents, which tend to be more severe due to the trucks' significant kinetic energy. In Pennsylvania, the severity of large truck-involved crashes is especially concerning, with a notable rise in fatalities per truck-mile traveled from 2018 to 2022 (2). Equally alarming is the rise in the percentage of large truck-involved fatalities among speeding-related fatalities in Pennsylvania, which surged to 40% in 2022. Figure 1 illustrates a concerning trend: large truck-involved fatality rates (in terms of truck miles traveled) in Pennsylvania have risen significantly since 2018. In Pennsylvania, 20% of the fatalities involving large trucks over the last decade (2013-2022) were single-vehicle (SV) crashes, which is higher than the national average of 19% (3). Figure 1 Large Truck-involved Fatalities in Speeding-related Fatalities in Pennsylvania: 2013-2022 Source: FARS – Large Trucks, Speeding; Transportation Planning Division – Truck Miles Travelled, PennDOT Previous studies have conducted crash severity analyses using 'speeding driving' as an explanatory variable (4–6). Other studies have focused on identifying specific factors that induce speeding-related behaviors among drivers. This study addresses a gap in current research by comparing speeding and non-speeding crashes as a reference among Pennsylvania's heavy trucks. Utilizing six years of crash data (2018–2023), the research examines factors associated with increased crash severity when trucks are speeding. The methodology incorporates unobserved factors within the dataset, aiming to provide a more accurate analysis. Through this approach, the study seeks to inform targeted interventions to improve road safety in Pennsylvania by addressing the unique risks associated with large truck speeding.

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Session Number	**Poster Session 3213**
Session Title	Safety Performance and Analysis for Safe Road Users and Safe Speeds
Paper Number	TRBAM-25-05417
Paper Title	**<u>Spatial Statistical Analysis of Bicycle Crashes in Ohio</u>**
Abstract	Rising pedestrian and bicycle crashes in the United States have created an unsafe environment for non-motorized users. Numerous reasons, such as high vehicular traffic, underfunding, insufficient bicycle infrastructure, pollution, and zoning laws, have resulted in low bicycle users in the US compared to their European counterparts. In the last decade, many studies have been done to understand these crashes and find the proper solutions to overcome them. Our study used four spatial statistical methods to analyze bicycle crashes that resulted in injuries and fatalities across Ohio at three spatial scales: county, census tract, and block group levels. Results from our analysis indicated that major cities, such as Toledo, Cleveland, Akron, Columbus, and Cincinnati, are highly prone to bicycle crashes and, therefore, require immediate mitigation measures. The study suggested countermeasures that can be implemented to reduce the chances of such crashes. [Keywords: bicycle, crashes, spatial analysis, GIS, cluster analysis]

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Sponsoring Committee Standing Committee on Safety Performance and Analysis (ACS20)

Session Number **Poster Session 3213**

Session Title Safety Performance and Analysis for Safe Road Users and Safe Speeds

Paper Number TRBAM-25-06072

Paper Title **Accounting for Gender and Age Differences in the Duration between a Previous Non-fatal Crash and a Fatal Crash**

Abstract Identifying factors that significantly affect drivers that are repeatedly involved in traffic violations or non-fatal crashes (defined here as recidivist drivers) is very important in highway safety studies. This study sought to understand the relationship between a set of variables related to previous driving violations and the duration between a previous non-fatal crash and a subsequent fatal crash, taking into account the age and gender of the driver. By identifying the characteristics of this unique driver population and the factors that influence the duration between their crash events strategies can be put in place to prevent the occurrence of future and potentially fatal crashes. To do this, a five-year (2015-2019) historical fatal crash data from the United States was used for this study. Out of 15,956 fatal crashes involving recidivist drivers obtained, preliminary analysis revealed an overrepresentation of males (about 75%). It was also found that the average duration between the two crash events was about a year and a half, with only an average of one month difference between male and female drivers. Using hazard-based duration models, factors such as number of previous crashes, previous traffic violations, primary contributing factors and some driver demographic characteristics were found to significantly be associated with the duration between the two crash events. The duration between the two events increased with driver's age for drivers who were involved in only one previous crash and the duration was shorter for those that were previously involved in multiple crashes. Previous DUI violations, license suspensions, and previous speeding violations were found to be associated with shorter durations, at varying degrees depending on the driver's age and gender. The duration was also observed to be longer if the fatal crash involved alcohol or drug use among younger drivers but shorter among middle-aged male drivers. These findings reveal interesting dynamics that may be linked to recidivist tendencies among some drivers involved in fatal crashes. The factors identified from this study could help identify crash countermeasures and programs that will help to reform such driver behaviors.

Keywords: Recidivist Drivers, Hazard Duration, DUI, Repeated Offenders, Speeding Violations

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Session Number	**Poster Session 3213**
Session Title	Safety Performance and Analysis for Safe Road Users and Safe Speeds
Paper Number	TRBAM-25-05799
Paper Title	**Investigating the Impact of Speed Variation on Intersection Crashes Using Pervasive Traffic Data**
Abstract	Speed and speed variation significantly influence the risk of road traffic crashes (RTCs). However, there is a notable lack of research on this topic within the context of developing nations. This gap is primarily due to the unavailability of comprehensive traffic and crash data. Traditional methods of traffic data collection are not feasible due to the high costs associated with installation and maintenance. Consequently, this study aims to explore the potential of using pervasive speed data to predict crashes. To investigate this association, the study utilised three years of fatal crash data from Delhi, India, along with pervasive speed data for 1863 intersections. A zero-inflated negative binomial model was developed to examine the relationship between hourly variations in speed and the frequency of fatal crashes. The findings revealed that a one-unit increase in the standard deviation of speed corresponds to a 9.6% increase in the frequency of fatal crashes. Conversely, with a one-unit increase in the standard deviation of speed, the odds of an intersection initially having no crashes (structural zero) decrease by approximately 4%. This increased frequency in both cases can be attributed to more frequent lane changes and aggressive driving behaviour resulting from increased speed variation. Keywords: Speed variation, Road traffic crashes, Pervasive speed data, Intersection safety, Zero Inflated 16 Model

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Session Number	**Poster Session 3213**
Session Title	Safety Performance and Analysis for Safe Road Users and Safe Speeds
Paper Number	TRBAM-25-03811
Paper Title	**An Analysis of the Safety Impact of Changing Speed Limit From 55 MPH to 60 MPH on Two-Lane, Two-Way Road Segments In Minnesota**
Abstract	The objective of this study was to evaluate the safety impacts of increasing the speed limit from 55 mph to 60 mph on rural two-lane, two-way state highway road segments in Minnesota. An empirical Bayes (EB) before-after analysis was used to estimate crash modification factors (CMFs) for both segments and intersections. The segment analysis showed an 8 percent reduction in total crashes that was statistically significant, alongside a significant 15 percent increase in KAB injury crashes. The aggregate CMFs for all intersections show on average between 10% to 20% statistically significant reduction in total and injury crashes. The investigation of speed data showed some evidence of a larger increase in KAB crashes in segments with a larger increase in mean speed after the speed limits were increased. The aggregate estimated crash safety effects (for total and injury crashes) for combined segments and intersection sites show a reduction in total crashes but an increase in the KAB injury crashes. Keywords: Empirical Bayes, speed limit, Minnesota, Crash modification factor, Injury, mean speed, two-14 lane.

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Sponsoring Committee	Standing Committee on Safety Performance and Analysis (ACS20)
Session Number	**Poster Session 3213**
Session Title	Safety Performance and Analysis for Safe Road Users and Safe Speeds
Paper Number	TRBAM-25-04444
Paper Title	**Assessing Disparities in Driver Exposure and Fatal Crash Risks in Nighttime Driving**
Introduction	Driving at night is particularly hazardous. The nighttime fatality rate on the nation's roadways is three times higher than the daytime rate, and 76% of vehicle-pedestrian fatalities occur at night (1). This increased risk at night is attributed to factors such as reduced visibility, higher speeds due to light traffic, and a greater likelihood of impaired and drowsy driving (2, 3). A substantial body of research has investigated disparities in traffic fatalities and injury across various demographic variables, including age, gender, socioeconomic status, and ethnicity (4–8). However, many past studies lack a detailed examination of nighttime driving exposure and associated crash risks across various demographic characteristics, such as gender, socioeconomic status, and ethnicity. This study aims to address these gaps by using the 2021-2023 American Driving Survey (ADS) to analyze nighttime driving exposure and trip purpose among American drivers in the post-COVID-19 era. The study also aims to add to the limited literature addressing disparities in crash risk at nighttime by exploring fatality risks associated with nighttime driving experienced by different population groups.

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Sponsoring Committee	Standing Committee on Safety Performance and Analysis (ACS20)
Session Number	**Poster Session 3213**
Session Title	Safety Performance and Analysis for Safe Road Users and Safe Speeds
Paper Number	TRBAM-25-01522
Paper Title	**How Driver Socioeconomic Profiles Relate to Speeding and Hard Braking Events on Roads: A Perspective Based on Departure Locations Reflected by Vehicle Trajectory Data**
Introduction	Human factors contribute to a great percentage of traffic crashes and injuries. In 2021, there were 12,330 fatalities in speeding-related crashes, which is about one-third of total traffic fatalities in the U.S. (1). Previous studies indicate a trend where younger drivers are more prone to speeding violations than older drivers (2, 3), higher-income populations have an increased frequency of speeding violations (3). Besides, individuals with higher education levels are more susceptible to speeding infractions than those with lower educational attainment (3). As these studies used data such as survey questionnaires (4–6) or interviews (7, 8), sample experiments (9, 10), and analysis of speeding tickets (2, 11), very few established findings are based on naturalistic vehicle movements. The advent of vehicle telemetry allows for the applications of high-resolution vehicle trajectories, marking a significant leap forward in this context and enabling the acquisition of naturalistic driving data from vehicles in motion. The study collected high-resolution trajectory data in Clark County, Nevada, where hard-braking and speeding were extracted and compared among various socioeconomic groups. This research introduces a novel approach to applying newly emerging data to understand driving behavioral characteristics across socioeconomic profiles, aiding agencies in developing targeted policies and strategies to facilitate transportation equity and safety.

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Sponsoring Committee	Standing Committee on Safety Performance and Analysis (ACS20)
Session Number	**Lecter Session 4004**
Session Title	The Future of Safety Performance and Analysis
Paper Number	TRBAM-25-03330
Paper Title	**Enhancing Intersection Safety through Kinetic Energy Management and Categorical Crash Data Analysis**
Abstract	This paper evaluates the Federal Highway Administration's (FHWA) current recommended methodology for assessing intersection safety through kinetic energy management. It was found that the existing Safe Systems Intersection (SSI) model, which predicts crash severity based on theoretical changes in velocity, is built on solid fundamental principles and correlates well with crash severity. However, it lacks accuracy when applied to real-world intersection-specific crash data. Analyzing over 700,000 recorded crashes from the Georgia Department of Transportation’s (GDOT) AASHTOWare safety database revealed significant discrepancies between the SSI model's predictions and actual crash severities. Specifically, the SSI model often overestimates the likelihood of fatal and severe injuries; this is likely due to its assumptions about crash characteristics and the generalized data set used to fit the model. To overcome this issue, a methodology was proposed using categorical crash analysis and refined assumptions on crash characteristics to achieve better accuracy. This tailored approach and metric was coined the kinetic velocity index (KVI). Grounded in kinetic energy principles and tailored to categorical crash data specific to intersections, the KVI model incorporates comprehensive crash data specific to intersections. Results demonstrate that the KVI model not only fits empirical data better but also simplifies the calculation process, enhancing its practical application for transportation professionals. The KVI model's superior accuracy and usability make it a valuable tool for improving road safety measures and infrastructure planning, ultimately contributing to the reduction of traffic-related fatalities and serious injuries.

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Sponsoring Committee	Standing Committee on Safety Performance and Analysis (ACS20)
Session Number	**Lecter Session 4004**
Session Title	The Future of Safety Performance and Analysis
Paper Number	TRBAM-25-04099
Paper Title	**Better Safety Analyses through Smarter Data: Adding Open-Street-View and Traffic Calibrated-LBS Data to Pedestrian Crash Analysis in Lincoln, NE**
Abstract	Pedestrian crashes are a significant concern in the United States, with pedestrian fatalities increasing and outpacing those of vehicle occupants. This research investigates the potential of new data sources to enhance pedestrian safety analysis and crash modeling. Specifically, it examines the use of StreetLight-calibrated traffic volumes and Mapillary detections of street objects for modeling pedestrian crash counts and severity. By integrating these innovative data sources, the study aims to improve the accuracy and granularity of safety evaluations. Both generalized linear models and machine learning (ML) models, including random forests (RF) and gradient boosting machines (GBM), demonstrated acceptable performance and solid portrayal of crash dynamics, with ML models providing better predictive power at the cost of complexity and lower interpretability. Additionally, the weighted random forest classifier showed high accuracy in predicting crash severity. Key variables in our analysis encompassed StreetLight volumes and various Mapillary open street-view (OSV) detections, including traffic signals, crosswalks, advertisement signs, store signs, streetlights, and arrow markings. The association between these variables and crash counts and severity aligns with our understanding of crash patterns. Overall, the research underscores the importance of leveraging detailed, real-world data to improve pedestrian safety analyses and contribute to more effective safety strategies and policy decisions. Keywords: Pedestrian Safety, Smart Data, Crash Modeling

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Sponsoring Committee	Standing Committee on Safety Performance and Analysis (ACS20)
Session Number	**Poster Session 4073**
Session Title	Safety Performance and Analysis for Safe Vehicles
Paper Number	TRBAM-25-00827
Paper Title	**Spatio-Temporal Accident Detection through Traffic Impact Analysis Using Connected Vehicle Data**
Introduction	Traffic accidents represent a significant threat to public safety and a major disruption to the efficient flow of vehicles on road networks, posing a critical challenge for both emergency responders and traffic management authorities. According to theWorld Health Organization, road traffic accidents result in over 1.3 million deaths annually, with many more sustaining serious injuries, highlighting the urgent need for effective accident detection and response systems WHO (1). In addition to the human cost, accidents cause congestion, reduce mobility, and lead to significant economic losses. Efficient accident detection and prompt response can mitigate these negative impacts, but current systems face limitations in terms of accuracy and timeliness. While various methods have been developed for accident detection, many rely on static sensor infrastructure (e.g., roadside cameras Tian et al. (2) or loop detectors Liyanage et al. (3)) or postevent reporting by individuals. These approaches often suffer from delayed detection and limited spatial coverage. Moreover, they struggle with accurately detecting accidents in real-time, particularly in cases involving rapid traffic flow changes. There remains a research gap in developing real-time, high-precision detection methods that leverage dynamic data from connected vehicles. The use of real-time vehicle data to differentiate between congestion caused by accidents and that caused by other factors, as well as to track the formation and resolution of these patterns, has not been thoroughly explored in current research. This study aims to address these limitations by evaluating an advanced accident detection method that leverages real-time data from vehicles continuously transmitting their GPS positions to a central server. This data is analyzed using Kerner's three-phase traffic theory (3PTT) Kerner (4), which models the complex behavior of traffic flow transitions. By integrating this theory with an innovative rule-based algorithm, our approach identifies accident-prone locations and times with high precision. The algorithm assesses traffic patterns based on data from a connected vehicle fleet, analyzing the formation and dissipation of congestion. The research uses a robust global dataset consisting of 2,500,000 vehicle probes from various regions, with different levels of vehicle fleet penetration. Ground truth data is incorporated from traffic services that aggregate information from police reports, public authorities, and individual users. This diverse and comprehensive dataset allows for a thorough evaluation of the proposed method, particularly its ability to detect both the onset of traffic jams due to accidents and their resolution. Studies using similar datasets can be found in Kessler and Bogenberger (5), Paczia et al. (6) and Rempe et al. (7).

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Session Number	**Poster Session 4073**
Session Title	Safety Performance and Analysis for Safe Vehicles
Paper Number	TRBAM-25-02168
Paper Title	**Influences of Individual Heterogeneity on Vehicle Damage in Two-Vehicle Lane-Changing Related Crashes: A Semi-Parameter Copula-Based Model Considering Temporal Instability**
Abstract	Lane-changing behavior is a significant contributing factor to traffic crashes and exhibits individual heterogeneity in vehicle damage severity. To address this, we developed a semi-parametric copula-based joint logit model, flexibly constructing the dependence between lane-keeping and lane-changing vehicles in vehicle damage through diverse copula structures. This approach aims to investigate the factors influencing differences in damage severity resulting from lane-changing behavior. Our model also accounts for temporal instability among years and non-linear fluctuations in driver age and crash time. he lane-changing crash data analyzed in this study was collected from the Orlando region between 2016 and 2019. Vehicle, road, event, environmental, and driver characteristics were comprehensively considered to examine their effects. Findings emphasize the importance of constructing crash severity dependencies based on driving behavior and demonstrate the efficacy of semi-parametric estimation. Furthermore, our findings reveal the heterogeneous differences in vehicle damage caused by lane-changing behavior. Keywords: Traffic safety; copula-based approach; vehicle damage; lane-changing behavior; 44 Individual heterogeneity

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Session Number	**Poster Session 4073**
Session Title	Safety Performance and Analysis for Safe Vehicles
Paper Number	TRBAM-25-03841
Paper Title	**Improving Representative Accuracy of Connected Vehicles' Hard-Braking Events for Crashes Through Maximizing their Spatio-temporal Correlation**
Abstract	Historically, the traffic safety solutions are based on crash records and thus traffic safety improving solutions may not available until crashes have occurred. The emerging connected vehicle (CV) data including hard brakes of moving vehicles which is a preventive surrogate of crashes. It is reasonable to assume that, if a location becomes prone to crashes, then the passing vehicles must have frequent hard brakes before a real crash occur. The hard-braking events in the CV data set was examined to correlate with crashes. While such correlations were reportedly high in previous studies, a fundamental question still needs answers: What's the optimal spatio-temporal coverage of hard brakes to best represent the crash potential? Different spatio-temporal coverage of hard-braking events (including the distance from the crash site and time before and after the crash) will result in different characteristics of hard-braking events and the representative accuracy of hard-braking events for crashes can be adversely affected. We developed a multi-objective analysis framework to optimize the spatio-temporal coverage of hard brakes to best represent the crashes. The presented approach involves a data reduction algorithm. A set of measures of effectiveness (MOE) are established by correlating hard brakes with crashes. Then through the multi-objective optimization, we identify the optimal time and space thresholds for maximizing crash-brake correlation factors. In the case study for the Dallas-Fort-Worth area, it was found that a 1.25-hour time interval (before and after the crash) and a 300-foot distance threshold can effectively correlate a crash with the corresponding hard-braking events. Keyword: Connected Vehicle Data, Spatio-temporal Analysis, Multi-Objective Optimization, Crash-Brake Correlation Factor (CBCF), Traffic safety

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Session Number	**Poster Session 4073**
Session Title	Safety Performance and Analysis for Safe Vehicles
Paper Number	TRBAM-25-05004
Paper Title	**Examining the Role of Vehicle Dimensions and Advanced Driving Assistance Systems on Pedestrian and Bicyclist Injury Severity Outcomes**
Abstract	In the event of a crash between active traveler and motor vehicle, vehicle characteristics (both internal and external vehicle features) are likely to play a significant role. With regards to external and internal vehicle features, it might be beneficial to examine the interplay of vehicle dimensions and Advanced Driving Assistant System (ADAS) on active traveler injury severity outcomes. Towards that end, the major contribution of this study is grounded in examining the effect of vehicle type (represented by vehicle length and width) on active traveler injury severity outcomes while also controlling for ADAS and other exterior features of motor vehicles. Specifically, we propose a joint modeling framework to examine vehicle types and injury severity outcomes as two dimensions of the active traveler injury severity mechanisms. In the joint modeling process of this study, the vehicle type component is estimated by using random regret minimization based multinomial logit model, while the injury severity component is estimated by using generalized 1rdered logit formulation. Further, the time-varying effects of exogenous variables are accommodated by using piecewise linear function of crash year. The proposed model is demonstrated by using active traveler crash data from Queensland, Australia for the years 2015 through 2022. The outcomes of the study will inform future vehicle design in improving active traveler safety. Keywords: Pedestrian; Bicyclist; ADAS; Regret minimization; Joint model

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Sponsoring Committee	Standing Committee on Safety Performance and Analysis (ACS20)
Session Number	**Poster Session 4073**
Session Title	Safety Performance and Analysis for Safe Vehicles
Paper Number	TRBAM-25-06076
Paper Title	**Identifying High-Risk Locations on Expressways Using Connected Vehicle Data: An Empirical Analysis**
Introduction	Road traffic collisions, causing approximately 1.19 million fatalities annually, are a global public health crisis (1). Traditional safety analysis rely on historical collision data, which suffer from limited sample sizes, underreporting, and delayed identification of high-risk locations (2). To address these limitations, connected vehicle (CV) technology provides real-time data on vehicle dynamics and driving behaviors, offering new opportunities for proactive road safety management (3, 4). High-risk location identification methods are categorized into statistical, model-based, and GIS-based approaches. Statistical methods, such as crash frequency and rate techniques, are intuitive and widely applicable but fail to address the discrete and dynamic nature of traffic systems (5). Model-based approaches, including Poisson and negative binomial models, use safety performance functions (SPFs) to predict collision frequency, though they often require Bayesian adjustments to mitigate regression-to-the-1mean bias (6, 7). GIS-based methods, such as kernel density estimation, Moran's I and and Getis-Ord Gi*, are effective in visualizing spatial clustering and identifying hotspots (8, 9); however, they may fail to capture the dynamic nature of real-time driver behavior and the temporal variations in risk exposure. This study integrates connected vehicle (CV) warning data with spatial autocorrelation analysis to identify high-risk locations, and employs statistical regression models to examine the relationship between the frequency of warnings and the number of collisions. By incorporating hotspot co-occurrence analysis with Welch's t-test, the findings validate the effectiveness of CV data in enhancing potential risk identification.

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Session Number	**Poster Session 4073**
Session Title	Safety Performance and Analysis for Safe Vehicles
Paper Number	TRBAM-25-06120
Paper Title	**Evaluating Traffic Safety Information Strategies for Identified Hazardous Infrastructures Using Autonomous Vehicle Demonstration Data**
Introduction	Autonomous vehicles (AVs) are steadily advancing toward commercialization, with Level 4 technologies currently in the demonstration phase. These vehicles promise to improve traffic safety and operational efficiency by minimizing human factors, such as delayed response times and erratic driving behaviors. However, mixed traffic environments, where AVs coexist with manually-driven vehicles (MVs), are expected to persist in the near future due to limited AV market penetration (1-2). Such mixed traffic poses challenges stemming from heterogeneous driving behaviors, making preemptive safety evaluations crucial. Existing studies on AV safety have predominantly relied on simulation-based analyses to examine traffic safety and operational efficiency under varying AV penetration rates (3-4). While effective, simulation analyses often lack the complexity and variability of real-world traffic environments. Complementary research using actual AV accident reports and trajectory data has employed techniques such as text mining, decision trees, and machine learning models to assess accident causes and severity (5-6). This study aims to bridge the gap between simulation-based and real-world analyses by integrating AV trajectory data with accident reports to identify and define vulnerable sections in mixed traffic environments. Using data from Sejong City AV demonstrations and California DMV accident reports, the study employs advanced methodologies, including statistical analysis, association rule analysis, and topic modeling, to pinpoint accident-prone scenarios and sections (7-8). Furthermore, this study evaluates the effectiveness of various safety management strategies—such as Variable Message Signs (VMS), Road Signs, and Logo Projectors—through simulations and linear mixed model analyses. These approaches collectively provide actionable insights for improving traffic safety in mixed environments.

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Session Number	**Poster Session 4073**
Session Title	Safety Performance and Analysis for Safe Vehicles
Paper Number	TRBAM-25-01258
Paper Title	**Exploring Factors Influencing Crash Occurrence Involving Autonomous Vehicle: Random Parameters Model with Heterogeneity in Means and Variances Approach**
Abstract	Autonomous vehicle (AV) technologies are expected to play a crucial role in reducing traffic crashes occurred by human factors; however, foreseeable coexistence of AVs with human-driven vehicles (HDVs) for an extended transition period raises safety concerns. Understanding factors influencing AV-involved crashes is crucial, especially as human drivers may struggle to comprehend the behavior of AVs during interactions. This study addresses this gap by employing a random parameter probit model with heterogeneity in means and variances. Dataset comprises AV crash records obtained from the California Department of Motor Vehicles from 2018 to the first quarter of 2024. Crashes on roadway segments and intersection are modeled separately. Modeling results reveal that factors such as poor lighting conditions, braking maneuver of AVs, proceeding straight movement of HDVs, involvement of bikes/scooters, residential land-use significantly contribute to AV-involved crash occurrence on segments and at intersections. On segments, first quarter of the year, the retail/entertainment land use, sideswipe collision, dangerous maneuver of HDVs and proceeding straight moment of AVs affect the likelihood of AV-involved crashes. Meanwhile, at intersection, rear-end collision, raining/snowing, unusual road conditions, four-leg intersection, lack of pedestrian island/intersection control significantly increases the probability of AV-involved crashes while angle collision and large skew angle decreases it. The findings highlight the need for more targeted goals to improve AV's safety, such as enhancing AV sensor perception capabilities, incorporating scenario-based tests by categorization of crash location, and developing mass education initiatives to facilitate the broader acceptance and understanding of AV technologies. Keywords: Autonomous Vehicle, Crash Analysis, Random Parameters with Heterogeneity in Means and Variances, Roadway Segment, Intersection, Road Safety

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Session Number	**Poster Session 4073**
Session Title	Safety Performance and Analysis for Safe Vehicles
Paper Number	TRBAM-25-02400
Paper Title	**Predicting Crash Likelihood at Intersections Using Connected Vehicle Data**
Abstract	Crash likelihood prediction model is a crucial proactive traffic safety management strategy. While numerous studies have focused on crash prediction for freeways, the application of this strategy to intersections is relatively rare. In this study, we propose inTersection-Transformer (inTformer), a time-embedded attention-based Transformer model to predict crash likelihood at intersections. The inTformer model predicts whether crashes will occur at intersections within the next 15 minutes. We developed these prediction models using traffic data from connected vehicles, a previously unexplored data source for intersection crash prediction. Due to the complex traffic flow patterns at intersections, we used a zone-specific modeling approach by dividing the intersection region into within-intersection and approach zones. The inTformer models achieved a sensitivity of up to 73% in the 'within-intersection' zone and up to 74% in the 'approach' zone. Benchmarking the optimal zone-specific inTformer models against several established deep learning models confirmed the superiority of the proposed inTformer. Further, we identified low speeding increased crash likelihood in the 'within-intersection' zone, while high split failure rates increased crash likelihood in the 'approach' zone. Keywords: Connected Vehicles, Transformer, Intersection Safety, Crash Likelihood

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Session Number	**Poster Session 4073**
Session Title	Safety Performance and Analysis for Safe Vehicles
Paper Number	TRBAM-25-01012
Paper Title	**A Car-following Safety Active Control Framework Based on Short-term Safety Evolution Pattern Prediction**
Introduction	Early identification and control of driving risks can significantly enhance the effectiveness of collision avoidance, making the prediction of driving risks crucial for driving safety. After predicting driving risks, safety control algorithms can be employed for risk avoidance. As illustrated in Figure 1, referencing the description of the system's safety evolution process based on macro resilience (1), the evolution segments of micro car-following safety can be categorized into three patterns: Safety, Disturbance, and Resilience. When driving safety remains above the safety boundary, it is defined as Safety. Due to the instability of manual driving operations and the influence of uncertain and heterogeneous factors, driving safety inherently fluctuates. When the fluctuation range is below the safety boundary but does not decline to the risk boundary, it is defined as Disturbance. Although car-following safety control has been extensively analyzed, distinct research gaps remain: (1) While existing studies predict future driving risk from the perspective of risk extremes and status, few focus on the prediction of evolution patterns; (2) The prediction models in existing studies are generally too simplistic to capture the interactive effectiveness of the multivariable driving features, which limits prediction precision; (3) Car-following risk prediction and safety control are closely related. Although many studies have conducted independent research on these topics, the integration and application of the predict-control framework require further exploration. In response to the aforementioned research gaps, this study will predict driving risk from the perspective of risk evolution patterns and construct a predict-control framework based on deep learning and Model Predictive Control (MPC) techniques. The study makes three primary contributions: -The concept of the driving safety evolution pattern is proposed, filling the gap in the application of the resilience concept in micro-behavior analysis. The car-following resilience processes are selected from the highD natural driving dataset, categorizing the driving safety evolution patterns into Safety, Disturbance, and Resilience. -The driving risk evolution pattern prediction model is proposed, combining the CNN-GRU network with dual attention mechanisms. The feature and temporal attention mechanisms are employed for information enhancement. The proposed model achieves optimal performance among mainstream models, with an average F1 score of 0.931. -The predict-control framework is constructed based on safety evolution pattern prediction and MPC weight optimization. When the prediction pattern is Resilience, the MPC control algorithm is applied for safety control. Grid search is utilized to optimize the weights of the objective function of MPC, resulting in a significant improvement in overall driving safety after adopting this framework. Meanwhile, the feature distribution of different patterns and the application of the proposed framework in various scenarios are analyzed in detail.

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Session Number	**Poster Session 4073**
Session Title	Safety Performance and Analysis for Safe Vehicles
Paper Number	TRBAM-25-04975
Paper Title	**Leveraging Computer Vision for Enhanced Pedestrian Crash Typing 2 Analysis: A Multi-step, Multi-class Framework**
Abstract	Pedestrian safety remains a critical concern as the number of pedestrian fatalities continues to rise. Traditional crash databases often lack detailed information about pedestrian actions and intentions at the time of crashes, necessitating labor-intensive manual reviews of crash narratives and diagrams. To address this challenge, our study focuses on leveraging computer vision (CV) and machine learning (ML) techniques to enhance a previous analysis of PBCAT crash type, specifically the pedestrian maneuver, by only using natural language processing (NLP) Models. Researchers developed a multi-step, multi-class framework that integrates YOLO (You Only Look Once) for the object detection and Support Vector Machines (SVM) for the classification tasks. This framework aims to classify pedestrian maneuvers into subtypes first thereby improving the overall accuracy. Results show that the combined CV and ML approach significantly outperforms standalone NLP models, particularly in complex classification scenarios. The accuracy scores improved to 58.9% for crossing and 56.9% for non-crossing, compared to 19.57% for the NLP-only model in multiclass classification. The findings suggest the potential for automated tools to replicate human analyst tasks, making large-scale crash analysis more feasible and accurate.

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Sponsoring Committee	Standing Committee on Safety Performance and Analysis (ACS20)
Session Number	**Poster Session 4073**
Session Title	Safety Performance and Analysis for Safe Vehicles
Paper Number	TRBAM-25-03192
Paper Title	**Incorporating the Influence of Vehicle Mix on Crash Frequency and Severity**
Abstract	The current approaches for crash frequency and severity prediction in the Highway Safety Manual (HSM) do not employ vehicle mix information. In this research effort, we build advanced alternatives to HSM methods while incorporating vehicle mix information. Two model systems: (a) multivariate Poisson-lognormal model (MVPLN) and (b) negative binomial-ordered probit fractional split model (NB-OPFS) are estimated by incorporating vehicle mix variables. The developed model systems can also capture the influence of observed and unobserved heterogeneity of different independent variables including vehicle mix variables. We estimate the models for three facility types including Urban Arterial 4-Lane Divided segments, Rural 3-Leg STOP Controlled and Rural 4-Leg STOP Controlled intersections using data from four Highway Safety Information System (HSIS) states including California, Illinois, Minnesota, Washington, and three Non-HSIS states including Connecticut, Florida and Texas. For modeling crashes at each facility level, we adopt a pooled modeling technique that accounts for state specific observed and unobserved heterogeneity in the pooled datasets. A comprehensive set of independent variables including traffic volume, vehicle mix indicators, roadway characteristics and state-specific indicators are considered in the analysis. The model comparison exercise is conducted based on a comprehensive set of quantitative and qualitative metrics. The study highlights how different methodological approaches perform better for different facilities. The study findings also underscore how capturing the observed and unobserved impacts of vehicle mix variables improves model performance in crash frequency and severity dimensions across the facility types. Keywords: Crash frequency, Crash severity, Vehicle mix variables, Pooled model, Unobserved effects.

Authors	Zhuangyuan Fan, University of Hong Kong Ting Lian, University of Hong Kong Feiyang Zhang, University of Hong Kong Becky P.Y. Loo, University of Hong Kong
Sponsoring Committee	Standing Committee on Safety Performance and Analysis (ACS20)
Session Number	**Poster Session 4073**
Session Title	Safety Performance and Analysis for Safe Vehicles
Paper Number	TRBAM-25-04113
Paper Title	**Identifying Risk Factors for Bus Crashes in a Dense and Dynamic Road Environment: Insights from Using Computer Vision Tools**
Abstract	In road safety research, bus crashes are particularly noteworthy because of the large number of bus passengers involved and the challenge that it puts to the road network (with the closure of multiple lanes or entire roads for hours) and the public health care system (with multiple injuries that need to be dispatched to public hospitals within a short time). The significance of improving bus safety is high in cities heavily relying on buses as a major means of public transport. The recent paradigm shifts of road design from primarily vehicle-oriented to people-oriented urge us to examine street and pedestrian behavioural factors more closely. Notably, the street environment is highly dynamic, corresponding to different times of the day. To fill this research gap, this study leverages a rich dataset - video data from bus dashcam footage - to identify some high-risk factors for estimating the frequency of bus crashes. This research applies deep learning models and computer vision techniques and constructs a series of behavioural and street factors: pedestrian exposure factors, pedestrian jaywalking, bus stop crowding, sidewalk railings, and sharp turning locations. Important risk factors are identified, and future planning interventions are suggested. In particular, road safety administrations need to devote more efforts to improve bus safety along streets with a high volume of pedestrians, recognise the importance of railings in protecting pedestrians from serious bus crashes, and take measures to ease bus stop crowding to prevent slight bus injuries. Keywords: Computer vision, Road Safety, Jaywalking

Authors	Yazhou Li, Southeast University Hao Yu, Southeast University Yuchen Wang, Southeast University, Jiulonghu Weiying Shen, Southeast University
Sponsoring Committee	Standing Committee on Safety Performance and Analysis (ACS20)
Session Number	**Poster Session 4073**
Session Title	Safety Performance and Analysis for Safe Vehicles
Paper Number	TRBAM-25-05546
Paper Title	**A Novel Traffic Safety Field Model Considering Vehicle Motion Relationship**
Abstract	With technological advances and the increasing complexity of road traffic systems, the study of driving risk fields has become a new way to solve complex traffic safety problems. Although existing risk field models provide a certain foundation for traffic safety analysis, they have limitations in representing traffic safety. To overcome these limitations, a novel traffic safety field model is proposed in this paper. The model integrates the relative motion of objects and risk field theory and aims to assess the interrelationships and potential risks more accurately between vehicles and other participants in the traffic system. The model defines the safety field as the risk relationship field formed between objects and vehicles in each motion state in the road system. In addition, this paper puts special emphasis on vehicle lateral safety and develops a vehicle lateral safety field model to assess the risk of a vehicle when it interacts with other traffic bodies at the side. In order to verify the effectiveness of the new model, this paper conducts a comparative analysis in a variety of typical traffic scenarios. The results of the analyses show that, compared with existing models, the traffic safety field model demonstrates higher accuracy and reliability in traffic safety assessment, which is important for improving drivers' and traffic managers' understanding of driving risks and countermeasures. Keywords: Traffic Safety Field, Driving Risk Assessment, Lateral Safety, Time to Collision

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Reuben Tamakloe, No Organization
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Sponsoring Committee Standing Committee on Safety Performance and Analysis (ACS20)

Session Number **Poster Session 4073**

Session Title Safety Performance and Analysis for Safe Vehicles

Paper Number TRBAM-25-00341

Paper Title **Identifying Patterns and Risk Factors in SUV-Related Pedestrian Crashes Using Cluster Correspondence Analysis**

Abstract Sports Utility Vehicles (SUVs) have become increasingly popular for their versatility, but they are also known for being involved in more severe pedestrian crashes compared to standard passenger cars due to their mass and design. However, there has been minimal effort to thoroughly understand the unique characteristics of SUV-pedestrian crashes and the associated critical factors. This study utilizes the Cluster Correspondence Analysis (CCA) method, a machine learning-based approach to simultaneously segregate SUV type vehicle (light trucks/vans, and SUVs) and pedestrian crash data into homogeneous groups and extract cluster-specific factors associated with crashes. Specifically, the tool is applied to analyze 3852 SUV-pedestrian crashes that occurred in Louisiana between 2017 and 2021. One notable discovery from the CCA is that SUV-related pedestrian crashes often involve children who are identified as inattentive pedestrians. These incidents predominantly occur during daylight. Additionally, it was also identified that SUV-pedestrian crashes mostly occurred at intersections with traffic signals due to driver inattention, posing risks to elderly pedestrians. A detailed cluster-based comparative analysis indicates that crashes involving high-speed SUVs in open country areas under controlled traffic conditions contributed to the highest number of fatal pedestrian injuries. These clusters also present the highest percentage of male pedestrians, the highest incidence of non-collision with a motor vehicle, and a significant involvement of pedestrians aged 25 to 45. The insights drawn from this study are anticipated to provide safety professionals with a deeper understanding of different categories of SUV-pedestrian collisions and the associated factors.

Keywords: Pedestrian; Traffic crashes; Cluster Correspondence Analysis; Sports Utility Vehicle; 22 Fatal

3 Network Screening

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Network screening is the identification of crash hotspots, also referred to as hazardous road locations, high-risk locations, accident-prone locations, black spots, sites with promise, or priority investigation locations. Network screening is the first step of the highway safety management process, and it is vital that a sound procedure is used; otherwise, resources will be wasted on locations that are incorrectly identified as unsafe while those that are unsafe will remain untreated.

The subcommittee identified **18 papers** strictly related to network screening. Some papers in this category provide a case study of an application in a specific context. Other studies discuss methods with suggestions on the possibility of using these methods for network screening. Both groups of studies are included in this review. Several papers dealt with network screening aiming at enhancing the HSM procedures; indeed, novel SPFs and CMFs are proposed. Moreover, the EB method has been frequently used to rank road sites, as well as the Spatial Autocorrelation. Machine and Deep Learning algorithms are also frequently used to assess the safety level of facilities. Finally, novel data sources coming from both CAVs, and video from cameras and drones, are used for proactive network screening.

It is worth mentioning that the present report is the consequence of a systematic review of all papers submitted to the TRBAM and included into the ACS10 and ACS20 sessions (i.e., workshop, lectern, and poster sessions). The following set of keywords has been used for further refine this report and discover all the candidate papers to be included:

- Screening;
- Rank (including rank, ranking, ranked, etc.);
- Black (including black-spot and blackspot);
- Priorit* (including priority, prioritization, prioritizing, prioritized, etc.);
- Empirical (including Empirical Bayesian);
- Hot (including Hot-spot and hotspot);
- Network;
- Location;
- Hazard (including hazardous);
- Allocat* (including allocation, allocate, allocated, allocating, etc.);
- Prone;
- Promis* (including promise and promising);
- High (including high-risk);

Considering the **aim**, the following Table reports the authors, the paper number, the type (Poster Session, PS, and Lectern Session, LS) and session number, the title, and the leading aim of the **18 papers** strictly related to network screening.

Authors	Paper n.	Session	Title	Aim of the Study
Park et al.	TRBAM-25-05224	LS 2171	Traffic Conflict-Based Micro-level Hotspots Identification at Signalized Intersections	To identify micro-level hotspots within three signalized intersections using traffic conflict measures derived from drone video.
Das and Mathew	TRBAM-25-05753	PS 2240	Identification of Hazardous Locations Based on Unsafe Driving Event Detection Using Telematics Data	To define a framework for identifying hazardous driving locations by analyzing the spatial distribution of recurring unsafe driving events that are detected from naturalistic driving data
Ohlms and Dougald	TRBAM-25-03915	PS 2240	Traffic Gaps and Trail Gaps near “The Gap”: Examining a Trail Crossing that Did Not Register as a Need in Statewide Screening Processes	This paper presents findings from a study that evaluated existing site conditions at Keys Gap and identified potential countermeasure treatments to reduce exposure and risk to trail users.
Kim et al.	TRBAM-25-06120	PS 4073	Evaluating traffic safety information strategies for identified hazardous infrastructures using autonomous vehicle (AV) demonstration data	To identify vulnerable sections and evaluates the effectiveness of traffic management strategies, such as Variable Message Signs (VMS).
Singh et al.	TRBAM-25-05082	PS 4073	Network-wide spatiotemporal extreme value theory model for estimating crash risks from traffic conflicts using autonomous vehicle sensor data	To perform traffic safety analysis by validating extreme value theory models in conjunction with traffic conflict techniques for assessing rear-end crash risks network-wide.
Li et al.	TRBAM-25-06076	PS 4073	Identifying High-Risk Locations on Expressways Using Connected Vehicle Data: An Empirical Analysis	To demonstrate the potential of Connected Vehicles' warnings, including headway monitoring and forward collision warnings, to identify high-risk locations in real time.
Okafor et al.	TRBAM-25-05230	PS 4073	Integrating Connected Vehicle Hard Braking Event Data for Proactive Road Network Safety Screening	This study examines the potential integration of hard braking events (HBE) from connected vehicles (CV) as crash surrogates for network screening.
Adil and Thakur	TRBAM-25-02541	PS 4081	Identifying High Risk Roadway Segments for Dynamic First Responder Allocation	To identify high-risk roadway segments where Motor Vehicle Crashes (MVC) may occur with high probability.
Comeau and Xiong	TRBAM-25-02725	PS 3039	Comparing Location-Based and Home-Addressed Based Approaches in Evaluating Societal Crash and Congestion Costs	To identify the most impactful infrastructure projects (in terms of congestion and safety) to prioritize funding on to address these costs.
Shita el al.	TRBAM-25-06141	PS 3039	Prioritization and Implementation of Safe Routes to School (SRTS) in Austin, Texas	To improve students' safety when walking or biking to school by prioritizing safe routes to school projects (SRTS).
Corbett-Davies et al.	TRBAM-25-04703	PS 3039	Prioritizing Safety Treatment of Rural Corridors using Curve Context	To define a proactive corridor prioritization framework for rural roads in the United States, based on horizontal curve risk.
Lan et al.	TRBAM-25-03996	PS 3039	Comparison of Segment Ranking and Sliding Window Ranking Methods for Rural Two-lane Undivided Roadways in North Carolina	To compare the performance of ranking individual segments with EB method versus the sliding window approach in network screening processes.
Dhakal and Al-Kaisy	TRBAM-25-00754	PS 3039	Comparative Analysis of Three Proposed Network Screening Methods on Rural Highways	To improve rural highway safety by evaluating and comparing innovative network screening methods.
Zhao et al.	TRBAM-25-01335	PS 3147	Integrating Road Network Characteristics in Traffic Crashes Analysis Based on Heterogeneous Graph Neural Networks	To reveal insights into the impact of various factors on traffic safety at a macro-level.
Akuh et al.	TRBAM-25-04952	PS 3147	Predicting crash severity and unsafe driver behavior hot spots in South Carolina using machine learning models and a GIS framework	This paper explores how driver behavior contributes to the severity of crashes involving two vehicles in South Carolina and seeks to identify hot spots for these behaviors.
Jee and Oh	TRBAM-25-00443	PS 3147	Ensemble-based Machine Learning Approach to Prioritize Driving Safety Indicators Using Connected Vehicle System Data for Proactive Safety Analytics	To design a methodology for prioritizing driving safety indicators for effective safety evaluation
Wang et al.	TRBAM-25-03697	PS 3213	Developing Road-HFACS: A Novel Approach Quantifying Human Factors Analysis and Classification System with Bayesian Network for Road Traffic Incidents	To provide a systematic tool for identifying the diverse factors contributing to incidents, paving the way for more effective safety interventions and policies
Zhai et al.	TRBAM-25-02628	PS 3213	Developing Equity-Aware Safety Performance Functions for Identifying Hotspots of Pedestrian Involved Crashes	To identify hotspots, this study proposes a novel concept of equity-aware safety performance functions (SPFs), enabling a distinct treatment of equity-related variables such as race and income.

From a **methodological perspective** and **application perspective**, the following Table reports the authors, the paper number, the methods implemented with leading details, and the study area and/or road facility covered of the **18 papers** strictly related to network screening.

Authors	Paper Number	Methodological Perspective	Application Perspective
Park et al.	TRBAM-25-05224	TTC, modified TTC, and PET are used as traffic conflict measures. To determine the optimal conflict measure and its threshold for each intersection, authors developed a crash frequency model based on a generalized linear model. The selected conflict measures and thresholds were then used to identify micro-level hotspot sections using kernel density.	Three signalized intersections, collecting data from drone video, crash history, and open street map.
Das and Mathew	TRBAM-25-05753	Telematics data involving different vehicles and drivers is used in this study to demonstrate the robustness of the framework.	The study route selected is an 18 km stretch of urban road in Mumbai, India
Ohlms and Dougald	TRBAM-25-03915	The study propose a plot to define a relation between accepted gap length and delay based on video data.	Data collection involved obtaining: (1) Appalachian Trail (A.T.) user counts at Keys Gap, (2) Route 9 traffic volumes and speeds, (3) Route 9 traffic gaps, (4) trail user delay and accepted crossing gaps, and (5) qualitative data from A.T. hikers.
Kim et al.	TRBAM-25-06120	The study integrates real-world AV trajectory data with accident reports and exploits simulations and linear mixed models.	Data from Sejong City AV demonstrations and California DMV accident reports
Singh et al.	TRBAM-25-05082	This study proposes a spatiotemporal generalised extreme value (GEV) modelling framework to estimate the rear-end crash risks at a network level utilising the traffic conflicts extracted from AV sensors.	This study utilises the Argoverse II motion forecast dataset, collected by a fleet of Argo AI Avs. The study network comprises 57 sub-sections classified into 28 intersections and 29 mid-blocks.
Li et al.	TRBAM-25-06076	This study integrates spatial autocorrelation methods and advanced statistical modeling, including instrumental variable approaches.	This study selects 9 expressways in Shanghai as research objects, covering approximately 645 kilometers.
Okafor et al.	TRBAM-25-05230	After an initial spatial autocorrelation and Spearman correlation, the suitability of HBE as a surrogate safety measure for network screening was examined for four crash types, including all crashes, rear-end crashes, no-injury crashes, and severe crashes.	The study used the 2017 Highway Performance Monitoring System (HPMS) inventory road network data for Alabama.
Adil and Thakur	TRBAM-25-02541	This study utilizes advanced machine learning techniques and optimization algorithms (XGBoost Classifier model, refined with SMOTE and Tomek Links), integrating data on weather, traffic volume, and road conditions to identify high-risk roadway segments.	2017 MVC data over a 1,000-mile corridor from Dallas, TX to Chicago, IL.
Comeau and Xiong	TRBAM-25-02725	This study assesses the trade-off between data accuracy and data availability in two methodologies to estimate societal crash and congestion costs, focusing on the comparison between county-level location-based aggregation and home-addressed based approaches.	The study assessed crash data in the state of Massachusetts and utilized the results of the Boston Region MPO's TDM23 travel demand model to evaluate these trade-offs.
Shita el al.	TRBAM-25-06141	The study considers mixed-effects ordered and binary logit models to determine the likelihood of the recommendations being ranked as high benefit or high cost-benefit.	Austin's SRTS data between 2016 and 2023 including about 4,600 observed safety issues along school routes
Corbett-Davies et al.	TRBAM-25-04703	Road centerline geometry and speed limit data is used to estimate typical operating speeds and "curve context" – the degree to which the estimated operating speed of a curve differs from its safe traversal speed. A Safety Performance Function is used to estimate underlying risk, based on curve context and other geometric and traffic variables.	Road network and crash datasets from California and Arkansas were used to develop and evaluate the predictive model
Lan et al.	TRBAM-25-03996	The stufy performed an EB- and sliding window-based approach for screening a road network.	Data from rural two-lane undivided roadways in North Carolina
Dhakal and Al-Kaisy	TRBAM-25-00754	The study focused on methods requiring minimal resources to conduct a screening procedure. They are Global Risk Scoring Method, the Crash Risk Index Method, and the Predicted Empirical Bayes Method.	1,495-mile sample of state-owned rural two-lane roadways in Oregon. Traffic, geometry, roadside, and crash data from 2011–2020 were obtained.
Zhao et al.	TRBAM-25-01335	This study integrates road network structures with urban traffic safety analysis using a Heterogeneous Graph Neural Network (HGN).	Traffic Analysis Zones (TAZs) in Greater London, utilizing data on traffic flow, Points of Interest (POI), and road network characteristics.
Akuh et al.	TRBAM-25-04952	Six machine learning algorithms (K-nearest neighbors (KNN), Random Forest (RF), Decision Tree (DT), J48, Logistic Regression, and Naïve Bayes) are employed to develop classification models to predict crash severities.	Data obtained from the South Carolina Department of Transportation (SCDOT) contained over 1 million road crash records from 46 counties from 2017 to 2022
Jee and Oh	TRBAM-25-00443	Classification machine learning models (SVM, ANN, and KNN) are calibrated to select indicators that have a greater impact on identifying hazardous sections.	An integrated dataset based on trajectories of individual vehicles equipped with CV systems. The spatial range is between Yangjae IC and Giheungdongtan IC on the

			Gyeongbu Freeway and Jonam JC and Sangil IC on the Sudogwon Je1sunhwan Freeway in South Korea, which totals 74 km
Wang et al.	TRBAM-25-03697	The classification framework of road incidents was conducted through a Bayesian Network designed with reference to the Model Minimum Uniform Crash Criteria from the U.S. National Highway Traffic Safety Administration and the Road Traffic Incident Information Collection Project Table in China.	100 road traffic investigation reports across 28 provinces in China from 2001 to 2021
Zhai et al.	TRBAM-25-02628	Equity-aware SPFs introduce a fairness distance and integrate it into the log likelihood function of the negative binomial regression as a form of partial lasso regularization. A parameter is used to control the importance of the regularization term. SPFs are employed to compute the potential for safety improvement (PSI).	three-year (2017-2019) geocoded crash data to assess equity in pedestrian safety at the census tract level in Virginia, USA.
Park et al.	TRBAM-25-05224	TTC, modified TTC, and PET are used as traffic conflict measures. To determine the optimal conflict measure and its threshold for each intersection, authors developed a crash frequency model based on a generalized linear model. The selected conflict measures and thresholds were then used to identify micro-level hotspot sections using kernel density.	Three signalized intersections, collecting data from drone video, crash history, and open street map.

Below, for each of the **18 papers** involving network screening, the following information is provided: authors, sponsoring committee, session number, session title, paper number, paper title, and abstract (or statement of significance).

Authors	Nuri Park, Hanyang University Juneyoung Park, Hanyang University, Ansan Yang-Jun Joo, University of Central Florida Mohamed Abdel-Aty, University of Central Florida
Sponsoring Committee	Standing Committee on Transportation Safety Management Systems (ACS10)
Session Number	Lectern Session 2171
Session Title	**Decision Making with Safety Surrogates**
Paper Number	TRBAM-25-05224
Paper Title	**Traffic Conflict-Based Micro-level Hotspots Identification at Signalized Intersections**
Abstract	This study aims to identify micro-level hotspots within three signalized intersections using traffic conflict measures derived from drone video. We employed an algorithm designed to calculate detailed conflicts for various conflict angles and vehicle sizes. Time-to-collision (TTC), modified TTC, and post-encroachment time are used as traffic conflict measures. To determine the optimal conflict measure and its threshold for each intersection, we developed a crash frequency model based on a generalized linear model. The selected conflict measures and thresholds were then used to identify micro-level hotspot sections using kernel density. This study contributes to traffic safety by identifying effective traffic conflict measures for micro-level hotspot identification and offering more detailed safety management strategies.

Authors	Aathira K. Das, Indian Institute of Technology, Bombay Tom Mathew, Indian Institute of Technology, Bombay
Sponsoring Committee	Standing Committee on Safety Performance and Analysis (ACS20)
Session Number	Poster Session 2240
Session Title	**Safety Performance and Analysis for Safe Roads**
Paper Number	TRBAM-25-05753
Paper Title	**Identification of Hazardous Locations Based on Unsafe Driving Event Detection Using Telematics Data**
Abstract	Road safety is a crucial aspect of transportation systems worldwide, with the primary goal of preventing accidents, injuries, and fatalities on the road. Identifying hazardous driving locations is essential to ensure road safety. Hazardous locations are spots where unsafe driving events are frequently observed, and the transportation infrastructure can significantly contribute to such behaviors. Therefore, this study proposes a framework for identifying hazardous driving locations by analyzing the spatial distribution of recurring unsafe driving events that are detected from naturalistic driving data without requiring any predefined thresholds, reference patterns, or rules. Telematics data involving different vehicles and drivers is used in this study to demonstrate the robustness of the framework. Our motivation is to develop a proactive measure to identify hazardous locations before unsafe driving occurs. This could aid in developing an automated real-time driver warning system for cautious driving or an automated sensor bar for safety audits.

Authors	Peter Ohlms, Virginia Department of Transportation Lance Dougald, Virginia Department of Transportation
Sponsoring Committee	Standing Committee on Safety Performance and Analysis (ACS20)
Session Number	Poster Session 2240
Session Title	**Safety Performance and Analysis for Safe Roads**
Paper Number	TRBAM-25-03915
Paper Title	**Traffic Gaps and Trail Gaps near "The Gap": Examining a Trail Crossing that Did Not Register as a Need in Statewide Screening Processes**
Abstract	Although the use of crash data is an effective way for identifying locations where safety treatments are warranted, there may be some locations where, lacking evidence of crashes, unique site conditions necessitate an evaluation of other datasets including geometric conditions, user demand, and user experiences. This paper describes an approach for such an assessment based on one case study site, a trail crossing on a rural two-lane highway, where the researchers collected data to better assess site challenges and the potential benefits of proactive treatments. Sight distance limitations at this particular location meant that installation of a marked crosswalk was not supported under state DOT policy; although a marked crosswalk was likely not an appropriate solution, other potential treatment options were identified.

Authors	Hojae Kim, Hanyang University, Ansan Nuri Park, Hanyang University Songha Lee, Hanyang University, Ansan Juneyoung Park, Hanyang University Samgyu Yang, University of Central Florida
Sponsoring Committee	Standing Committee on Safety Performance and Analysis (ACS20)
Session Number	Poster Session 4073
Session Title	**Safety Performance and Analysis for Safe Vehicles**
Paper Number	TRBAM-25-06120
Paper Title	**Evaluating traffic safety information strategies for identified hazardous infrastructures using autonomous vehicle (AV) demonstration data**
Abstract	This research addresses critical safety challenges in mixed traffic environments involving autonomous and manually-driven vehicles. By integrating real-world AV trajectory data with accident reports, the study identifies vulnerable sections and evaluates the effectiveness of traffic management strategies, such as Variable Message Signs (VMS), through simulations and linear mixed models. The findings provide actionable insights for enhancing traffic safety and operational efficiency, making it highly relevant to policymakers, researchers, and practitioners. Attendees of the TRB Meeting will benefit from the study's innovative methodology and practical implications for managing the transition to autonomous mobility systems.

Authors	Sunny Singh, QUT: Queensland University of Technology Yasir Ali, Loughborough University Md. Mazharul Haque, Queensland University of Technology
Sponsoring Committee	Standing Committee on Safety Performance and Analysis (ACS20)
Session Number	Poster Session 4073
Session Title	**Safety Performance and Analysis for Safe Vehicles**
Paper Number	TRBAM-25-05082
Paper Title	**Network-wide spatiotemporal extreme value theory model for estimating crash risks from traffic conflicts using autonomous vehicle sensor data**
Abstract	Autonomous vehicle (AV) trials on public roads have generated unprecedented detailed datasets, which has the potential to aid the development of comprehensive conflict-based network-wide safety models. Existing conflict-based extreme value theory models, mostly based on roadside sensors, are restricted to a few concentrated locations and are not scalable to the network level because of the lack of capability to account for spatial heterogeneity. This study proposes a spatiotemporal generalised extreme value (GEV) modelling framework to estimate the rear-end crash risks at a network level utilising the traffic conflicts extracted from AV sensors. This study contributes to the literature in the following ways. First, this study contributes significantly to traffic safety analysis by validating extreme value theory models in conjunction with traffic conflict techniques for assessing rear-end crash risks network-wide, addressing a notable gap where large-scale, conflict-based crash risk assessments are relatively rare. Second, the study develops a network-wide safety analysis framework that uses AV sensor data to obtain trajectory information, providing rich behavioural information about road user interactions and their surroundings, which is often missing in extreme value theory studies, as noted in a recent review study.

Authors	Xueao Li, Tongji University Xiaodong Li, Tongji University Junhua Wang, Tongji University Ting Fu, Tongji University Qiangqiang Shangguan, Tongji University Qiangqiang Shangguan, Tongji University
Sponsoring Committee	Standing Committee on Safety Performance and Analysis (ACS20)
Session Number	Poster Session 4073
Session Title	**Safety Performance and Analysis for Safe Vehicles**
Paper Number	TRBAM-25-06076
Paper Title	**Identifying High-Risk Locations on Expressways Using Connected Vehicle Data: An Empirical Analysis**
Abstract	This research leverages connected vehicle (CV) data to address limitations in traditional road safety analysis, such as long accumulation period, limited data volume, imprecise location description and underreporting. By utilizing empirical data from Shanghai expressways, the study demonstrates the potential of CV warnings, including headway monitoring and forward collision warnings, to identify high-risk locations in real time. By integrating spatial autocorrelation methods and advanced statistical modeling, including instrumental variable approaches, the research provides a robust framework for analyzing the relationship between warnings and collisions. This study offers TRB attendees valuable insights into a novel, data driven approach to proactive road safety management, with actionable implications for policymakers, engineers, and researchers dedicated to improving urban traffic safety.

Authors Sunday Okafor, Garver
Steven Jones, University of Alabama
Jeffrey Bullard, Danmarks Tekniske Universitet
Praveena Penmetsa, University of Alabama
Kofi Adanu, University of Alabama
Jun Liu, University of Alabama

Sponsoring Committee Standing Committee on Safety Performance and Analysis (ACS20)

Session Number Poster Session 4073

Session Title **Safety Performance and Analysis for Safe Vehicles**

Paper Number TRBAM-25-05230

Paper Title **Integrating Connected Vehicle Hard Braking Event Data for Proactive Road Network Safety Screening**

Abstract Advancing road safety necessitates a systematic departure from reliance on historical crashes to alternative measures to facilitate proactive road safety improvement. This study examines the potential integration of hard braking events (HBE) from connected vehicles (CV) as crash surrogates for network screening. After an initial spatial autocorrelation and Spearman correlation, the suitability of HBE as a surrogate safety measure for network screening was examined for four crash types, including all crashes, rear-end crashes, no-injury crashes, and severe crashes. The common hotspots analysis showed that a significant proportion of the crash-based hotspots were also identified using HBE as follows: all crashes (86.25%), rear-end crashes (96.83%), no-injury crashes (85.37%), and severe injury crashes (78.22%). The comparison of the common hotspots ranking based on crash data and HBE revealed that the rear-end crashes had the least TRD for the top 20 and 30 hotspots. The average ranking difference shows a decreasing trend as the number of top hotspots increases for all the crash types except for severe crashes. These findings indicate that HBE could be more appropriate for identifying locations with elevated risks of rear-end crashes than other considered crash types. This study provides helpful insight into the potential of HBE as crash surrogates for network screening. The findings can assist safety management agencies in conducting timely road network performance evaluations and identifying locations that could benefit from advanced safety improvement to mitigate the possible manifestation of traffic conflicts into crashes.

Authors Syed Mohammad Adil, Connect Dynamics, Inc.
Aayush Thakur, Connect Dynamics, Inc.

Sponsoring Committee Standing Committee on Transportation Safety Management Systems (ACS10)

Session Number Poster Session 4081

Session Title **Advancements in Emergency Response, Incident Management, and Post-Crash Care: Innovative Approaches to Enhancing First Responder Safety and Efficiency**

Paper Number TRBAM-25-02541

Paper Title **Identifying High Risk Roadway Segments for Dynamic First Responder Allocation**

Abstract Motor Vehicle Crashes (MVCs) are a leading cause of unintentional injury and mortality in the U.S., with 36,500 fatalities and 4.5 million injuries reported in 2019, leading to a $340 billion societal burden. Fatalities increased by 10% the following year. This study utilizes advanced machine learning techniques and optimization algorithms, integrating data on weather, traffic volume, and road conditions to identify high-risk roadway segments. This approach aims to enhance emergency response deployment, improving public safety and reducing the economic impact of MVCs. As part of an NSF-funded project, we analyzed 2017 MVC data over a 1,000-mile corridor from Dallas, TX to Chicago, IL. Using an XGBoost Classifier model, refined with SMOTE and Tomek Links, we identified MVC predictors such as time of day, traffic flow, and weather conditions. The DBSCAN algorithm was then applied to locate MVC hotspots. Relocating EMS services closer to these hotspots led to a 33.5% reduction in median response distances (from 3.79 miles to 2.52 miles) and a 31.7% improvement in median response times (from 6.66 minutes to 4.55 minutes). This demonstrates the benefits of dynamic EMS positioning to high-risk areas. Our methodology aims to reduce MVC response times, optimize Traffic Incident Management (TIM), and Emergency Medical Services (EMS) deployment, thus lowering operational costs and enhancing MVC impact mitigation. This approach supports dynamic planning for TIM/EMS resource allocation.

Authors	Daniel Comeau, HNTB Chenfeng Xiong, Villanova University
Sponsoring Committee	Standing Committee on Transportation Safety Management Systems (ACS10)
Session Number	Poster Session 3039
Session Title	**Transportation Safety Management Systems from Start to Finish**
Paper Number	TRBAM-25-02725
Paper Title	**Comparing Location-Based and Home-Addressed Based Approaches in Evaluating Societal Crash and Congestion Costs**
Abstract	Traffic congestion and safety pose two of the largest challenges for transportation planners and engineers worldwide, placing significant economic, environmental, and social burdens on the public. In the United States (US) crashes were estimated to have cost the American public $340 billion in 2019, with congestion costs estimated to be over $166 billion in 2017. With funding from the historic Infrastructure Investment and Jobs Act (IIJA) becoming available to transportation agencies around the US, it is vital that agencies identify the most impactful infrastructure projects to prioritize funding on to address these costs. At the same time, the US is seeking to address the lack of infrastructure spending in disadvantaged communities in previous decades. To guide this infrastructure spending, data is required to properly analyze the locations most in need of funding. This study assesses the trade-off between data accuracy and data availability in two methodologies to estimate societal crash and congestion costs, focusing on the comparison between county-level location-based aggregation and home-addressed based approaches. The study assessed crash data in the state of Massachusetts and utilized the results of the Boston Region MPO's TDM23 travel demand model to evaluate these trade-offs.

Authors	Hellen Shita, Florida International University Sarah Kasomi, HDR Norris Novat, Leidos, Inc. Boni Kutela, Texas A&M Transportation Institute
Sponsoring Committee	Standing Committee on Transportation Safety Management Systems (ACS10)
Session Number	Poster Session 3039
Session Title	**Transportation Safety Management Systems from Start to Finish**
Paper Number	TRBAM-25-06141
Paper Title	**Prioritization and Implementation of Safe Routes to School (SRTS) in Austin, Texas**
Abstract	In the early 2000s, various jurisdictions across the U.S. initiated safe routes to school projects (SRTS) to improve students' safety when walking or biking to school. In different areas, various criteria are considered when prioritizing such projects. In Austin, Texas, the main criteria are the project's overall benefit or the cost-benefit. However, less is known about what projects will likely have high benefits or high cost-benefits, as one project recommendation could have multiple improvement suggestions. Austin's SRTS data between 2016 and 2023 includes about 4,600 observed safety issues along school routes, ranked on a 5-Likert scale in terms of overall benefit and cost-benefit. Therefore, this study applied mixed-effects ordered and binary logit models to determine the likelihood of the recommendations being ranked as high benefit or high cost-benefit. In addition, the study identified the likelihood of the recommendations being reviewed and implemented after that. Results indicate that recommendations involving bike facilities, trails, and speed-related measures are more likely to be ranked with high overall benefits. Projects that mitigate difficult crossings improve faded crosswalk markings, and speed-related improvements will likely be ranked with high cost-benefits. The findings also indicate that recommendations likely to be ranked high in cost-benefit are likely to be reviewed and implemented, suggesting that cost-benefit might outweigh the overall benefits when it comes to prioritization. The practical applications of the findings are summarized and can be crucial to guide other SRTS projects in Texas and across the United States.

Authors	Joseph Corbett-Davies, Abley Ltd Chris Tredinnick, Abley Ltd Shane Turner, Abley Ltd Paul Durdin, Abley Ltd Steve Abley, Abley Ltd
Sponsoring Committee	Standing Committee on Transportation Safety Management Systems (ACS10)
Session Number	Poster Session 3039
Session Title	**Transportation Safety Management Systems from Start to Finish**
Paper Number	TRBAM-25-04703
Paper Title	**Prioritizing Safety Treatment of Rural Corridors using Curve Context**
Abstract	Horizontal curves are a significant source of crash risk on rural road networks. Historically, high-risk curves are identified reactively, based on examination of crash history. However, to reduce the influence of random variation in observed crashes, proactive approaches, which estimate underlying crash risk, are increasingly preferred. To efficiently target road safety investment, a scalable, proactive approach to estimating rural crash risk is required. This paper presents a proactive corridor prioritization framework for rural roads in the United States, based on horizontal curve risk. Road centerline geometry and speed limit data is used to estimate typical operating speeds and "curve context" – the degree to which the estimated operating speed of a curve differs from its safe traversal speed. A Safety Performance Function is used to estimate underlying risk, based on curve context and other geometric and traffic variables. Estimation and validation of the model using Arkansas and California datasets indicates that poor curve context is a significant predictor of crash risk. Variables used in the model are readily available for the entire United States, allowing estimation of crash risk without reliance on crash or detailed roadway data. Corridors are prioritized according to predicted crash risk for out-of-context curves per unit of corridor length. This approach, which facilitates the display of corridor prioritization via an interactive map based tool, highlights corridors where treatments to address curve context are expected to deliver the greatest crash reductions relative to treatment costs. A case study of the Arkansas network is also presented. Targeting safety improvements on prioritized corridors is expected to produce significant reductions in rural road crashes.

Authors	Bo Lan, UNC Highway Safety Research Center Meghna Chakraborty, UNC Highway Safety Research Center Raghavan Srinivasan, University of North Carolina, Chapel Hill Daniel Levitt, No Organization
Sponsoring Committee	Standing Committee on Transportation Safety Management Systems (ACS10)
Session Number	Poster Session 3039
Session Title	**Transportation Safety Management Systems from Start to Finish**
Paper Number	TRBAM-25-03996
Paper Title	**Comparison of Segment Ranking and Sliding Window Ranking Methods for Rural Two-lane Undivided Roadways in North Carolina**
Abstract	For network screening purposes, Empirical Bayes (EB) method has been used for some decades now. Agencies may use the expected number of crashes or the potential for safety improvement (PSI) as ranking criteria by the EB method. These ranking measures could be implemented in different ways, including ranking individual segments or using a sliding window approach. For the approaches based on the EB method, traffic volume and other site characteristics are required for developing and applying the safety performance functions. However, due to unknown traffic volumes or other site characteristics on certain segments, there may be gaps along a route. Accounting for these gaps increases the complexity in implementing a sliding window algorithm. Additionally, the sliding window method is computationally more complex than the segment-level ranking method, and consequently has been less utilized in extant research. To this end, this study compared the performance of ranking individual segments versus the sliding window approach using data from rural two-lane undivided roadways in North Carolina. For the sliding window method, the sliding and window lengths were 0.1 miles and 0.3 miles, respectively. Overlaps between top ranked window segments were removed for comparing the performance of these two methods. Between the two approaches, we compared the sum of estimated EB expected crashes and PSIs for the ranked top 10, 20, 40, 50, 60, 80, and 100 miles. The results of this study show that these two methods are fairly comparable with the sliding window method being arguably better at identifying the hazardous locations.

Authors	Ahmed Al-Kaisy, Montana State University Bishal Dhakal, WSP
Sponsoring Committee	Standing Committee on Transportation Safety Management Systems (ACS10)
Session Number	Poster Session 3039
Session Title	**Transportation Safety Management Systems from Start to Finish**
Paper Number	TRBAM-25-00754
Paper Title	**Comparative Analysis of Three Proposed Network Screening Methods on Rural Highways**
Abstract	This research will interest TRB Meeting attendees as it addresses critical challenges in improving rural highway safety by evaluating and comparing innovative network screening methods. With rural roads accounting for a disproportionate number of traffic fatalities, the findings provide actionable insights for transportation professionals seeking cost-effective, data-driven approaches to identify high risk locations. The study's focus on methods requiring minimal resources makes it particularly relevant to local agencies and practitioners aiming to optimize safety interventions under constrained budgets. By highlighting practical applications and comparative performance metrics, the presentation offers valuable knowledge to support evidence-based decision-making in highway safety programs.

Authors	Jiahui Zhao, Southeast University Zhibin Li, Southeast University Pan Liu, Southeast University
Sponsoring Committee	Standing Committee on Safety Performance and Analysis (ACS20)
Session Number	Poster Session 3147
Session Title	**Safety Performance and Analysis Using Machine Learning or Artificial Intelligence**
Paper Number	TRBAM-25-01335
Paper Title	**Integrating Road Network Characteristics in Traffic Crashes Analysis Based on Heterogeneous Graph Neural Networks**
Abstract	Safety considerations are crucial in transportation planning, with aggregated crash modeling at the macro level revealing insights into the impact of various factors on traffic safety. This study introduces a novel approach by integrating road network structures with urban traffic safety analysis using a Heterogeneous Graph Neural Network (HGN). We analyze the relationship between road network configurations and crash counts within Traffic Analysis Zones (TAZs) in Greater London, utilizing data on traffic flow, Points of Interest (POI), and road network characteristics. Feature importance analysis using SHAP values highlights critical periods and locations influencing crash occurrences, providing valuable insights for traffic management and safety improvements.

Authors Raymond Akuh, Clemson University
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Sponsoring Committee Standing Committee on Safety Performance and Analysis (ACS20)

Session Number Poster Session 3147

Session Title **Safety Performance and Analysis Using Machine Learning or Artificial Intelligence**

Paper Number TRBAM-25-04952

Paper Title **Predicting crash severity and unsafe driver behavior hot spots in South Carolina using machine learning models and a GIS framework**

Abstract Multi-vehicle collisions account for the largest proportion of road crashes in the US, with unsafe driver behavior being a major contributing factor. This paper explores how driver behavior contributes to the severity of crashes involving two vehicles in South Carolina and seeks to identify hot spots for these behaviors. We employed six machine learning algorithms (K-nearest neighbors (KNN), Random Forest (RF), Decision Tree (DT), J48, Logistic Regression, and Naïve Bayes) to develop classification models to predict crash severities. Overall, a stable performance was achieved for all six models, but the KNN was the best-performing classification model followed by the RF and DT models. After identifying significant problematic driving behaviors, an optimized hot spot analysis tool was used to identify hot spots for these behaviors at the county level. The spatial analysis revealed that some behaviors, such as failure to yield the right of way and disregarding traffic signs/signals, were geographically common traffic violations. However, specific counties were identified as hot spots for speeding, aggressive driving, and driving under the influence (alcohol) behaviors. This research provides information for policymakers to make costeffective decisions in support of safety programs by targeting limited resources for training, public information campaigns, and other countermeasures to areas of the state with the greatest potential for impact.

Authors Jeonghoon Jee, Hanyang University, Ansan
Cheol Oh, Hanyang University

Sponsoring Committee Standing Committee on Safety Performance and Analysis (ACS20)

Session Number Poster Session 3147

Session Title **Safety Performance and Analysis Using Machine Learning or Artificial Intelligence**

Paper Number TRBAM-25-00443

Paper Title **Ensemble-based Machine Learning Approach to Prioritize Driving Safety Indicators Using Connected Vehicle System Data for Proactive Safety Analytics**

Abstract Driving safety indicators can quantitatively estimate crash potential, which enables proactive evaluations of traffic safety. Real-time traffic safety evaluation can contribute to crash prevention by identifying hazardous sections immediately. To implement an effective traffic safety evaluation model, selecting indicators that have a significant impact on identifying the presence of hazardous situations is necessary. The purpose of this study was to design a methodology for prioritizing driving safety indicators for effective safety evaluation. The outcome of this study is expected to be utilized as a valuable foundation for selecting indicators in safety evaluations for proactive traffic safety management.

Authors	Xuesong Wang, Tongji University Yanru Zhou, Tongji University Ashleigh Filtness, Loughborough University Chao Wang, Tongji University Xiaowei Tang, Tongji University Shikun Liu, Tongji University
Sponsoring Committee	Standing Committee on Safety Performance and Analysis (ACS20)
Session Number	Poster Session 3213
Session Title	**Safety Performance and Analysis for Safe Road Users and Safe Speeds**
Paper Number	TRBAM-25-03697
Paper Title	**Developing Road-HFACS: A Novel Approach Quantifying Human Factors Analysis and Classification System with Bayesian Network for Road Traffic Incidents**
Abstract	The Road-HFACS framework provides a systematic tool for identifying the diverse factors contributing to these incidents, paving the way for more effective safety interventions and policies.

Authors	Guocong Zhai, National University of Singapore Kun Xie, Old Dominion University Di Yang, Morgan State University Hong Yang, Old Dominion University
Sponsoring Committee	Standing Committee on Safety Performance and Analysis (ACS20)
Session Number	Poster Session 3213
Session Title	**Safety Performance and Analysis for Safe Road Users and Safe Speeds**
Paper Number	TRBAM-25-02628
Paper Title	**Developing Equity-Aware Safety Performance Functions for Identifying Hotspots of Pedestrian Involved Crashes**
Abstract	Crashes are frequently disproportionally observed in socioeconomically disadvantaged areas. Despite the evident disparities in transportation safety, there has been limited exploration of quantitative approaches to incorporating equity considerations into road safety management. This study proposes a novel concept of equity-aware safety performance functions (SPFs), enabling a distinct treatment of equity-related variables such as race and income. Equity-aware SPFs introduce a fairness distance and integrate it into the log likelihood function of the negative binomial regression as a form of partial lasso regularization. A parameter is used to control the importance of the regularization term. Equity-aware SPFs are developed for pedestrian-involved crashes at the census tract level in Virginia, USA, and then employed to compute the potential for safety improvement (PSI), a prevalent metric used in hotspot identification. Results show that equity-aware SPFs can diminish the effects of equity-related variables, including poverty ratio, black ratio, Asian ratio, and the ratio of households without vehicles, on the expected crash frequencies, generating higher PSIs for disadvantaged areas. Based on the results of Wilcoxon signed-rank tests, it is evident that there are significant differences in the rankings of PSIs when equity awareness is considered, especially for disadvantaged areas. This study adds to the literature a new quantitative approach to harmonize equity and effectiveness considerations, empowering more equitable decision-making in safety management, such as allocating resources for safety enhancement.

4 Safety Performance Functions

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Studies related to safety performance functions (SPFs) aim to predict the number or frequency of crashes and analyze the factors contributing to crash occurrence. The subcommittee identified 15 papers that are related to SPFs. The papers are classified by type of roadway facilities, type of crashes, scope, data source, and methodology.

Research on SPFs can be categorized by the type of roadway facility analyzed. Some studies focused on the safety performance of signalized intersections (25-01386 and 25-04602), and segment (25-00955, 25-02602, 25-05657), one paper focuses on a specific issue, such as crashes caused by distractions on-ramp segments (25-00750). Additional research concentrated on developing SPFs for rural two-lane highways (25-03413 and 25-06342), freeways (25-00956 and 25-05992). In addition, two papers developed macro-level SPFs to predict crashes for a geographic area rather than at a specific segment or intersection site (25-03718 and 25- 04831)

The papers explore various methodologies for estimating SPFs. Some papers use the classical approach with the Negative Binomial model (25-02602, 25-03413), while others test alternative methodologies such as the Poisson Lognormal Lindley model (25-05992, 25-00955), random parameter approaches to address issues like excess zeros in the data (25-00750) or temporal variability (25-04831, 25-04756) and spatial variability (25-06342).

Some studies have considered external factors such as socio-demographic conditions (25-05657), Time to Collision (25-04602) and the impact of the COVID-19 pandemic (25-05657).

SPFs regarding different crash types and severities have also been widely conducted. The crash severities investigated included total crashes (25-05992), fatal crashes (25-00080, 25-00750, and 25-04831), and severe injury crashes (25-00080, 25-00750, and 25-04602). Furthermore, some papers address specific issues related to vulnerable road users, such as motorcyclist safety on rural multilane segments and intersections (25-00065 and 25-00080), and pedestrian safety near urban bus stops (25-04784.

Below, for each of the 15 papers involving safety performance functions, the following information is provided: authors, sponsoring committee, session number, session title, paper number, paper title, and abstract.

Authors	Bharat Pathivada, Western Kentucky University Arunabha Banerjee, Western Kentucky University Kirolos Haleem, Western Kentucky University Tathagatha Khan, Indian Institute of Technology, Dhanbad Dylan Justice, Western Kentucky University
Sponsoring Committee	Transportation Safety Management Systems (ACS10)
Session Number	**3039**
Session Title	**Transportation Safety Management Systems from Start to Finish**
Paper Number	25-00065
Paper Title	**Motorcycle Safety Performance Functions along Kentucky's Rural Multilane Segments**
Abstract	This study identified key factors influencing motorcycle crash frequency along rural multilane roadway segments in Kentucky, considering both pre- and post-COVID-19 periods. The findings will facilitate targeted safety interventions to reduce motorcycle crash frequency on rural multilane roadways, such as adding centerline rumble strips on undivided roads and enhancing motorcyclist safety measures.

Authors	Arunabha Banerjee, Western Kentucky University Tathagatha Khan, Indian Institute of Technology, Dhanbad Kirolos Haleem, Western Kentucky University Bharat Pathivada, Western Kentucky University
Sponsoring Committee	Safety Performance and Analysis (ACS20)
Session Number	**2206**
Session Title	**Safety Performance and Analysis with Crash Predictions**
Paper Number	25-00750
Paper Title	**Developing Fatal-and-Injury Distraction-Specific Safety Performance Functions along Ramp Segments**
Abstract	The present study offers the following main contributions: (a) focusing on analyzing FI distraction-related crashes along ramp segments, (b) using a myriad of ZI-based models (ZINB, ZICMP, and ZIHTCMP) for developing FI distraction-specific SPFs along ramp segments to finally recommend the optimum SPF, (c) using a comprehensive list of explanatory variables at ramp segments, and (d) performing an in-depth investigation of the identified ramp segment HCLs involving FI distraction-related crashes to help propose targeted countermeasures for reducing FI distracted driving crashes along interchange ramp segments.

Authors	Bharat Pathivada, Western Kentucky University Arunabha Banerjee, Western Kentucky University Kirolos Haleem, Western Kentucky University Tathagatha Khan, Indian Institute of Technology, Dhanbad
Sponsoring Committee	Transportation Safety Management Systems (ACS10)
Session Number	**3039**
Session Title	**Transportation Safety Management Systems from Start to Finish**
Paper Number	25-00080
Paper Title	**Developing Safety Performance Functions for Fatal and Severe Motorcycle Crashes at Intersections**
Abstract	This study developed motorcycle safety performance functions (SPFs) for fatal and severe injury (FSI) crashes at intersections in Kentucky, addressing a critical gap in intersection safety for motorcyclists. Using the Conway-Maxwell-Poisson (CMP) model and its extensions, the research identified key factors affecting FSI motorcycle crash frequency at intersections, including AADT, traffic control type, and intersection layout. Based on the findings, several countermeasures were proposed to improve motorcyclist safety and reduce FSI motorcycle crashes at intersections

Authors	Atul Subedi, Utah State University Sailesh Acharya, National Renewable Energy Laboratory (NREL) Patrick Singleton, Utah State University Michelle Mekker, High Street Consulting Group, LLC
Sponsoring Committee	Transit Safety and Security (AP080)
Session Number	4087
Session Title	**Texture Evaluation and Friction Response: The Rub on Safety**
Paper Number	25-00955
Paper Title	**Safety Performance Functions and Crash Modification Factors for Skid Resistance on Interstate and Non-Interstate Highways**
Abstract	Pavement friction is crucial for road safety, especially in adverse weather. This study investigates the relationship between pavement friction—measured as Skid Number (SN)—and crash frequency on Utah highways. Using data from 2016–2019 for I-15 (interstate) and US-89 (non-interstate), negative binomial models were estimated to establish safety performance functions (SPFs) and crash modification factors (CMFs). The models accounted for traffic volume, segment length, and roadway geometric characteristics, examining various crash types, including dry and wet weather, property damage only, and injury-related crashes. Results show a significant negative association between SN and crash frequency for all crash types on both highway types. Higher SN values (more friction) were linked to fewer crashes. A 10-unit increase in SN was associated with a 7–8% reduction in dry weather crashes on both highway segments. For wet weather crashes, the same increase in SN resulted in a 13% decrease on non-interstate and a 21% decrease on interstate highways. The impact of SN on reducing crashes was particularly strong on interstate highways during wet conditions, indicating that pavement friction is vital for safety in these scenarios. Additionally, the safety impact of skid resistance was greater on segments with more curved portions. These findings suggest that enhancing pavement friction through measures like high friction surface treatments could significantly improve traffic safety. The results support the continued collection of skid data by transportation agencies to identify high-risk locations and prioritize friction improvement efforts to enhance roadway safety.

Authors	Farzin Maniei, Parsons Corporation Stephen Mattingly, University of Texas, Arlington
Sponsoring Committee	Safety Performance and Analysis (ACS20)
Session Number	**2206**
Session Title	**Safety Performance and Analysis with Crash Predictions**
Paper Number	25-00996
Paper Title	**Investigating the Impact of Recommended Fragment Size to Improve Crash Count Prediction Models**
Abstract	The I-4 Express Lanes introduce innovative freeway design on Interstate 4, significantly impacting traffic safety and operations. This research develops short-term Safety Performance Functions (SPFs) for express lanes (ELs) and general-purpose lanes (GPLs) using crash data from February 2022 to February 2024. Utilizing microscopic lane-level traffic detector data and unique geometric design features, the study aims to predict annual weekday crash frequency, revealing safety changes over time. The proposed short-term crash prediction model employs the Poisson Lognormal Lindley (PLN-L) technique, effectively addressing excessive zeros in crash data, particularly on the ELs. The analysis considers independent variables such as lane-level traffic characteristics, geometric data (e.g., standard segment types, EL access-specific segment types, their lengths, and ramp lengths), and the impact of different time periods. Significant variables for EL and GPL segments include lane-level traffic exposure and other factors. Key findings indicate that the average speed in the rightmost lanes significantly impacts EL safety, with higher crash rates observed at merge segments. For GPLs, specific segment types and short lengths (≤1500 ft) are correlated with increased crashes. Significant variables include lane-level traffic exposure and other contributing factors. These insights are valuable for operators, policymakers, and practitioners in evaluating the safety efficacy of the I-4 EL strategy and identifying critical crash factors. This study aims to encourage proactive safety strategies and produce SPFs for special locations suitable for future editions of the Highway Safety Manual.

Authors	Lei Han, University of Central Florida Mohamed Abdel-Aty, University of Central Florida Yang-Jun Joo, University of Central Florida Shaoyan Zhai, University of Central Florida Dongdong Wang, University of Central Florida
Sponsoring Committee	Safety Performance and Analysis (ACS20)
Session Number	**2240**
Session Title	**Safety Performance and Analysis for Safe Roads**
Paper Number	25-01386
Paper Title	**Intersection Crash Frequency Analysis Considering Drivers' Visual Environment Features**
Abstract	Existing intersection crash analysis studies primarily focus on macro-level infrastructure and traffic conditions. However, drivers' micro-level visual perception of the surrounding environment may also influence their driving behavior and safety, a factor that has not yet been fully investigated. To address this gap, this study developed a deep learning model to extract drivers' visual environment features from Google Street View (GSV) images. Eight-angle GSV images were collected to capture the entire intersection environment, and six types of objects in the images were segmented: sky, road, buildings, vegetation, vehicles, and walk areas. The pixel proportions of these objects were then aggregated to represent the features of the drivers' visual environment. These features, combined with geometric design, traffic, and socioeconomic factors, were incorporated into a Negative Binomial model to analyze their impact on intersection crashes. The empirical study used data from 501 signalized intersections in Florida. The results revealed that: 1) Including visual environment features improves model fit compared to traditional approaches, as shown by lower AIC and BIC values and a higher R^2. 2) For total crashes, intersections near underserved communities experience more crashes. Two visual environment features—buildings and vegetation—are significantly negatively correlated with crash frequency. 3) Contributing factors vary by crash type. Overall, a higher proportion of buildings and vegetation at intersections reduces the frequency of rear-end, sideswipe, and severe crashes, while a higher proportion of road and vehicles increases visual complexity, potentially impacting safety.

Authors	Vinayak Dixit, University of New South Wales Anurag Pande, California Polytechnic State University, San Luis Obispo
Sponsoring Committee	Safety Performance and Analysis (ACS20)
Session Number	**2206**
Session Title	**Safety Performance and Analysis with Crash Predictions**
Paper Number	25-02602
Paper Title	**Roadway Safety Performance Estimation Using Incomplete Data**
Abstract	This paper proposes a method for estimating safety performance functions using only data from sites that have experienced more than a minimum threshold of crashes in a given period. The method assumes that the crash frequency distribution at such sites follows a negative binomial distribution with a constant mean and dispersion parameter. Using a maximum likelihood approach, the method estimates the model parameters and provides confidence intervals for the estimates. The method is applied to a dataset of fatal/injury collisions from corridor segments along an approximately 19-mile I-80 corridor in California (USA). To assess the validity of the approach, an SPF was estimated from the complete dataset and compared with results obtained by truncating the data to include only sites with collision counts above certain thresholds. The results indicate that the proposed method produces similar estimates of the mean crash frequency and dispersion parameter, but with narrower confidence intervals and lower standard errors. Additionally, the proposed method avoids the problem of zero inflation, which affects the conventional approach when using data from all sites rather than exclusively from sites with higher crash counts. The results also demonstrate that, even at a lower threshold of data availability (e.g., 3 crashes), reasonable SPFs can be estimated. The study discusses the advantages and limitations of the proposed method and suggests directions for future research, particularly emphasizing its value in adopting a safe systems approach in the developing world.

Authors	Bekir Bartin, Ozyegin Universitesi Kaan Ozbay, New York University
Sponsoring Committee	Safety Performance and Analysis (ACS20)
Session Number	**2206**
Session Title	**Safety Performance and Analysis with Crash Predictions**
Paper Number	25-03413
Paper Title	**Safety Performance Functions for Rural Two-Lane Two-Way Roadways in New Jersey**
Abstract	n.d.

Authors	Tianyu Shen, Morgan State University Di Yang, Morgan State University Kun Xie, Old Dominion University Hong Yang, Old Dominion University Xianfeng Yang, University of Maryland, College Park Mansoureh Jeihani, Morgan State University
Sponsoring Committee	Safety Performance and Analysis (ACS20)
Session Number	**2240**
Session Title	**Safety Performance and Analysis for Safe Roads**
Paper Number	25-04602
Paper Title	**Development of a Functional Conflict-based Safety Performance Function for Signalized Intersections Using the pNEUMA Data**
Abstract	This research proposes a new functional conflict-based Safety Performance Function (SPF) model that addresses gaps in existing SPF models, which primarily rely on aggregated safety data. By capturing intra-signal cycle variations, this study provides a more precise understanding of how safety risk factors evolve over time. The findings offer actionable insights for proactive traffic safety management, making it highly relevant for TRB attendees interested in innovative methodologies to improve road safety.

Authors	Richard Dzinyela, Texas A&M Transportation Institute Mohammadali Shirazi, University of Oklahoma, Norman Subasish Das, Texas State University Dominique Lord, Texas A&M University
Sponsoring Committee	Safety Performance and Analysis (ACS20)
Session Number	**2206**
Session Title	**Safety Performance and Analysis with Crash Predictions**
Paper Number	25-04756
Paper Title	**Time-Dependent Negative Binomial-Lindley Model for Addressing Temporal Variations and Excess Zeros in Crash Data**
Abstract	This research addresses two critical challenges in crash data analysis: excess zeros and temporal variations. The study demonstrates the derivation and application of the NBL-TiDP model and its superiority over traditional models in addressing these issues. Attendees interested in improving traffic safety, modeling techniques, understanding the effects of temporal factors on crash data, and refining predictive capabilities in transportation safety will find this presentation both innovative and practical. The research is grounded in robust statistical modeling and validated through simulation and empirical datasets

Authors	Mohammad Anis, Texas A&M University Srinivas R. Geedipally, Texas A&M Transportation Institute Dominique Lord, Texas A&M University
Sponsoring Committee	Transit Safety and Security (AP080)
Session Number	**3082**
Session Title	**Special Topics in Transit Safety: Vulnerable Road Users and Transit Collisions**
Paper Number	25-04784
Paper Title	**Safety Performance Functions by Random Parameters Negative Binomial-Lindley Model for Pedestrian Safety Near Bus Stops**
Abstract	This study addresses the critical need for enhanced pedestrian safety near bus stops on urban roadways by analyzing the risk factors contributing to pedestrian crashes associated with roadway and bus stop characteristics. Although pedestrian crashes near bus stops are common, previous research has provided limited quantitative analysis of the factors influencing crash likelihood. To address this gap, the study develops Safety Performance Functions (SPFs) to evaluate various factors contributing to crashes, using crash data from 596 bus stop sites in Fort Worth, Texas, between 2015 and 2019. The methodology employs the Random Parameters Negative Binomial-Lindley (RPNB-L) model, which incorporates a mixed distribution approach to account for variability in the influence of explanatory variables across different observations. The RPNB-L model demonstrated statistically superior performance compared to the Negative Binomial (NB) and fixed-coefficient Negative Binomial-Lindley (NB-L) models. Key findings reveal that exposure variables, the roadway environment, and bus stop design features significantly impact pedestrian crash frequency. These insights provide a foundation for transportation agencies to implement targeted countermeasures to enhance roadway safety near bus stops, ultimately aiming to reduce and prevent pedestrian crashes in urban environments.

Authors	Kazi Redwan Shabab, CDM Smith Inc Tanmoy Bhowmik, Portland State University Mohamed Zaki, University of Western Ontario Naveen Eluru, University of Central Florida
Sponsoring Committee	Safety Performance and Analysis (ACS20)
Session Number	**2206**
Session Title	**Safety Performance and Analysis with Crash Predictions**
Paper Number	25-04831
Paper Title	**A Joint Count and Generalized Ordered Fractional Split Approach for Addressing Temporal Instability in Road Safety Analysis**
Abstract	This study addresses temporal instability in multivariate crash frequency models using data from the Greater Orlando Region (2011-2019). It compares the performance of the Joint Negative Binomial-Generalized Ordered Probit Fractional Split (NB-GOPFS) model with that of the Mixed Negative Binomial model, with a specific emphasis on parameter temporal variability. The dataset includes four injury severity categories: no injury, minor injury, non-incapacitating injury, and serious injury. The independent variables considered include sociodemographic, land use, and transportation infrastructure variables. Performance assessments using root mean square error (RMSE) values show that the NB-GOPFS model consistently outperforms the Mixed Negative Binomial model in accuracy and parsimony. The NB-GOPFS approach enhances prediction accuracy and model simplicity, making it effective for crash frequency modeling with temporal instability in exogenous variables. This study supports the integration of advanced multivariate models in transportation safety analysis to improve intervention strategies and policymaking.

Authors	Qikang Zheng, Southeast University Fariya Sharmeen, KTH Royal Institute of Technology Chengcheng Xu, Southeast University
Sponsoring Committee	Safety Performance and Analysis (ACS20)
Session Number	**2206**
Session Title	**Safety Performance and Analysis with Crash Predictions**
Paper Number	25-05657
Paper Title	**Analyzing Crash Frequency and Crash Type Dynamics in Sweden from 2017 to 2022 Using a Hierarchical Modeling Approach**
Abstract	This research addresses critical aspects of traffic safety by examining crash frequency and types on national-level roads in Sweden, using a hierarchical modeling approach that accounts for both segment-specific and regional factors. The findings highlight the influence of environmental variables, road design, and sociodemographic conditions on crash dynamics, offering a detailed understanding to guide targeted safety interventions. Additionally, the study evaluates the impact of the COVID-19 pandemic on crash patterns, providing timely insights into how unprecedented global events affect road safety.

Authors	Abdulrahman Faden, University of Central Florida Mohamed Abdel-Aty, University of Central Florida Samgyu Yang, University of Central Florida Abdulrahman Faden, University of Central Florida
Sponsoring Committee	Safety Performance and Analysis (ACS20)
Session Number	**2206**
Session Title	**Safety Performance and Analysis with Crash Predictions**
Paper Number	25-05992
Paper Title	**Developing Temporal Safety Performance Functions for Fully Separated Express Lanes Using the Poisson Lognormal Lindley (PLN-L) Model**
Abstract	The I-4 Express Lanes introduce innovative freeway design on Interstate 4, significantly impacting traffic safety and operations. This research develops short-term Safety Performance Functions (SPFs) for express lanes (ELs) and general-purpose lanes (GPLs) using crash data from February 2022 to February 2024. Utilizing microscopic lane-level traffic detector data and unique geometric design features, the study aims to predict annual weekday period crash frequency, revealing safety changes over time. The proposed short-term crash prediction model employs the Poisson Lognormal Lindley (PLN-L) technique, effectively addressing excessive zeros in crash data particularly on the ELs. The analysis considers independent variables such as lane-level traffic characteristics, geometric data (e.g., standard segment types, EL access specific segment types, their lengths, and ramp lengths), and the impact of different time periods. Significant variables for EL and GPL segments include lane-level traffic exposure and other factors. Key findings indicate that the average speed in the rightmost lanes significantly impacts EL safety, with higher crash rates observed at merge segments. For GPLs, specific segment types and short lengths (≤1500 ft) are correlated with increased crashes. Significant variables include lane-level traffic exposure and other contributing factors. These insights are valuable for operators, policymakers, and practitioners in evaluating the safety efficacy of the I-4 EL strategy and identifying critical crash factors. This study aims to encourage proactive safety strategies and produce Safety Performance Functions (SPFs) for special locations suitable for future editions of the Highway Safety Manual.

Authors	Prakash Poudel, Pennsylvania State University Eric Donnell, Pennsylvania State University, University Park Vikash Gayah, Pennsylvania State University, University Park
Sponsoring Committee	Safety Performance and Analysis (ACS20)
Session Number	**2240**
Session Title	**Safety Performance and Analysis for Safe Roads**
Paper Number	25-06342
Paper Title	**Safety Performance of Passing Zone Segments on Two-lane Rural Highways in Pennsylvania: Comparing Crash Modification Factors using Causal Inference and Unobserved Heterogeneity Models**
Abstract	Although passing zones on two-lane rural highways are intended to enhance safety and mobility, the safety research literature has not documented Crash Modification Factors (CMFs) for the presence of passing zones on such roads. This study addresses this gap by developing a CMF for the presence of passing zones on two-lane rural roads and analyzing the results using two established modeling approaches.

5 Crash Severity Prediction

Alfonso Montella, Maria Rella Riccardi, and Antonella Scarano
University of Naples Federico II

The subcommittee identified **ninety-three papers** dealing with crash severity prediction. Indeed, the identification of factors contributing to crash severity is crucial for planning, designing, and managing a safer transport system. The large number of papers dealing with crash severity prediction highlights how this issue is becoming important for the scientific community. Great emphasis is given to fatal and injuries crashes also at political level. The UN General Assembly Resolution 74/299 declares the period 2021–2030 as the Second Decade of Action for Road Safety, with the target of decreasing road traffic deaths and injuries by at least 50 per cent from 2021 to 2030. Furthermore, the EU set the goal of halving the number of serious injuries in the EU by 2030 from the 2021 baseline using a common definition based on the MAIS 3+ trauma scale.

The papers are distributed across ten different sessions:

- 2123 Creating a Safer System: A Lectern-Poster Session;
- 2171 Decision Making with Safety Surrogates;
- 2206 Safety Performance and Analysis with Crash Predictions;
- 2240 Safety Performance and Analysis for Safe Roads;
- 3039 Transportation Safety Management Systems from Start to Finish;
- 3147 Safety Performance and Analysis Using Machine Learning or Artificial Intelligence;
- 3213 Safety Performance and Analysis for Safe Road Users and Safe Speeds;
- 4004 The Future of Safety Performance and Analysis;
- 4073 Safety Performance and Analysis for Safe Vehicles;
- 4081 Advancements in Emergency Response, Incident Management, and Post-Crash Care: Innovative Approaches to Enhancing First Responder Safety and Efficiency.

Twenty-seven papers investigated vulnerable road users highlighting how the safety of pedestrian, cyclist and powered two-wheelers is a growing concern for transportation planners and safety engineers:

- Pedestrians (25-00341; 25-00524; 25-01266; 25-01356; 25-02110; 25-02183; 25-02461; 25-03225; 25-03750; 25-04099; 25-04271; 25-04418; 25-04729; 25-05004; 25-05800; 25-03146; 25-03254);
- Cyclists (25-02793; 25-03101; 25-04418; 25-04710; 25-04729; 25-05004; 25-05800);
- Powered Two-Wheelers (25-00080; 25-00102; 25-01286; 25-03313; 25-04418; 25-04710; 25-05036; 25-06304; 25-06437).

Below, for each of the forty papers involving crash severity prediction, the following information is provided: authors, sponsoring committee, session number, session title, paper number, paper title, and abstract.

Authors	Samgyu Yang, University of Central Florida Mohamed Abdel-Aty, University of Central Florida Zubayer Islam, University of Central Florida Dongdong Wang, University of Central Florida
Sponsoring Committee	ACS20
Session Number	2206
Session Title	**Safety Performance and Analysis with Crash Predictions**
Paper Number	25-02171
Paper Title	**Large-Scale Real-time Crash Prediction: A Comprehensive System and Analyses**
Abstract	The rapid increase in traffic volume and complexity necessitates advanced real-time crash prediction systems to enhance road safety. This study introduces a comprehensive crash risk prediction system that integrates real-time traffic and weather data, using advanced machine learning techniques. The system features a modular architecture, including crash prediction, CCTV integration and user-friendly GUI modules, providing precise and timely predictions. Segment-specific models tailored to different segment types ensure accuracy and relevance. The system's performance was thoroughly evaluated, achieving high sensitivity and low false alarm rates. Specifically, the best model configuration achieved sensitivity improvements in the range of 0.839-0.918 and false alarm rate reductions to 0.073-0.208, depending on the segment type. The results demonstrate that the system can accurately predict crashes and provide timely warnings, enabling traffic operators to take preemptive actions such as adjusting traffic management systems, deploying emergency response teams, or providing real-time warnings to drivers. By predicting both the occurrence and severity of crashes, as well as the risk of secondary crashes, the system enhances the overall efficiency and effectiveness of traffic crash management. Continuous evaluation and adjustment of the system's parameters are essential to maintain its accuracy and reliability under changing traffic conditions. This comprehensive approach to crash prediction represents a significant advancement in proactive traffic management and road safety enhancement.

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Sponsoring Committee	ACS20
Session Number	2206
Session Title	**Safety Performance and Analysis with Crash Predictions**
Paper Number	25-02717
Paper Title	**Sequential Accidents on Likelihood of Having Injuries: Assessing the Relationship between the Likelihood of Having Injuries of the Current and Previous Crashes**
Abstract	Drivers are tending to be involved in multiple accidents during their lifetime, resulting in injuries or even fatalities. This study aims to investigate the likelihood of getting injuries in current accidents if drivers get injured during their most recent accidents. A sample of 6282 Jordanian drivers who experienced three accidents were included in this study and their characteristics, vehicles' features, environmental factors as well as drivers' behaviors. The outcomes of accidents were categorized into non-injury and injury and a random parameter bivariate probit model with means heterogeneity approach is applied to address prevailing unobserved heterogeneity as well as correlation between crash outcomes of two consecutive crashes that were modeled. Two models were estimated for the first-second crashes and second-third crashes, respectively. The model estimation results highlighted the significant correlation among three crashes. Moreover, vehicle brand and features, environment where crashes occurred, seatbelt usage, and violation of traffic rules have significant contributions to the likelihood of having injuries in crashes. These findings can facilitate policymakers, and road operators to understand the pattern of sequential crashes, identify risky drivers who are frequently involved in crashes with injuries, and take appropriate actions to prevent drivers from having more injuries or fatalities in the future.

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Sponsoring Committee	ACS20
Session Number	2206
Session Title	**Safety Performance and Analysis with Crash Predictions**
Paper Number	25-03631
Paper Title	**Quantifying Road Network Structure and Its Impact on Traffic Crashes: A Bayesian Hierarchical Approach**
Abstract	Road traffic crashes (RTCs) are a major cause of fatalities worldwide. Recent studies indicate that the influence of road network structure on RTCs has not been adequately explored, and the results from the limited previous studies are inconsistent. This inconsistency can be attributed to the methodologies employed in earlier studies, which often relied on visual inspection to quantify road network structure. This approach is both subjective and impractical. Additionally, the failure to account for spatial autocorrelation and overdispersion in modelling can also lead to inconsistent results. This study aims to address these gaps by using graph theory metrics to quantify road network structure and developing a statistical model to understand how network characteristics like connectivity, density, complexity and centrality correlate with RTCs, accounting for overdispersion, unobserved heterogeneity and spatial autocorrelation. Using a Bayesian hierarchical model, the study conducts a spatial analysis of fatal RTCs at ward level for Delhi, India. The findings reveal a significant association between higher road network connectivity and increased fatal RTC risk. Areas with a higher density of intersections involving major roads also experience more fatal crashes. Intersections deviating from the typical 90-degree angle (higher skewness) are linked to higher fatal RTCs. Conversely, an efficient network structure (less circuity) is associated with lower fatal RTCs, while network centrality shows a negative correlation with fatal RTCs. These results should not be interpreted in isolation, as road network characteristics also interact with factors like traffic volumes, speeds, and environmental conditions impacting safety.

Authors	Kazi Redwan Shabab, CDM Smith Inc Tanmoy Bhowmik, Portland State University Mohamed Zaki, University of Western Ontario Naveen Eluru, University of Central Florida
Sponsoring Committee	ACS20
Session Number	2206
Session Title	**Safety Performance and Analysis with Crash Predictions**
Paper Number	25-04831
Paper Title	**A Joint Count and Generalized Ordered Fractional Split Approach for Addressing Temporal Instability in Road Safety Analysis**
Abstract	This study addresses temporal instability in multivariate crash frequency models using data from the Greater Orlando Region (2011-2019). We compare the performance of the Joint Negative Binomial-Generalized Ordered Probit Fractional Split (NB-GOPFS) Model with the performance of the Mixed Negative Binomial Model with a specific emphasis on parameter temporal variability. The dataset includes four injury severity categories: no injury, minor injury, non-incapacitating injury, and serious injury. The independent variables considered include sociodemographic, land use, and transportation infrastructure variables. Performance assessments using root mean square error (RMSE) values show that the NB-GOPFS model consistently outperforms the Mixed Negative Binomial model in accuracy and parsimony. The NB-GOPFS approach enhances prediction accuracy and model simplicity, making it effective for crash frequency modeling with temporal instability in exogenous variables. This study supports the integration of advanced multivariate models in transportation safety analysis to improve intervention strategies and policymaking.

Authors	Kommoju Prathyusha, Indian Institute of Technology, Roorkee Amit Agarwal, Indian Institute of Technology, Roorkee Indrajit Ghosh, Indian Institute of Technology, Roorkee
Sponsoring Committee	ACS20
Session Number	2206
Session Title	**Safety Performance and Analysis with Crash Predictions**
Paper Number	25-05809
Paper Title	**ENHANCING CRASH SEVERITY PREDICTIONS ON NATIONAL HIGHWAYS: AN ORDERED MODELING APPROACH WITH FEATURE SELECTION**
Abstract	The present study investigates the factors contributing to crash severity, accounting for its ordered nature. The data is collected for National Highways in Himachal Pradesh, India; a crash severity analysis is performed using the Ordered Logit Model, Ordered Forest, and Ordered Support Vector Machines. The dataset used for analysis is enhanced using class balancing techniques like Synthetic Minority Over-Sampler Technique, Random Undersampling, and Synthetic Minority Over-Sampler Technique-Edited Nearest Neighbours. The redundant variables are removed using feature selection techniques based on mutual information scores and the chi-square test. The results indicate that dangerous driving in rural areas increases the likelihood of crashes by 0.24. Collision types such as head-on and runoff roads increased the possibility of severe crashes by 0.44 and 1.68, respectively. Some of the factors contributing to the increase in crash severity include poor weather and vehicle conditions in conjunction with the age group 25-35 (0.95), declining gradient of road with single carriageway (0.83), and Motorized Two-Wheelers (MTW) (0.91). Conversely, using cars, Light Commercial Vehicles (LCVs), and vans reduces the possibility of severe crashes by 0.68 when they are an impacted vehicle and by 0.42 when both vehicle types involved in the crashes are among cars, LCVs, and vans. Therefore, the targeted interventions and strategies focusing on these identified factors enhance safety. The study's findings help guide policymakers and planners in improved decision-making and targeted safety intervention planning.

Authors	Hellen Shita, Florida International University HM Nayem, Florida International University Priyanka Alluri, Florida International University
Sponsoring Committee	ACS20
Session Number	2206
Session Title	**Safety Performance and Analysis with Crash Predictions**
Paper Number	25-05847
Paper Title	**Predicting Injury Severity of Work Zone Crashes Along Florida Freeways**
Abstract	With increasing demand for capacity improvement, future highway construction, and the need for newer infrastructure, the U.S. will likely experience more and more extended work zones along its roadways. Work zones are often characterized by lower speeds, changes in traffic patterns, and sometimes narrower lanes, leading to safety compromises of workers, motorists, and other road users. As higher speed limits usually characterize freeways, the significant speed reductions along work zones create substantial shifts for drivers. The abrupt changes in speed and traffic patterns influence the occurrence of crashes as well as injury severity. This study used 2018 to 2022 Florida's work zone data in conjunction with freeway crashes to determine factors influencing the injury severity of crashes occurring along its freeway work zones. Six models, including the K-nearest neighbor, support vector machine, random forest, extreme gradient boosting, multinomial logistic regression, and ordinal regression, were compared in terms of their prediction performance using various metrics. The random forest model was observed to be superior in its classification capacity and hence used for the data analysis. Variable importance and partial dependency plots were used to interpret the model and understand the influence of roadway, environmental, temporal, and human factors associated with work zone crash injury severity. Findings from this study will be helpful to traffic engineers and other responsible agencies in freeway work zone planning to reduce crash injuries and improve roadway safety.

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Sponsoring Committee	ACS20
Session Number	2240
Session Title	**Safety Performance and Analysis for Safe Roads**
Paper Number	25-00049
Paper Title	**Crash Injury Severity Investigation along Interstate-64 in Kentucky**
Abstract	This study identified the factors affecting crash injury severity along Kentucky's primary interstate, Interstate-64. The analysis utilized a variety of microscopic real-time weather variables (air temperature, relative humidity, solar radiation, precipitation, and wind speed), as well as detailed traffic, roadway, environmental, driver-specific, and vehicle-related variables. Additionally, microscopic hourly traffic volume data (extracted from automatic traffic recorder (ATR) loops) and hourly travel speed were used instead of relying on the macroscopic annual average daily traffic. Notably, the study incorporated the rarely-explored real-time weather variable, solar radiation (in Watts/m^2).

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Sponsoring Committee	ACS20
Session Number	2240
Session Title	**Safety Performance and Analysis for Safe Roads**
Paper Number	25-02613
Paper Title	**Evaluating the Impact of Pavement Conditions on Road Safety by Analyzing Crash Frequency and Severity**
Abstract	Road safety is impacted by a range of factors that can be categorized into human, vehicle, and roadway/environmental elements. This research explores the connection between pavement performance and road safety, particularly in relation to crash frequency and severity, using data from the Iowa Department of Transportation (DOT) for 2022. By merging crash data with pavement inventory data, we conduct a spatial analysis that incorporates the geographical coordinates of crash sites with the conditions of road segments. Statistical methods are applied to compare crash rates and severities across various pavement condition categories. To pinpoint the most influential factors affecting crash rates and severity, we use machine learning models along with negative binomial and ordered probit regression models. The study's key findings reveal that higher speed limits, well-maintained roads, and improved friction scores correlate with lower crash rates, whereas rougher roads and adverse weather conditions are linked to higher crash severity. This analysis emphasizes the critical need for prioritizing pavement maintenance and integrating safety-focused design principles to boost road safety. Additionally, the study underscores the ongoing need for research to better understand and address the intricate relationship between pavement performance and road safety.

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Sponsoring Committee ACS20

Session Number 2240

Session Title **Safety Performance and Analysis for Safe Roads**

Paper Number 25-04856

Paper Title **Injury Severity Analysis of Workzone Crashes in North Carolina**

Abstract This study utilizes data obtained from the Highway Safety Information System (HSIS) on crashes occurring in the workzones in North Carolina to model injury severities and identify critical factors. The study uses two years of crash data (2021-2022). An ordered logit model is developed to identify the factors affecting different levels of injury severities for the years 2021-2022. The severity levels were divided into three categories: 1) fatal and grievous, 2) minor and possible injury, and 3) no injury. The results showed that environmental settings (urban or rural) significantly impact workzone crashes with higher injury severity in rural areas. Lighting conditions and terrain type are important in determining the severity of crashes. Dark roadways tend to increase the severity of crashes significantly. Road configuration and curvature are crucial in determining the severity, with one-way divided roads causing less severe crashes than two-way divided roads. Access control is a significant variable highlighting the importance of regulating the extent of accessibility to roads that have workzones.

Workzone-activity-related factors were explored by examining marginal effects for further interpretation of results. The need for correct work-zone management strategies is discussed at the end of the study, highlighting the importance of access control in workzones, enhanced lighting conditions, speed management strategies in rural areas and level terrains, and education of very young drivers.

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Sponsoring Committee ACS20

Session Number 2240

Session Title **Safety Performance and Analysis for Safe Roads**

Paper Number 25-05589

Paper Title **Analyzing Head-On Crash Severity on Rural Two-Lane Roads**

Abstract Although head-on collisions are relatively fewer with respect to total traffic crashes, they account for a high percentage of fatalities and serious injuries. This study employed Ordinal Logistic Regression (OLR) to investigate the contributing factors that affect the injury severity of head-on crashes on rural two-lane roads in North Carolina. Utilizing data from the Highway Safety Information System (HSIS), this analysis categorizes injury severity into three levels and correlates it with various roadway, temporal, and environmental factors. The model's predictors include lighting condition, road surface type, and intersection traffic control, with the outcome variable reflecting increasing injury severity from no injury to fatality. The results indicate severe injuries are less likely at intersections and more common on arterials and collectors, with wider shoulders correlating with higher injury severity. This study contributes to traffic safety by identifying key factors influencing head-on crash outcomes on rural two-lane roads, which could guide infrastructure improvements and policy revisions.

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Sponsoring Committee ACS20

Session Number 2240

Session Title **Safety Performance and Analysis for Safe Roads**

Paper Number 25-03039

Paper Title **A Hybrid Data Mining Framework to Investigate Roadway Departure Crashes on Rural Two-lane Highways: Applying Fast and Frugal Tree with Association Rules Mining**

Abstract
The complexity of factors contributing to roadway departure (RwD) crashes on rural highways necessitates advanced analytical approaches to enhance traffic safety. This study presents a hybrid data mining framework that combines the Fast and Frugal Tree (FFT) and Association Rules Mining (ARM) algorithms to identify the patterns of RwD crashes on rural 2-lane highways in Louisiana state. The research is focused on addressing two critical research questions (RQ), RQ1: Which variable features contribute to the fatal-severe RwD crashes? RQ2: Focusing on the identified top factors contributing to fatal-severe RwD crashes, how co-occurrence of different crash-contributing factors increase the likelihood of RwD crashes? For the analysis, this research team collected crash data from the Louisiana Department of Transportation and Development, encompassing a total of 22,988 unique RwD crashes on rural 2-lane highways. Based on the findings, the FFT model identified the top variable features contributing to fatal-severe RwD crashes, including no use of seatbelts, alcohol-impaired driver condition, male gender, 12 am – 6 am, dark-no-streetlight, 45-54 years age group, light truck, on-grade vertical alignment, and so on. Subsequently, ARM explored how these factors interact and associate, revealing intricate drivers' behavioral patterns related to RwD crashes. This comprehensive analysis uncovers not only the individual impact of these factors but also their combined effects, offering a deeper understanding of the dynamics of RwD crashes. This research contributes valuable insights into evidence-based, data-driven strategies to reduce the frequency and severity of RwD crashes on rural highways, advancing traffic safety initiatives and improving safety on rural 2-lane roadways.

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Sponsoring Committee ACS20

Session Number 2240

Session Title **Safety Performance and Analysis for Safe Roads**

Paper Number 25-04696

Paper Title **Analyzing Contributing Factors to Crashes Involving Mobile and Stationary Work Zones**

Abstract
hile work zones are crucial for infrastructure sustainability, they pose significant public safety challenges. Nationally, work zone fatalities have been increasing, with Ohio observing a similar trend. This study analyzed crash severity factors involving mobile and stationary work zones using Ohio crash data from 2019 to 2023. Bayesian binary and hierarchical models were developed and compared, with the hierarchical model performing better. The hierarchical model significantly accounted for the unexplained variation in crash severity which would have been ignored in the binary model. Factors contributing to higher fatal injury likelihoods in both work zones included alcohol or drug use, speeding, vehicle damage, higher posted speed limits, and multi-vehicle crashes. Contrary, safety equipment use and divided roadways decreased the risks in both types. Mobile work zones on curved segments decreased crash severity, while stationary work zones saw increased severity with older and out-of-state drivers, specific collision types, and pre-crashactions. The study recommends using intelligent transportation systems, such as dynamic speed display and advanced traveler information systems, to reduce work zone crashes. The Bayesian hierarchical model's performance highlights its ability to capture complex interactions and variability in crash data. These findings are expected to inform the development of countermeasures for reducing work zone severity.

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Sponsoring Committee	ACS20
Session Number	2240
Session Title	**Safety Performance and Analysis for Safe Roads**
Paper Number	25-00157
Paper Title	**Analysis of Factors Influencing the Severity of Lateral and Longitudinal Conflicts in Diverging Areas: A Correlated Mixed Logit Approach with Heterogeneity in Means**
Abstract	This study addresses the critical issue of traffic safety in urban expressway diverging areas, where high conflict risks are prevalent. By employing innovative modeling techniques and high-precision trajectory data, it provides new insights into the factors influencing traffic risks.

Authors	Lei Han, University of Central Florida Mohamed Abdel-Aty, University of Central Florida Yang-Jun Joo, University of Central Florida Shaoyan Zhai, University of Central Florida Dongdong Wang, University of Central Florida
Sponsoring Committee	ACS20
Session Number	2240
Session Title	**Safety Performance and Analysis for Safe Roads**
Paper Number	25-01386
Paper Title	**Intersection Crash Frequency Analysis Considering Drivers' Visual Environment Features**
Abstract	Existing intersection crash analysis studies primarily consider macro infrastructure and traffic conditions. However, drivers' micro-level visual perception of the surrounding environment might impact also their driving behavior and thus safety, which has not been investigated yet. Therefore, this study developed a deep learning model to extract drivers' visual environment features from Google Street View (GSV) images. Eight-angle GSV images were collected to capture the entire intersection environment, and six types of objects in the images were segmented: sky, road, buildings, vegetation, vehicle, and walk area. Their pixel proportions were then aggregated as the drivers' visual environment's features. These features, along with geometric design, traffic, and socioeconomic features, were combined into a Negative Binomial model to analyze their impact on intersection crashes. Data from 501 signalized intersections in Florida were used for the empirical study. Results show that: 1) The inclusion of visual environmental features results in better model fit than the traditional approach, as reflected by lower AIC and BIC values and a higher R2. 2) For total crashes, intersections near more underserved communities would suffer more crashes. Two visual environment features (i.e., buildings and vegetation) are significantly negative correlated with crash frequency. 3) The contributing factors vary for different crash types. Overall, a high proportion of buildings and vegetation at intersections can reduce rear-end, sideswipe, and severe crashes. However, the proportions of road and vehicle increase visual complexity, thus being significantly positive with the frequency of rear-end and vulnerable road user crashes.

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Sponsoring Committee	ACS20
Session Number	2240
Session Title	**Safety Performance and Analysis for Safe Roads**
Paper Number	25-03617
Paper Title	**Segmentation of Risk Factors for Fatal Crashes at Urban Signalized Intersections: A Hybrid Approach**
Abstract	Signalized intersections are frequently installed in developing countries to facilitate efficient traffic flow and seldom to increase traffic safety. As a result, fatal collisions still occur at intersections with signals. The purpose of this study is to gain a better understanding of signalized intersection safety by identifying and segmenting traffic and geometric risk factors associated with fatal crashes. For this purpose, a thorough road inventory survey—primary crash data—was used to analyze crashes at 67 signalized intersections in 7Hyderabad, an Indian metropolitan city. This paper proposes a hybrid segmentation strategy that classifies a group of important crash factors determining crash fatality at urban signalized intersections by combining machine learning, data mining, and statistical modeling results. The proposed segmentation divided the crash parameters into four distinct categories: very high, high, moderate, and low-risk factors. The key findings show that major road width, number of lanes, lack of right turn protection, all-red time, and clear road markings are the most influential factors contributing to fatal crashes at signalized intersections. Based on the findings, several policy recommendations were proposed. The segmentation of signalized intersection features would provide useful insights into the level of their influence and the impact of signalized intersection design on safety in developing countries. The study's findings and proposed policy insights may assist transportation officials in developing, prioritizing, and implementing specialized safety countermeasures for signalized intersections.

Authors	Mohammed Mohammed, University of Massachusetts, Amherst Jimi Oke, University of Massachusetts, Amherst
Sponsoring Committee	ACS20
Session Number	2240
Session Title	**Safety Performance and Analysis for Safe Roads**
Paper Number	25-05661
Paper Title	**A Spatial Typology Analysis of Crash Characteristics across 2480 Census Tracts**
Abstract	Roadway safety is a critical concern globally, with motor vehicle crashes resulting in significant fatalities and injuries each year. This study aims to develop a data-driven spatial crash typology to enhance our understanding of crash characteristics and improve road safety interventions. Using crash data from Massachusetts and Connecticut, we integrated and standardized datasets, employing Uniform Manifold Approximation and Projection (UMAP) for dimensionality reduction and Gaussian Mixture Modeling (GMM) for clustering. Our analysis identified distinct crash types based on spatial and temporal patterns, vehicle types, and environmental conditions. We validated our typology using a Random Forest classifier, achieving an accuracy of 94%, demonstrating the robustness of our approach. The resulting typology offers valuable insights into crash dynamics, enabling targeted safety measures for different geographic areas in New England. Future research will expand the dataset to include additional states and refine the typology for broader applicability.

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Sponsoring Committee	ACS20
Session Number	2240
Session Title	**Safety Performance and Analysis for Safe Roads**
Paper Number	25-02421
Paper Title	**Determination of the Impact of Roadside Infrastructure on Fatal Crash Occurrence: An Empirical Analysis Using Power Spectral Segment Length.**
Abstract	Highway segmentation into appropriate segment lengths is an essential and fundamental step in standard crash modelling methodology. The current segmentation approaches rely on engineering judgment or individual experience. The main objective of this study is to determine a Power Spectral Segment Length (PSSL) and then evaluate the impact of roadside infrastructure on fatal crash occurrence on rural two-lane highways. The study methodology is based on spectral analysis of crashes in the one-dimensional Spatial Frequency Domain (SFD), where the frequency components represent the inherent patterns of crash distribution along highways. Based on this finding, the PSSL can be determined, and subsequently, the Power Spectral Percentage can be calculated. These metrics can be used to assess the segmentation performance. This study used a Random Parameter Negative Binomial model to determine how roadside infrastructure affects the frequency of fatal crashes on two rural two-lane National Highways and one State Highway in Haryana, India. Three models were developed for each highway: one for the PSSL, another for a segment length shorter than the PSSL, and the third model for a segment length longer than the PSSL. The parameter estimates are statistically significant and more intuitive in their interpretations corresponding to the PSSL-based model. The model results reveal that the roadside service areas, including fuel stations, eateries, and the population, are the most statistically significant parameters and are positively associated with fatal crash occurrences on all the highways. This study demonstrates the utilization of SFD analysis to determine an appropriate segment length for crash analysis.

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Sponsoring Committee	E0000, ACH20, ACH40, ACS10, ACS20, AED30, AED40, AEP25, AEP30, AEP60, AJE15, AKC50, AKD70, AKM40, AKP40, AME10, AME50, AMR00, AMR10, AMR20, AMS30, AMS40, AP075, AV070
Session Number	3109
Session Title	**Transportation Research Board Minority Student Fellows**
Paper Number	25-02425
Paper Title	**Preliminary Analysis of Construction Work Zone on Roadways in Florida by Crash Severity**
Abstract	Construction zones are inherently hazardous, posing significant risks to construction workers and motorists. Despite existing safety measures, construction zones continue to witness fatalities and serious injuries, imposing economic burdens. Addressing these issues requires understanding root causes and implementing preventive strategies centered around the 4Es (Engineering, Education, Enforcement, Emergency Response) and 4Is (Information Intelligence, Innovation, Insight into communities, Investment, and Policies). Proper safety management, integrating these strategic initiatives, aims to reduce and potentially eliminate fatalities and serious injuries in work zones. In Florida, road construction work zone fatalities and serious injuries remain a critical concern, especially in urban counties. Despite a $12 billion infrastructure investment in 2022, Florida ranks eighth nationally for fatal work zone crashes involving commercial motor vehicles (CMVs). Analysis from 2019 to 2023 shows an average of 71 fatalities and 309 serious injuries annually in Florida's work zones, reflecting a persistent safety challenge. High-risk counties include Orange, Broward, Duval, Hillsborough, Pasco, Miami-Dade, Seminole, Manatee, Palm Beach, and Lake. This study presents a preliminary analysis of work zone crashes in Broward, Duval, Hillsborough, and Orange counties. A multilogit model assessed attributes contributing to fatalities and serious injuries, such as crash type, weather and light conditions, work zone type, type of shoulder, presence of workers, and law enforcement. Results indicate significant contributing factors, highlighting opportunities to use machine learning for alerting drivers and construction managers, ultimately enhancing safety protocols and reducing fatalities.

Authors

Sponsoring Committee ACS20

Session Number 3147

Session Title **Safety Performance and Analysis Using Machine Learning or Artificial Intelligence**

Paper Number 25-02220

Paper Title **Driver’s Injury Severity Prediction for Two-Vehicle Crashes: A Hybrid Approach Using Machine Learning Algorithms**

Abstract A precise prediction of crash severity in road accidents significantly improves traffic safety. Despite driver’s fatal injuries in a two-vehicle crash causing significant human losses in developing countries, limited research has been conducted to identify the impacts of contributing factors responsible for driver’s injury severity in a two-vehicle crash. This study aims to propose an interpretable hybrid machine learning model in predicting injury severity for drivers in a two-vehicle crash and identifying the contributing factors. The hybrid model was compared with five individual machine learning algorithms for performance evaluation Dhaka’s recent two-vehicle crash data (2017-2020) from a sample of 1494 crashes was used. Feature selection was carried out by random forest features importance. The results showed that the hybrid model, built on combining logistic regression, random forest, and adaptive boosting, outperforms other individual models with an accuracy of 75% and an AUC score of 0.71. Among the individual models, the random forest algorithm performed better. The most significant features impacting the driver's injury severity in a two-vehicle crash were the day of the week, vehicle type, time of the day, vehicle maneuver, and road geometry.

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Sponsoring Committee ACS20

Session Number 3147

Session Title **Safety Performance and Analysis Using Machine Learning or Artificial Intelligence**

Paper Number 25-02793

Paper Title **Exploring Spatial Variations in Factors Influencing Bicyclist Injury Severity in Traffic Crashes: A Spatial Machine Learning Approach**

Abstract Bicyclists are vulnerable road users, and their safety has become more important as cycling has increased in the past decade. Many studies have tried to find factors linked to bicyclist injuries in crashes. But these factors can vary due to hidden differences in geographic and socioeconomic contexts, which past research often overlooks. This study aims to explore how these factors change across different areas and their impact on injury severity.

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Sponsoring Committee	ACS20
Session Number	3147
Session Title	**Safety Performance and Analysis Using Machine Learning or Artificial Intelligence**
Paper Number	25-03124
Paper Title	**Analysis and Prediction of Traffic Accidents Based on Interpretable Spatial Machine Learning: A Case Study in California**
Abstract	Traffic accidents are not only the leading cause of fatalities and disabilities but also impose substantial economic losses on society. However, understanding the nonlinear and heterogeneous relationship between environmental factors and traffic accidents remains challenging. This study establishes an interpretable spatial machine learning framework to address the nonlinearity, spatial heterogeneity, and interpretability of this issue through the geographically weighted support vector machine (GW-SVM) model. Utilizing a large-scale traffic accident dataset and leveraging multi-source big data, this study provides both global and local interpretations of the nonlinear associations in California, United States. Our findings highlight that: (1) the Visibility factor plays a more significant role in the relationship between environmental factors and traffic accident severity. (2) All environmental variables, encompassing both natural and socio-economic factors, exhibit nonlinear and threshold effects on traffic accidents. (3) Compared to existing models, the GW-SVM model demonstrates improved performance in predicting the severity of urban road traffic accidents. These findings are of great significance for reducing the risk of traffic accidents.

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Sponsoring Committee	ACS20
Session Number	3147
Session Title	**Safety Performance and Analysis Using Machine Learning or Artificial Intelligence**
Paper Number	25-03146
Paper Title	**Beyond the Conventional: Exploring Pedestrian Safety on Interstates with Bayesian and Machine Learning Models**
Abstract	This presentation offers critical insights into pedestrian safety on interstates by leveraging statistical and machine learning approaches. The study identifies unsafe pedestrian actions, roadway, and vehicle characteristics that influence pedestrian crash injury severity on interstates, providing actionable recommendations for infrastructure improvements, policy interventions, and public awareness campaigns.

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Sponsoring Committee	ACS20
Session Number	3147
Session Title	**Safety Performance and Analysis Using Machine Learning or Artificial Intelligence**
Paper Number	25-01619
Paper Title	**Enhancing Autonomous Vehicle Safety: A Hybrid Ensemble Learning-Logit Model for Accident Severity Prediction and Analysis**
Abstract	This presentation introduces a Hybrid Ensemble Learning-Logit Model (HELLM) to enhance autonomous vehicle (AV) safety by accurately predicting accident severity and identifying key influencing factors such as automation levels, speed, and driver behavior. The findings provide actionable insights for transportation policy, traffic safety, and AV system development, offering strategies for speed control, intersection management, and vehicle design improvements. This research aligns with TRB's mission to promote safer, more efficient transportation systems through innovation.

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Sponsoring Committee	ACS20
Session Number	3147
Session Title	**Safety Performance and Analysis Using Machine Learning or Artificial Intelligence**
Paper Number	25-03254
Paper Title	**Elderly Pedestrian Crash Severity: Exploringthe Role of Human Perceived Streetscape Design Using Explainable Ensemble Learning**
Abstract	This study examined the role of human-perceived streetscape design features on elderly pedestrian injury severity using street view imagery and computer vision techniques. An explainable ensemble learning framework incorporated both crash-related factors and perceived streetscape design features. Using Seoul, South Korea, as a case study, a city with a high proportion of elderly residents. This study provides evidence for planners to adopt cost-effective street design interventions to improve elderly pedestrian safety.

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Sponsoring Committee	ACS20
Session Number	3147
Session Title	**Safety Performance and Analysis Using Machine Learning or Artificial Intelligence**
Paper Number	25-03514
Paper Title	**To Balance or Not to Balance? Applying a Machine Learning Technique to Oversample Severe Injury Crashes in Work Zones**
Abstract	This research address the critical issue of severe injury crashes in work zones by integrating SMOTE with the Random Forest model to address data imbalance and enhance predictive accuracy. This study provides a novel, data-driven framework that will interest TRB attendees focused on traffic safety, machine learning, and evidence-based policy-making.

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Sponsoring Committee	ACS20
Session Number	3147
Session Title	**Safety Performance and Analysis Using Machine Learning or Artificial Intelligence**
Paper Number	25-03619
Paper Title	**Generative AI for Class Imbalance in Crash Severity Estimation with Mixed Data Types**
Abstract	While estimating crash severity is crucial for reducing fatality and ensuring road safety, achieving accurate estimation is challenging due to the significant class imbalance in crash data, which leads to parameter bias and overfitting in the models. To address these challenges, this study employs a novel generative model or data augmentation, the variational autoencoder with Bayesian Gaussian mixture (VAE-BGM). This model integrates the strengths of Bayesian inference and autoencoder technique to effectively manage data imbalance and the complexity of mixed data types within crash severity estimation. To gain a more comprehensive insight into the factors influencing crash severity on highways, we integrate traditional crash-related variables with real-time data from Vehicle Detector Systems (VDS). We evaluate the effectiveness of VAE-BGM alongside various data augmentation techniques, including Synthetic Minority Oversampling Technique (SMOTE), Adaptive Synthetic (ADASYN) sampling, and Conditional Tabular Generative Adversarial Network (CTGAN). The results demonstrate that VAE-BGM significantly outperforms other data augmentation methods in improving the crash severity model's performance. The feature importance analysis identifies the crash type, cause, and nearby traffic volumes as key factors, underscoring the importance of incorporating on-site VDS information in the crash severity model. This research not only advances methodological approaches in traffic safety analysis but also offers an in-depth analysis of the factors influencing crash severity on highways by combining traditional crash-related variables with on-site VDS detector data.

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Sponsoring Committee	ACS20
Session Number	3147
Session Title	**Safety Performance and Analysis Using Machine Learning or Artificial Intelligence**
Paper Number	25-04952
Paper Title	**Predicting Crash Severity and Unsafe Driver Behavior Hot Spots in South Carolina using Machine Learning Models and a GIS Framework**
Abstract	Multi-vehicle collisions account for the largest proportion of road crashes in the US, with unsafe driver behavior being a major contributing factor. This paper explores how driver behavior contributes to the severity of crashes involving two vehicles in South Carolina and seeks to identify hot spots for these behaviors. We employed six machine learning algorithms (K-nearest neighbors (KNN), Random Forest (RF), Decision Tree (DT), J48, Logistic Regression, and Naïve Bayes) to develop classification models to predict crash severities. Overall, a stable performance was achieved for all six models, but the KNN was the best-performing classification model followed by the RF and DT models. After identifying significant problematic driving behaviors, an optimized hot spot analysis tool was used to identify hot spots for these behaviors at the county level. The spatial analysis revealed that some behaviors, such as failure to yield the right of way and disregarding traffic signs/signals, were geographically common traffic violations. However, specific counties were identified as hot spots for speeding, aggressive driving, and driving under the influence (alcohol) behaviors. This research provides information for policymakers to make cost effective decisions in support of safety programs by targeting limited resources for training, public information campaigns, and other countermeasures to areas of the state with the greatest potential for impact.

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Sponsoring Committee	ACS20
Session Number	3147
Session Title	**Safety Performance and Analysis Using Machine Learning or Artificial Intelligence**
Paper Number	25-05032
Paper Title	**Analyzing the Factors Behind Heavy Vehicle Crashes: A Deep Learning Approach**
Abstract	The trucking industry is integral to the U.S. economy, handling 73.1% by value, 71.1% by cargo, and 42.0% by ton-miles of all commodities transported. Despite its importance, truck crashes, which caused 3,903 fatalities in 2014, have a higher fatality rate per vehicle compared to passenger cars and lead to significant economic disruptions. This paper aims to identify the most critical factors regarding heavy vehicle crashes in New Jersey. This study aims to address this research deficiency by employing three advanced machine learning models—Artificial Neural Network (ANN), Random Forest (RF), and Support Vector Machine (SVM)— to explore the complex factors influencing crash severity in heavy vehicles. Our findings reveal that ANN offers superior predictive ability in comparison to Random Forest and Support Vector Machine for assessing crash severity. Additionally, we identify run off the road as the most significant factor affecting crash severity. By bridging this gap, our research not only provides valuable insights for improving safety measures for large vehicles but also lays the groundwork for future studies in freight transportation. Future research directions include enhancing prediction models, developing real-time monitoring systems, and exploring interventions to reduce the incidence and impact of "Run off the road" crashes. This study thus contributes to addressing urgent safety concerns and advancing the field of heavy vehicle safety and transportation research.

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Sponsoring Committee ACS20

Session Number 3147

Session Title **Safety Performance and Analysis Using Machine Learning or Artificial Intelligence**

Paper Number 25-05368

Paper Title **CrashLLM: Modeling Traffic Crash Patterns and Discovering Causal Factors with Multimodal Data and Foundation Models**

Abstract Current research in traffic crash frequency modeling and analysis has predominantly approached the problem as classification tasks, focusing mainly on classification or ensemble learning methods. These approaches often overlook the intricate relationships among the complex infrastructure, environmental, human, and contextual factors related to traffic crashes and risky situations. In contrast, we initially propose a large-scale traffic crash language dataset, named CrashEvent, summarizing 19,340 real-world crash reports and incorporating infrastructure data, environmental and traffic textual and visual information in Washington State. Leveraging this rich dataset, we further formulate the crash event feature learning as a novel text reasoning problem and further fine-tune various large language models (LLMs) to predict detailed accident outcomes, such as crash types, severity, and number of injuries, based on contextual and environmental factors. The proposed model, CrashLLM, distinguishes itself from existing solutions by leveraging the inherent text reasoning capabilities of LLMs to parse and learn from complex, unstructured data, thereby enabling a more nuanced analysis of contributing factors. Our experiments results show that the proposed CrashLLM not only predicts the severity of accidents but also classifies different types of accidents and predicts injury outcomes, all with averaged F1 score boosted over 54.15% comparing with the state-of-the-art model. Furthermore, CrashLLM can provide valuable insights for numerous open-world what-if situational-awareness traffic safety analyses with learned reasoning features, which existing models cannot offer. We make our benchmark, datasets, and model publicly available for further exploration based on the manuscript's acceptance.

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Sponsoring Committee ACS20

Session Number 3147

Session Title **Safety Performance and Analysis Using Machine Learning or Artificial Intelligence**

Paper Number 25-05668

Paper Title **Crash Injury Prediction of Different Vehicle Types Using Machine Learning**

Abstract This study examined the factors for predicting crash injury severity across different vehicle types on Florida freeways using advanced machine learning models. Specifically, the Extreme Gradient Boosting (XGBoost), Random Forest (RF), Support Vector Machine (SVM), and K-Nearest Neighbor (KNN) models were used. Data from Signal Four Analytics from the years 2021 to 2023 containing crashes involving trucks, buses, and passenger cars were analyzed. Key variables included crash time, weather conditions, roadway characteristics, and driver behavior. The XGBoost model demonstrated superior performance in predicting injury severity with high accuracy, specificity, and precision. Findings indicate that crash type, driving under the influence, and posted speed limits are crucial factors affecting injury severity across all vehicle types. Trucks are most vulnerable on curves and freeways with speed limits greater than 65 mph. Buses are at greater risk during dark, unlighted conditions and severe weather. Passenger cars exhibit higher injury probabilities during PM peak hours and aggressive driving behavior. These insights underscore the need for targeted safety measures tailored to each vehicle type and highlight the potential of machine learning in traffic safety analysis. This study emphasizes the importance of understanding vehicle-specific risk factors to develop effective interventions and improve overall road safety.

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Sponsoring Committee	ACS20
Session Number	3147
Session Title	**Safety Performance and Analysis Using Machine Learning or Artificial Intelligence**
Paper Number	25-05976
Paper Title	**AI Conflict Observer: Severity and Scenario Identification for Multi-type Vehicle-to-Vehicle Conflict at Intersection Based on Transformer**
Abstract	The application of perception and edge computing technologies has provided extensive data support for conflict analysis at intersections. However, conflict analysis based on threshold and semantic rule methods struggles to address the challenges of data heterogeneity at different intersections. This study combines kinematic features of Holographic Intersection trajectory data to calibrate information on vehicle pair conflicts, and trains an AI Conflict Observer (AICO) model using Transformer that can automatically extract the severity and scenarios of vehicle-to vehicle (V2V) conflicts in bulk.

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Sponsoring Committee	ACS20
Session Number	3147
Session Title	**Safety Performance and Analysis Using Machine Learning or Artificial Intelligence**
Paper Number	25-03641
Paper Title	**Assessing Imbalanced Autonomous Vehicle Crash Severity Models: Using Unstructured Data by Latent Class and Applying Data Augmentation Techniques**
Abstract	Traffic crashes involving autonomous vehicles (AVs) occur steadily, and understanding the characteristics of accidents involving AVs is essential for establishing traffic safety measures in future mixed traffic environments. Previous studies, which applied various methods such as text analysis and rule extraction from AV crash data, faced challenges in generalizing relationships due to limited and heterogeneous crash data and failed to address the problem of imbalanced data distribution for crash severity levels. To bridge this gap, this study aims to enhance the reliability of AV crash severity analysis by developing a latent class prediction model for multiclass imbalanced data. The overall framework comprises three components: 1) identifying latent classes of AV crashes to address unobserved heterogeneity, 2) discovering latent thematic factors for each subclass using natural language processing, and 3) investigating crash injury data augmentation with a novel deep-learning method (Wasserstein generative adversarial network, WGAN). The findings indicated that AV crash data could be categorized into three subclasses with distinct latent thematic variables. Significant variables related to vehicle type, road space, and behavior were identified. The prediction model, trained on the resampled data, accurately identified the minority class (i.e., severe crashes), demonstrating the effectiveness of the proposed methods. Specifically, the best-performing CatBoost model showed that applying WGAN-based sampling methods and latent topic variables from text records improved the F1-score by 15.0% compared to the original data. Using the proposed framework, traffic safety management solutions in mixed traffic environments are achieved.

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Sponsoring Committee	ACS20
Session Number	3147
Session Title	**Safety Performance and Analysis Using Machine Learning or Artificial Intelligence**
Paper Number	25-06131
Paper Title	**Prediction and Interpretation of Crash Severity Using Machine Learning Based on Imbalanced Traffic Crash Data**
Introduction	Crashes pose a major societal issue, causing significant loss of life and economic damage. Predicting crash severity helps develop effective traffic safety policies, reducing casualties and property loss. Understanding key factors influencing severity is vital for implementing targeted safety measures. (1).Given the critical importance of predicting and interpreting key factors affecting crash severity, a variety of methods have been employed in previous studies. Traditional regression techniques such as Logit and Porbit have been used to analyze and predict the crash severity (2; 3). Traditional statistical methods, while interpretable, rely on strict assumptions that can affect accuracy. ML methods, like decision trees, SVM, RF, and XGBoost (4), better handle nonlinear relationships in crash severity prediction. Deep learning models such as LSTM, ANN, CNN, and RNN excel at processing complex data but require large, high-quality datasets to perform effectively(5-7) . MLmethods are increasingly being applied in the study of crash data(8). However, as a black box method, most ML methods lack explanatory analysis of the impact on the crash severity. The existing ML model interpretation methods can be roughly divided into model-based analysis and interpretation models (9). The widely used interpretation models include locally interpretable model agnostic interpretation (LIME), local sensitivity analysis (LSA)(10), party dependency graph (PDP)(11), global sensitivity analysis (GSA) (12) and shapley additive prediction (SHAP) (13). The explanatory model has been widely applied in the field of ML prediction interpretation, providing a reference for analyzing influencing factors and other aspects. Despite the strong performance of ML methods, data limitations, particularly the rarity of fatal injury (FI) crashes, lead to significant imbalance in crash datasets. This imbalance can result in biased models. Common solutions include resampling techniques such as under-sampling, which reduces majority class samples to address this issue(16; 17) and oversampling . The results of the existing studies indicate that under-sampling the majority of class data may cause the inherent distribution of the feature spaces underrepresented. Over-sampling methods avoid information loss but risk overfitting due to duplicate samples and weak variable correlations. Generative Adversarial Networks (GANs), including CTGANs, address these issues by enhancing sample diversity and improving minority class performance, partially overcoming ML limitations(14; 15) . Existing research primarily compares ML model performance in predicting crash severity, with limited focus on addressing data imbalance or incorporating interpretability. This gap is critical, as understanding traffic factors' impact is essential for effective safety measures. This study addresses these issues by evaluating the combined performance of various resampling methods and ML models, introducing SHAP to quantify key risk factors, and guiding safety measure development. The objectives are to: (i) compare predictive performance across sampling and ML frameworks, (ii) interpret ML predictions to understand crash severity factors, and (iii) quantify key risk factors to provide actionable insights.

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Sponsoring Committee ACS20

Session Number 3147

Session Title **Safety Performance and Analysis Using Machine Learning or Artificial Intelligence**

Paper Number 25-04855

Paper Title **Investigating the Contributing Factors to Crashes with and without the Presence of Work Zone Workers Using Machine Learning Techniques**

Abstract As the nation's roadways continue to deteriorate, the presence of work zones on US highways is anticipated to increase, highlighting the crucial need for the safety of both work zone workers and road users. This study combined descriptive statistics and SHapley feature important analysis to examine work zone crash data in Ohio from 2019 to 2023. The goal was to identify the factors 5 contributing to crash severity with and without the presence of work zone workers. Various machine learning models, including k-nearest neighbors, random forest, eXtreme gradient boosting, and Light gradient boosting machines, were employed to predict crash outcomes across three datasets. Light gradient boosting machines emerged as the best-performing model. SHapley values were then utilized to interpret the contributing factors on crash injury severity. The analysis indicated that shoulder and lap belt use consistently reduced crash severity across all datasets. Multi-vehicle crashes, sideswipes, angles, and rear-end crashes were among the variables that had an increasing influence on crash severity across the three datasets. The partial dependence plot revealed that the mobile work zone type significantly influenced worker-present crash severity, while out-of-state drivers were a significant factor in non-worker-present crashes. The findings of this study are intended to guide transportation practitioners and policymakers in enhancing work zone safety.

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Sponsoring Committee ACS20

Session Number 3147

Session Title **Safety Performance and Analysis Using Machine Learning or Artificial Intelligence**

Paper Number 25-01426

Paper Title **Tunnel Crash Severity and Congestion Duration Joint Evaluation based on Cross-stitch Networks**

Abstract Tunnels, with their limited space and restricted widths and heights, increase the likelihood of crashes and traffic congestion, where the severity and duration of one often exacerbate the other. To provide a holistic and data-driven perspective on tunnel safety and efficiency, a total of 3,024 crashes occurred in tunnels of Shanxi Province were collected with three injury severity outcomes and average congestion duration of 94.59 min. A comprehensive exploration of crash severity and congestion duration within tunnels is developed using soft parameter sharing method based on cross-stitch network. Specifically, five types of characteristics including crash, vehicle, road, environment, and temporal features of the crashes were extracted as inputs. A joint cross-stitch network model was proposed that contains two sub-multilayer perceptron (MLP) networks to evaluate the crash severity and duration, respectively. Between the MLP layers of two sub-networks, cross-stitch units were introduced to connect them and share model parameters with specific weights, which enforce two sub-networks simultaneously to extract the coupling relationships between variables and two targets (i.e., crash severity and duration). In addition, separate models (e.g., MLP, XGboost, and SVM) for only crash severity or duration evaluation were established for comparation. The results show that joint models surpassed the separate models in performance, achieving a 12.4% increase in sensitivity and a 9.2% increase in the F1 score for crash severity classification. Additionally, there was a reduction of 5.7% in MSE and 3.1% in MAE for evaluating crash congestion duration. Compared to separate models, the SHAP value distribution in the joint models revealed more pronounced effects of variables. Additionally, the joint models exhibited some features presenting inverse effects in the separate models, offering more reasonable interpretations. The results enhance our understanding of crashes and congestion in tunnels and inform several recommendations for tunnel management to reduce both crash severity and congestion duration.

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Sponsoring Committee	ACS20
Session Number	3147
Session Title	**Safety Performance and Analysis Using Machine Learning or Artificial Intelligence**
Paper Number	25-02912
Paper Title	**The Impact of Electric Vehicle's Strong Acceleration Performance on Traffic Safety Risks at Signalized Intersections**
Introduction	Since 2010, the global sales of light electric vehicles (EVs) have been consistently increasing, marking electrification as a major trend in the automotive industry. The electric motor in EVs differs from the engine in traditional fuel-powered vehicles. For instance, when the rotation speed of an EV's motor reaches 5000 revolutions per minute, the power can reach 300 kW, with a power-to-speed ratio of approximately 0.06 kW·min/rev. In contrast, a traditional fuel-powered vehicle at 5000 revolutions per minute has a power of less than 220 kW, with a power-to-speed ratio of 0.044 kW·min/rev. With the same transmission ratio, overall vehicle mass, and tire diameter, vehicle acceleration is proportional to the power-to-speed ratio. EVs can achieve accelerations 130% to 136% greater than traditional fuel-powered vehicles, potentially posing adverse effects on traffic safety. The strong acceleration performance of EVs is particularly evident at lower operating speeds. Among various low-speed scenarios, signalized intersections are integral components of the road network. Due to frequent changes in traffic signals, the acceleration and deceleration of traffic flows at these intersections are complex, leading to greater safety risks. Drivers' willingness to accelerate is typically higher for straight-ahead traffic compared to left or right turns, which makes straight-ahead traffic at signalized intersections more hazardous. Most studies on EVs are based on accident analysis, focusing on the characteristics and causes of EV accidents. Some researchers have analyzed the impact of EVs on traffic safety from the perspective of accident probability due to their low noise or from the perspective of accident severity due to their flammable and explosive nature. Existing studies are based on limited accident data and rarely consider the impact of EVs' strong acceleration performance. This study aims to investigate the impact of the strong acceleration performance of electric vehicles on traffic safety risks at signalized intersections. For this purpose, UAVs and roadside cameras are used to obtain vehicle information and construct a trajectory database containing different types of vehicles. A two-dimensional comprehensive safety surrogate indicator, considering both collision probability and severity, is proposed to achieve automatic quantification of traffic safety risks based on trajectory data. The study compares the straight-ahead traffic safety risks of electric vehicles and fuel-powered vehicles at signalized intersections from the perspectives of individual driving behavior and interactive behavior.

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Sponsoring Committee	ACS20
Session Number	3147
Session Title	**Safety Performance and Analysis Using Machine Learning or Artificial Intelligence**
Paper Number	25-04418
Paper Title	**Improving Autonomous Vehicle Crash Data by Data Mining and Artificial Intelligence Tools**
Abstract	Autonomous vehicles (AVs) have the potential to enhance road safety. However, integrating them into a human-dominated environment poses safety challenges, as AVs may still be prone to errors until all vehicles become autonomous. Hence, continuous monitoring and review of AV crashes are necessary to address safety issues. Current AV crash datasets, while informative, suffer from inconsistencies and missing information, impeding safety assessment of AVs. This paper aims to improve AV crash data quality to investigate AV crashes in San Francisco. Using data mining and web scraping techniques, data was collected and enhanced by extracting variables through image processing and natural language processing. Key variables extracted include injury severity, involvement of other parties, and proximity to intersections and traffic signals. Multinomial logistic regression was then used to investigate AV crashes injury severities. The analysis revealed that rear and front vehicle damage, driverless operation, and sideswipe crashes are associated with a decreased probability of minor injuries, while pedestrian, scooter, bike, motorcycle involvement in crashes and crashes located near traffic lights are associated with higher probability of minor injuries. Moreover, adverse weather, nighttime crashes, and involvement of pedestrians, scooters, bikes, and motorcycles are linked to a higher probability of major injuries. This study demonstrates the potential of AI tools in safety analysis, enhances the understanding of AV safety, and provides valuable insights for policymakers, manufacturers, and researchers by offering a framework to improve AV crash databases. The proposed methods, while focused on AV crashes, can be applied to any crash settings.

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Sponsoring Committee	ACS20
Session Number	3213
Session Title	**Safety Performance and Analysis for Safe Road Users and Safe Speeds**
Paper Number	25-01356
Paper Title	**Right-Turn Safety for Pedestrians: Insights from Multilevel Models of Conflicts in Utah**
Abstract	Pedestrians and vehicles frequently interact at signalized intersections, and a significant portion of recent pedestrian crashes at intersections involve right-turning vehicles. There is a need to proactively understand right-turn safety for pedestrians, without waiting for crashes to occur. Using the severity of conflicts between pedestrians and right-turning vehicles as a surrogate safety measure, the purpose of this study was to investigate associations of various conflict- and location-specific factors with pedestrian conflict severity, and ascertain variations across locations. First, data were collected for 1,640 pedestrian–right turn conflicts observed from over 1,000 hours of video at 34 intersections in Utah. Next, multilevel models (conflicts nested within intersections) were estimated to analyze the data. The results reveal an increase in conflict severity for pedestrians crossing when the signal was solid don't walk and for bicyclists using the crosswalk. Conflicts tended to be less severe: when more pedestrians were in the group, pedestrians were using a wheelchair or pushing a stroller, fewer vehicles were waiting to turn right; for large vehicles, vehicles turning right on red, conflicts during evening peak hours; and during hours with precipitation. Conflicts in the first crosswalk encountered by right-turning vehicles had longer encroachment times than conflicts in the second crosswalk. Similarly, when pedestrians approached the curb, higher encroachment time and pre-encroachment time were observed, while post-encroachment time was shorter. Crosswalk offset distance (from the outside edge of the right-most lane to the nearest line of the parallel crosswalk) and household size were negatively associated with conflict severity.

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Sponsoring Committee	ACS20
Session Number	3213
Session Title	**Safety Performance and Analysis for Safe Road Users and Safe Speeds**
Paper Number	25-03101
Paper Title	**Joint Analysis of E-bike Crash Types and Injury Severity at Different Locations Using a Copula-based Approach**
Abstract	This paper offers valuable insights into the evolving landscape of e-bike safety. By employing an innovative copula-based joint modeling framework, we effectively capture the complex dependencies between different crash types and their severity

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Sponsoring Committee	ACS20
Session Number	3213
Session Title	**Safety Performance and Analysis for Safe Road Users and Safe Speeds**
Paper Number	25-03741
Paper Title	**Factors Influencing the Severity of Personal Mobility Device Accidents: A Decision-Tree Method**
Abstract	Personal Mobility Device (PMD), designed for single or dual users and capable of speeds up to 25 km/h, presents a promising alternative to traditional transportation methods by reducing greenhouse gases and enhancing mobility flexibility. However, PMD accidents frequently result in greater severity compared to other transportation modes. This study analyzes six years of PMD accident data from Korea using the decision tree algorithm to identify key factors and their non-linear influences on accident severity. The findings reveal that individuals aged 40 and older face a significantly higher risk of severe outcomes in PMD-only accidents. Although PMD-to-vehicle collisions occur more frequently, PMD-only accidents are generally more severe, highlighting the need for mandatory helmet use and cautious handling. Environmental factors also play a role in severity, with a notable increase in accidents during morning hours between 6 AM and 12 PM, likely due to heightened commuting demand. Additionally, PMD-to-pedestrian accidents are more severe in spring and summer, with a rise in severity during autumn, particularly among younger drivers. This research provides practical insights for enhancing PMD safety and supports potential amendments to PMD-related regulations to mitigate accident severity and improve overall safety.

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Sponsoring Committee	ACS20
Session Number	3213
Session Title	**Safety Performance and Analysis for Safe Road Users and Safe Speeds**
Paper Number	25-00524
Paper Title	**Assessing Pedestrian Safety: Risk Factors in Georgia's Pedestrian-Vehicle Crashes**
Abstract	Pedestrian crashes, often underexamined compared to total road crashes, result in fatalities that are rising in the US. Our analysis, based on 18,083 pedestrian-vehicle crashes in Georgia from 2013 to 2022 provided by the Georgia Department of Transportation, uses an ordered probit model to identify risk factors for three levels of pedestrian injury: no injury to minor injury, serious injury, and fatality. The findings highlight the need to tailor road safety strategies to different age groups of pedestrians and drivers, with a focus on older pedestrians and young drivers. Proper street lighting and reduced speed limits are identified as key measures for improving pedestrian safety. Additionally, pedestrians in socially vulnerable regions face a higher risk of sustaining severe injuries. This study provides valuable guidelines for policymakers on how and where to implement targeted countermeasures to protect the most vulnerable road users.

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Sponsoring Committee ACS20

Session Number 3213

Session Title **Safety Performance and Analysis for Safe Road Users and Safe Speeds**

Paper Number 25-01266

Paper Title **Evaluating the Safety Impact of Mid-block Pedestrian Signals (MPS)**

Abstract The Florida Department of Transportation (FDOT) has recently started implementing a new signal system at mid-blocks called Mid-block Pedestrian Signals (MPS). This study aims to evaluate the effectiveness of these newly implemented MPSs. A total of 260 hours of video data were collected from five locations across Florida, with 130 hours recorded before MPS installation and 130 hours after installation. State-of-the-art computer vision technology was employed to detect and track various road users. A random parameters multinomial logit model with heterogeneity in the means was implemented to assess the safety of vehicle-pedestrian interactions by three conflict categories: No Conflict, Moderate Conflict, and Serious Conflict. Relative-Time-to-Collision (RTTC) values were utilized to classify these levels of conflict.
The analysis demonstrates that the presence of MPS significantly enhances safety outcomes by increasing the likelihood of avoiding conflicts and reducing the probabilities of both moderate and serious conflicts. Key factors influencing conflict probabilities were identified, including pedestrian and vehicle counts, average leading vehicle speed, standard deviation of leading vehicle speeds, and land-use mix, all of which increase the probability of serious conflicts. Interestingly, the analysis identified three significant interaction variables with MPS: average leading vehicle speed, standard deviation of leading vehicle speeds, and land-use mix. While these factors individually had a higher probability of leading to serious conflicts, the presence of MPS effectively mitigates these risks by moderating their adverse effects, increasing the likelihood of no conflicts. These results underscore the importance of MPS as an effective measure to improve safety at mid-block crossings.

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Sponsoring Committee ACS20

Session Number 3213

Session Title **Safety Performance and Analysis for Safe Road Users and Safe Speeds**

Paper Number 25-01286

Paper Title **Unveiling the Determinants of Injury Severities in E-Scooter Crashes: A Latent Class Binary Logit Analysis of Single and Multiple-Vehicle Crashes**

Abstract Given the growing rise of micromobility in cities across the globe, this study explores the determinants of injury severities in single- and multi-vehicle crashes involving e-scooters, using data from the United Kingdom. The analysis incorporates unobserved heterogeneity by identifying latent classes within the crash population, allowing for a nuanced understanding of the factors influencing crash outcomes. The findings provide insights into tailoring policy interventions for crash prevention and enhancing safety awareness among micromobility users, contributing to the safer integration of e-scooters into urban transportation networks.

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Sponsoring Committee	ACS20
Session Number	3213
Session Title	**Safety Performance and Analysis for Safe Road Users and Safe Speeds**
Paper Number	25-02110
Paper Title	**Assessing the Safety Nature of Pedestrian-Vehicle Interaction at Non-signalized Crosswalks**
Abstract	Uncontrolled crosswalks are often hotspots for pedestrian crashes, yet the dynamic states of pedestrian-vehicle interactions (PVI) and their impact on collisions remain underexplored. This study examines how the dynamic behavior of PVI influences pedestrian crossing safety from a new perspective. A methodology is proposed that utilizes computer vision and clustering techniques to analyze pedestrian-vehicle interactions. This involves extracting trajectory data from UAV video footage and modeling PVI dynamics. Interaction patterns are clustered, and two novel indicators are introduced to evaluate the state of interactions dynamically. A risk prediction model is used to validate the efficiency of these indicators. Additional analyses explore pedestrian crossing safety and decision-making based on interaction dynamics, with distinctions among interaction clusters. While increased collision exposure may elevate crash probability, it can also enhance risk perception. Frequent shifts in passing priority significantly raise the likelihood of severe conflicts. The proposed risk prediction model incorporating dynamic interaction indicators outperforms conventional models. Findings suggest that complex interaction experiences encourage vehicles to yield and shape conflict risks, providing valuable insights into pedestrian safety.

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Sponsoring Committee	ACS20
Session Number	3213
Session Title	**Safety Performance and Analysis for Safe Road Users and Safe Speeds**
Paper Number	25-03750
Paper Title	**Bayesian Networks in Identifying Patterns between Pedestrian and Driver Behavioral Interactions**
Abstract	Walking, as a sustainable and health-promoting mode of transportation, is increasingly recognized for its benefits, yet the growing rate of pedestrian crashes has emerged as a pressing public health issue. This study investigates the factors influencing pedestrian injury severity in pedestrian-motor vehicle crashes using data from Louisiana (2017–2021). A Bayesian Network (BN) analysis, a powerful probabilistic modeling approach, was employed to examine the interplay between driver and pedestrian behaviors, crash circumstances, and environmental factors. Key findings underscore the critical role of crossing behaviors, with a majority of crashes occurring away from intersections. The study also highlights the importance of driver attentiveness, crash location, pedestrian actions, and lighting conditions in determining injury severity. Counterfactual analyses provided further insights into how these variables interact to influence outcomes. The dual focus on driver and pedestrian characteristics offers a holistic understanding of the dynamics behind pedestrian crashes. These results carry significant implications for urban planning, transportation policy, and public health, emphasizing the need for targeted interventions to enhance pedestrian safety while promoting sustainable and eco-friendly mobility options.

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Sponsoring Committee ACS20

Session Number 3213

Session Title **Safety Performance and Analysis for Safe Road Users and Safe Speeds**

Paper Number 25-04710

Paper Title **Understanding Body Injury Patterns and Associated Severity of Micromobility Users Using Bayesian Networks and Text Mining**

Abstract Micromobility devices, including electric scooters and electric bicycles, are becoming increasingly popular across the United States, leading to a rise in crashes involving their users. However, less is known about their crash patterns, particularly the body injury patterns and resulting severities. This study compares body injury patterns for micromobility and traditional bicycle crashes by applying Bayesian networks and text mining to six years (2017-2022) of crash data from Washington State. The results indicate several similarities and disparities between the two types of road users. Both micromobility and non-micromobility users commonly experience injuries to the head-shoulder, head-neck, leg-knee, and leg-ankle areas. Unique to micromobility users are left leg pain and abrasions on the left side of the body. In contrast, non-micromobility users are more likely to suffer injuries to the right knee, and left shoulder, and abrasions on the right side. Additionally, micromobility crashes are more likely to be severe when involving head injuries and non-standard helmets, occurring at night, and non-intersection locations. Non-micromobility users are more likely to sustain severe injuries in crashes on high-posted speed limit roads, during turning movements, due to driver negligence or distraction, and when wearing less visible clothing. The findings suggest the need for additional regulations regarding micromobility devices, particularly focusing on managing vehicle speeds, creating dedicated facilities for these users, and enforcing traffic safety rules, especially at intersections.

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Sponsoring Committee ACS20

Session Number 3213

Session Title **Safety Performance and Analysis for Safe Road Users and Safe Speeds**

Paper Number 25-05036

Paper Title **Injury Severity Analysis of E-scooter Riders in England**

Abstract With the growing popularity of e-scooters, the associated accidents pose significant challenges to road transport safety. Using e-scooter-vehicle collision data from England from 2020 to 2023, we investigate factors that are associated with injury-severity sustained by e-scooter riders. We employed a multilevel random parameters model considering crash level, individual level, and 5 area level variables. The results show that the likelihood of serious and fatal injuries is positively associated with jobs density, age of riders, male riders, darkness, single carriageway, roads with speed limit of 40 mph and over, heavy vehicles, nighttime and early morning, e-scooter skidding and/or overturning, frontal impact, e-scooter entering the main road and the opponent vehicle going ahead. In contrast, the increase in the area level proportion of adults walking or cycling at least five times a week and motor vehicle moving off manoeuvre are found to decrease the likelihood of fatal or serious injuries. The findings offer policy implications for improving e-scooter safety.

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Sponsoring Committee	ACS20
Session Number	3213
Session Title	**Safety Performance and Analysis for Safe Road Users and Safe Speeds**
Paper Number	25-05322
Paper Title	**Unveiling the Speeding Behavior: Assessing the Speeding Risks and Driver Injury Severities in Single-Heavy Truck Crashes**
Abstract	This study addresses the critical issue of speeding-related crashes involving heavy trucks in Pennsylvania, a state with rising truck-related fatalities. By analyzing six years of crash data, it identifies factors that elevate injury severity, such as speeding on curves, high-speed roads, unbelted drivers, and vehicle malfunctions. Using a multinomial logit model, the study reveals nuanced insights into spatial, temporal, and vehicular risks, providing actionable policy recommendations. Suggested interventions include roadside barriers, flashing curve signage, targeted driver training for middle-aged drivers, and prioritizing inspections for drivers with prior speeding violations. These findings align with Vision Zero's 'Safe System Approach', which promotes integrated solutions for safer speeds, roads, vehicles, and users. Focusing on specific speeding-related risks in heavy truck crashes, this study offers data-driven recommendations that can improve safety for truck drivers and the public, enhancing road safety in Pennsylvania and beyond.

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Sponsoring Committee	ACS20
Session Number	3213
Session Title	**Safety Performance and Analysis for Safe Road Users and Safe Speeds**
Paper Number	25-06072
Paper Title	**Accounting for Gender and Age Differences in the Duration between a Previous Non-fatal Crash and a Fatal Crash**
Abstract	Identifying factors that significantly affect drivers that are repeatedly involved in traffic violations or non-fatal crashes (defined here as recidivist drivers) is very important in highway safety studies. This study sought to understand the relationship between a set of variables related to previous driving violations and the duration between a previous non-fatal crash and a subsequent fatal crash, taking into account the age and gender of the driver. By identifying the characteristics of this unique driver population and the factors that influence the duration between their crash events strategies can be put in place to prevent the occurrence of future and potentially fatal crashes. To do this, a five-year (2015-2019) historical fatal crash data from the United States was used for this study. Out of 15,956 fatal crashes involving recidivist drivers obtained, preliminary analysis revealed an overrepresentation of males (about 75%). It was also found that the average duration between the two crash events was about a year and a half, with only an average of one month difference between male and female drivers. Using hazard-based duration models, factors such as number of previous crashes, previous traffic violations, primary contributing factors and some driver demographic characteristics were found to significantly be associated with the duration between the two crash events. The duration between the two events increased with driver's age for drivers who were involved in only one previous crash and the duration was shorter for those that were previously involved in multiple crashes. Previous DUI violations, license suspensions, and previous speeding violations were found to be associated with shorter durations, at varying degrees depending on the driver's age and gender. The duration was also observed to be longer if the fatal crash involved alcohol or drug use among younger drivers but shorter among middle-aged male drivers. These findings reveal interesting dynamics that may be linked to recidivist tendencies among some drivers involved in fatal crashes. The factors identified from this study could help identify crash countermeasures and programs that will help to reform such driver behaviors.

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Sponsoring Committee ACS20

Session Number 3213

Session Title **Safety Performance and Analysis for Safe Road Users and Safe Speeds**

Paper Number 25-06304

Paper Title **Effect of Rider Kinematics and Expected Speed Differences on the Sideswipe Crash Risk of Powered Two-Wheelers: A Copula-Based Proactive Safety Approach**

Abstract For designing effective rider assistance systems for powered two-wheeler (PTW) safety, studying the relation between rider kinematics and safety-critical events is essential since it explains the rider's workload in mitigating the crash risk. However, such relations must also consider the expected speed differences of post-crash occurrences since it is indirectly related to the injury risk of PTWs. Hence, the present study investigates the relationship between rider kinematics, expected speed differences, and PTW safety margins. Using the detailed PTW conflict data obtained from microscopic trajectories, the present study analyzes the relationship between safety margins, rider kinematics and expected speed differences. The study employs a copula-based approach for modeling the association between safety margin, rider kinematics and injury risk related to the sideswipe PTW conflicts. Three surrogate safety measures (SSMs) were considered for this purpose: anticipated collision time (measures safety margin), yaw rate (measures rider kinematics), and DeltaV (measures injury risk). Using an unmanned aerial vehicle (UAV), video data were collected from the four-lane highway in India covering an extended road length. It was found that bivariate Gumbel Copula fits the safety margin, rider kinematics, and expected speed differences. The safety margin thresholds are found to be smaller than that of car drivers and the high fluctuations in the yaw rate values signify the application of rapid evasive maneuver. Understanding this inter-relationship between these three characteristics will help to better design the rider assistance systems.

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Sponsoring Committee ACS20

Session Number 3213

Session Title **Safety Performance and Analysis for Safe Road Users and Safe Speeds**

Paper Number 25-05799

Paper Title **Investigating the Impact of Speed Variation on Intersection Crashes Using Pervasive Traffic Data**

Abstract Speed and speed variation significantly influence the risk of road traffic crashes (RTCs). However, there is a notable lack of research on this topic within the context of developing nations. This gap is primarily due to the unavailability of comprehensive traffic and crash data. Traditional methods of traffic data collection are not feasible due to the high costs associated with installation and maintenance. Consequently, this study aims to explore the potential of using pervasive speed data to predict crashes. To investigate this association, the study utilised three years of fatal crash data from Delhi, India, along with pervasive speed data for 1863 intersections. A zero-inflated negative binomial model was developed to examine the relationship between hourly variations in speed and the frequency of fatal crashes. The findings revealed that a one-unit increase in the standard deviation of speed corresponds to a 9.6% increase in the frequency of fatal crashes. Conversely, with a one-unit increase in the standard deviation of speed, the odds of an intersection initially having no crashes (structural zero) decrease by approximately 4%. This increased frequency in both cases can be attributed to more frequent lane changes and aggressive driving behaviour resulting from increased speed variation.

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Sponsoring Committee	ACS20
Session Number	3213
Session Title	**Safety Performance and Analysis for Safe Road Users and Safe Speeds**
Paper Number	25-04444
Paper Title	**Assessing Disparities in Driver Exposure and Fatal Crash Risks in Nighttime Driving**
Abstract	Driving at night heightens crash risks due to reduced visibility, higher speeds from lighter traffic, and increased likelihood of impaired or drowsy driving This study assesses population group differences in night-time motor-vehicle driving exposure and fatality risks.

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Sponsoring Committee	ACS20
Session Number	3213
Session Title	**Safety Performance and Analysis for Safe Road Users and Safe Speeds**
Paper Number	25-01399
Paper Title	**Analyzing Speed-Difference Impact on Freeway Joint Injury Severities of Leading-Following Vehicles Using Statistical and Data-Driven Models**
Abstract	Rear-end (RE) crashes are notably prevalent and pose a substantial risk on freeways. This paper explores the correlation between speed difference among the following and leading vehicles (Δv) and RE crash risk. Three joint models, comprising both uncorrelated and correlated joint random-parameters bivariate probit (RPBP) approaches (statistical methods) and a cross-stitch multilayer perceptron (CS-MLP) network (a data-driven method), were estimated and compared against three separate models: Support Vector Machines (SVM), eXtreme Gradient Boosting (XGBoost), and MLP networks (all data-driven methods). Data on 15,980 two-vehicle RE crashes were collected over a two-year period, from January 1, 2021, to December 31, 2022, considering two possible levels of injury severity: no injury and injury/fatality for both drivers of following and leading vehicles. The comparative performance analysis demonstrates the superior predictive capability of the CS-MLP network over the uncorrelated/correlated joint RPBP model, SVM, XGBoost, and MLP networks in terms of recall, F-1 Score, and AUC. Significantly, numerous shared variables influence the injury severity outcomes for the following and leading vehicles across both statistical and data-driven approaches. Among these factors, the following vehicle (a truck) and the leading vehicle (a passenger car) demonstrate contrasting effects on the injury severity outcomes for both vehicles. Furthermore, the SHapley Additive exPlanations (SHAP) values from the CS-MLP network visually show the relationship between Δv and injury severity, revealing non-linear trends unlike the average effects shown by statistical methods. They indicate that the least injury outcomes for both following and leading vehicles occurs at a Δv of 0 to 10 mph, matching observed patterns in RE crash data. Additionally, a marked variation in the trend of SHAP values for the two vehicles is noted as the speed difference increases. Therefore, the findings affirm the superior performance of joint model development and substantiate the non-linear impacts of speed difference on injury outcomes. The adoption of dynamic speed control measures is recommended to mitigate the injury outcomes involved in two-vehicle RE crashes.

Authors	Thomas Cabe, Georgia Institute of Technology Viviana Abadia, No Organization Yichang Tsai, Georgia Institute of Technology
Sponsoring Committee	ACS20
Session Number	4004
Session Title	**The Future of Safety Performance and Analysis**
Paper Number	25-03330
Paper Title	**Enhancing Intersection Safety through Kinetic Energy Management and Categorical Crash Data Analysis**
Abstract	This paper evaluates the Federal Highway Administration's (FHWA) current recommended methodology for assessing intersection safety through kinetic energy management. It was found that the existing Safe Systems Intersection (SSI) model, which predicts crash severity based on theoretical changes in velocity, is built on solid fundamental principles and correlates well with crash severity. However, it lacks accuracy when applied to real-world intersection-specific crash data. Analyzing over 700,000 recorded crashes from the Georgia Department of Transportation's (GDOT) AASHTOWare safety database revealed significant discrepancies between the SSI model's predictions and actual crash severities. Specifically, the SSI model often overestimates the likelihood of fatal and severe injuries; this is likely due to its assumptions about crash characteristics and the generalized data set used to fit the model. To overcome this issue, a methodology was proposed using categorical crash analysis and refined assumptions on crash characteristics to achieve better accuracy. This tailored approach and metric was coined the kinetic velocity index (KVI). Grounded in kinetic energy principles and tailored to categorical crash data specific to intersections, the KVI model incorporates comprehensive crash data specific to intersections. Results demonstrate that the KVI model not only fits empirical data better but also simplifies the calculation process, enhancing its practical application for transportation professionals. The KVI model's superior accuracy and usability make it a valuable tool for improving road safety measures and infrastructure planning, ultimately contributing to the reduction of traffic-related fatalities and serious injuries.

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Sponsoring Committee	ACS20
Session Number	4004
Session Title	**The Future of Safety Performance and Analysis**
Paper Number	25-04099
Paper Title	**Better Safety Analyses through Smarter Data: Adding Open-Street-View and Traffic Calibrated-LBS Data to Pedestrian Crash Analysis in Lincoln, NE**
Abstract	Pedestrian crashes are a significant concern in the United States, with pedestrian fatalities increasing and outpacing those of vehicle occupants. This research investigates the potential of new data sources to enhance pedestrian safety analysis and crash modeling. Specifically, it examines the use of StreetLight-calibrated traffic volumes and Mapillary detections of street objects for modeling pedestrian crash counts and severity. By integrating these innovative data sources, the study aims to improve the accuracy and granularity of safety evaluations. Both generalized linear models and machine learning (ML) models, including random forests (RF) and gradient boosting machines (GBM), demonstrated acceptable performance and solid portrayal of crash dynamics, with ML models providing better predictive power at the cost of complexity and lower interpretability. Additionally, the weighted random forest classifier showed high accuracy in predicting crash severity. Key variables in our analysis encompassed StreetLight volumes and various Mapillary open street-view (OSV) detections, including traffic signals, crosswalks, advertisement signs, store signs, streetlights, and arrow markings. The association between these variables and crash counts and severity aligns with our understanding of crash patterns. Overall, the research underscores the importance of leveraging detailed, real-world data to improve pedestrian safety analyses and contribute to more effective safety strategies and policy decisions.

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Sponsoring Committee ACS20

Session Number 4004

Session Title **The Future of Safety Performance and Analysis**

Paper Number 25-03891

Paper Title **Injury Severity Analysis along Major Arterial Roads in Kentucky Using High-Resolution Weather Data**

Abstract The present study offers the following key contributions: (a) comprehensively investigates the factors influencing crash injury severity along major arterial roads in Kentucky, (b) using three modeling approaches (random parameter logit “RPL”, correlated RPL “CRPL”, and CRPL with heterogeneity in means “CRPLHM”) to account for unobserved heterogeneity across the crash observations, (c) using real-time weather information during 1-hour of the crash (retrieved from the High-Resolution Rapid Refresh “HRRR” model) which was integrated with the crash data retrieved from KYTC between 2019 and 2023, and (d) The results from the high-resolution weather variables’ impact on severe crash outcomes along major arterial roads could help suggest useful safety countermeasures and could eventually reduce the likelihood of severe crashes.

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Sponsoring Committee ACS20

Session Number 4073

Session Title **Safety Performance and Analysis for Safe Vehicles**

Paper Number 25-01641

Paper Title **Modelling Bus/Minibus Crash Injury Severity In Dhaka City, Bangladesh**

Abstract This study explores the severity of bus/minibus collisions in Dhaka, Bangladesh, a city heavily dependent on buses for daily transportation. Using police-reported crash data (2015-2022) from the Accident Research Institute (ARI) at Bangladesh University of Engineering and Technology. The study categorizes injury severity into fatal, major injury, minor injury, and property damage only. The dataset includes a range of factors, such as crash severity, year, gender, age, drunk driving, day of the week, time of day, light conditions, weather conditions, manner of collision, number of vehicles involved, traffic control, location, road geometry, road separation/dividers, road surface type, road surface condition, and traffic flow. An Ordered Logit model was developed using RStudio program to identify significant associations between these factors and crash severity. The model reveals how variables such as gender, age, time of day, collision features, and road conditions contribute to the severity of crashes in Dhaka. The study’s findings offer insights for developing strategies to mitigate bus/minibus-related crash injuries in the Dhaka City.

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Sponsoring Committee	ACS20
Session Number	4073
Session Title	**Safety Performance and Analysis for Safe Vehicles**
Paper Number	25-01946
Paper Title	**Investigation on the Association Between Vehicle Make and Road Injury Severity**
Abstract	Road traffic accidents present a pressing public health challenge, necessitating a deep understanding of road traffic injuries to devise effective preventive measures and enhance road safety. Global studies exploring injury severity factors often overlook the intricate relationship between vehicle make and injury severity. This research addresses this gap using a comprehensive 2022 dataset from Brazil. A structured methodology was employed: Firstly, Random Forest, Decision Tree, Gradient Boosting, and KNN were used to predict the probability of accident injury severity. Secondly, SHAP values were applied to interpret the influence of vehicle make on injury severity. Finally, the combination of PF-Growth and Genetic Algorithm identified correlations between vehicle makes and injury severity. The study identified vehicle make as a key factor influencing injury severity, with Random Forest outperforming other models with 86.27% accuracy. Additionally, the two-element association rule analysis revealed significant correlations between vehicle makes and injury severity: FIAT PALIO EDX with serious injuries, VW GOL 1.0L MC4 with fatal accidents, RENAULT SANDERO GTL 16HP with minor injuries, and FIAT TORO VOLCANO AT D4 with no injuries. In the four-element association rule analysis, 2011 NISSAN FRONTIER SE 25 X2 pickup truck was strongly associated with fatalities, 2003 SR RANDON SR CA semitrailer with serious injuries, 2016 RENAULT MASTER MBUS L3H2 microbus with minor injuries, and 2019 M. BENZ SPRINTER MARTM5 microbus with uninjured. These insights guide road safety strategies, highlight critical research areas, and contribute to global efforts to mitigate road accidents.

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Sponsoring Committee	ACS20
Session Number	4073
Session Title	**Safety Performance and Analysis for Safe Vehicles**
Paper Number	25-02168
Paper Title	**Influences of Individual Heterogeneity on Vehicle Damage in Two-Vehicle Lane-Changing Related Crashes: A Semi-Parameter Copula-Based Model Considering Temporal Instability**
Abstract	Lane-changing behavior is a significant contributing factor to traffic crashes and exhibits individual heterogeneity in vehicle damage severity. To address this, we developed a semi-parametric copula-based joint logit model, flexibly constructing the dependence between lane-keeping and lane-changing vehicles in vehicle damage through diverse copula structures. This approach aims to investigate the factors influencing differences in damage severity resulting from lane-changing behavior. Our model also accounts for temporal instability among years and non-linear fluctuations in driver age and crash time. The lane-changing crash data analyzed in this study was collected from the Orlando region between 2016 and 2019. Vehicle, road, event, environmental, and driver characteristics were comprehensively considered to examine their effects. Findings emphasize the importance of constructing crash severity dependencies based on driving behavior and demonstrate the efficacy of semi-parametric estimation. Furthermore, our findings reveal the heterogeneous differences in vehicle damage caused by lane-changing behavior.

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Sponsoring Committee	ACS20
Session Number	4073
Session Title	**Safety Performance and Analysis for Safe Vehicles**
Paper Number	25-02183
Paper Title	**Analysis of ADAS- and ADS-equipped Vehicle Crashes Using Mixed-effects Logistic Regression**
Abstract	With the advent of vehicle automation technologies, the question of the association between vehicles with automation capabilities and safety looms large among transportation professionals and researchers. So far, little is known about this topic, primarily due to the lack of empirical evidence and dearth of quality data. To this end, this study explores various factors influencing crash severity and other crash characteristics in vehicles with automated driving capabilities of different levels (ADAS and ADS) utilizing mixed effects logistic regression with crash data between 2021 and 2024 from NHTSA. The study reveals factors including vehicle mileage, lighting, roadway surface, and weather conditions, airbag deployment, safety belt use, crashes with pedestrians, and other vehicle movement significantly influenced ADAS-equipped vehicle crash severity. Also, predictors including speed limits, vehicle mileage, driver engagement type, weather conditions, crashes with pedestrians, and other vehicle maneuvers were significantly associated with ADS-equipped vehicle crash severity. Furthermore, while speed limits, vehicle age and mileage, and crashes with pedestrians impacted safety belt use and airbag deployment in ADAS-equipped vehicle crashes, factors including speed limits, crashes with pedestrians, vehicle age and mileage, driver engagement level, ADS-equipped vehicle and other vehicle movements, and crash location influenced safety belt use and airbag deployment in ADS-equipped vehicle crashes. The results of this study shed light on the limited knowledge pertaining to safety of automated vehicles and might help industry and researchers to delve more into the key areas of interest related to safety of vehicle automation technologies.

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Sponsoring Committee	ACS20
Session Number	4073
Session Title	**Safety Performance and Analysis for Safe Vehicles**
Paper Number	25-02341
Paper Title	**Crash Injury Severity Analysis under Different Levels of Driving Automation**
Abstract	Vehicles equipped with automated driving capabilities have shown potential to improve safety and operation. Advanced driver assistance systems (ADAS) and automated driving systems (ADS) have been recently developed to support vehicular automation. Studies on the injury severity outcomes of automated vehicles are still limited, particularly investigating the difference between injury severity outcomes for the ADAS and ADS equipped vehicles. To ensure a comprehensive analysis, a multi-source dataset that includes 1,001 ADAS crashes (SAE Level 2 vehicles) and 548 ADS crashes (SAE Level 4 vehicles) is used. Two random parameters multinomial logit models with heterogeneity in the means of random parameters are estimated to gain a better understanding of the variables impacting the crash injury severity outcomes for the ADAS and ADS vehicles. The model estimation results reveal that the weather, driver indicator, differences in the system sophistication that are captured by both manufacture year and high/low mileage as well as rear and front contact indicators all play a role in the injury severity outcomes. The results offer an exploratory assessment of safety performance of the ADAS and ADS equipped vehicles using the real-world crash data and can be used by stakeholders to refine the direction of their deployment and usage.

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Sponsoring Committee	ACS20
Session Number	4073
Session Title	**Safety Performance and Analysis for Safe Vehicles**
Paper Number	25-03517
Paper Title	**Are We Ready for Automated Vehicles? Evaluating Automated Driving Systems' Safety and Reliability Using Propensity Score Matching**
Abstract	This research offers critical insights into the safety challenges and operational risks of Automated Driving Systems (ADS), focusing on heightened injury risks in remote and fully autonomous configurations. It provides actionable recommendations for improving ADS safety, making it highly relevant to TRB attendees navigating the integration of ADS into transportation systems

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Sponsoring Committee	ACS20
Session Number	4073
Session Title	**Safety Performance and Analysis for Safe Vehicles**
Paper Number	25-05004
Paper Title	**Examining the Role of Vehicle Dimensions and Advanced Driving Assistance Systems on Pedestrian and Bicyclist Injury Severity Outcomes**
Abstract	In the event of a crash between active traveler and motor vehicle, vehicle characteristics (both internal and external vehicle features) are likely to play a significant role. With regards to external and internal vehicle features, it might be beneficial to examine the interplay of vehicle dimensions and Advanced Driving Assistant System (ADAS) on active traveler injury severity outcomes. Towards that end, the major contribution of this study is grounded in examining the effect of vehicle type (represented by vehicle length and width) on active traveler injury severity outcomes while also controlling for ADAS and other exterior features of motor vehicles. Specifically, we propose a joint modeling framework to examine vehicle types and injury severity outcomes as two dimensions of the active traveler injury severity mechanisms. In the joint modeling process of this study, the vehicle type component is estimated by using random regret minimization based multinomial logit model, while the injury severity component is estimated by using generalized ordered logit formulation. Further, the time-varying effects of exogenous variables are accommodated by using piecewise linear function of crash year. The proposed model is demonstrated by using active traveler crash data from Queensland, Australia for the years 2015 through 2022. The outcomes of the study will inform future vehicle design in improving active traveler safety.

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Sponsoring Committee ACS20

Session Number 4073

Session Title **Safety Performance and Analysis for Safe Vehicles**

Paper Number 25-05769

Paper Title **Investigating the Role of Advanced Driver Assistance Systems (ADAS) in Reducing Sideswipe Collisions in Rural Ohio**

Abstract Rural areas experience a higher fatality rate per distance traveled compared to urban areas. A significant portion of rural crashes are sideswipe collisions attributed to driver error. Advanced Driver Assistance Systems (ADAS), including Blind Spot Warnings (BSW), Lane Departure Warnings (LDW), and Lane Keeping Assistance (LKA), can help mitigate these types of collisions. Despite the availability of these technologies, there is limited literature exploring their benefits. This study analyzes the impact of vehicles with and without ADAS technologies, considering various factors contributing to sideswipe collisions in rural Ohio. Using Bayesian Networks, the study examines crash data collected from 49 rural counties in Ohio between 2017 and 2022. The crash statistics indicate that adult drivers are frequently involved in sideswipe crashes. Additionally, the analysis identifies vehicles with level 0 automation as being more likely to be involved in these collisions. The findings from the Bayesian Network suggest that vehicles equipped with either BSW, LDW, LKA, or all three technologies have a reduced probability of fatal or severe injury crashes. Ultimately, this study aims to inform transportation engineering professionals and policymakers that ADAS is a potential solution for significantly reducing sideswipe collisions in rural Ohio. It also advocates for implementing policies such as in-cab cameras to prevent distracted driving.

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Sponsoring Committee ACS20

Session Number 4073

Session Title **Safety Performance and Analysis for Safe Vehicles**

Paper Number 25-06397

Paper Title **Effects of Advanced Driving Assistance Systems (ADAS) on Driver Injury Severity Outcomes: A Joint Multinomial Logit and Generalized Ordered Logit Model**

Abstract The arrival of Connected and Autonomous Vehicles (CAVs), Autonomous Vehicles (AVs) and vehicles equipped with Advanced Driving Assistant Systems (ADAS) on our road networks marks a significant shift in transportation safety as these vehicles have the potential to reduce the frequency of road crashes, and also lessen the crash severity outcome. However, managing the mixed traffic environment (CAVS, AVS, traditional vehicle with ADAS, and traditional vehicle) requires thoughtful policies and adaptable traffic management strategies to maximize safety while minimizing risks. Towards that end, the major contribution of this study is grounded in examining the effects of ADAS features on driver injury severity outcomes while also controlling for other confounding factors. Specifically, we propose a joint model of ADAS features and driver injury severity component modeled as two dimensions of injury severity mechanism. In the joint modeling process of this study, the combinations of different ADAS features available in motor vehicles are modeled by employing multinomial logit model while driver injury severity outcomes component is modeled by employing generalized ordered logit model. The proposed model was estimated by using crash data from Queensland, Australia, for the year 2022. The results highlighted the superiority of ADAS features, especially AEB contributes towards reducing crash likelihood and driver injury severity outcomes.

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Sponsoring Committee ACS20
Session Number 4073
Session Title **Safety Performance and Analysis for Safe Vehicles**
Paper Number 25-02957
Paper Title **Do Electric Vehicles Lead to More Severe Crashes? A Causal Inference Approach Using Doubly Robust Estimation**

Abstract Electric vehicles (EVs) differ from conventional vehicles in several key aspects: they generally have greater inertia due to increased mass, larger torque, higher acceleration rates, and a lower center of gravity. However, the safety impact of these differences remains unclear and insufficiently studied. This research aims to explore the influence of EVs on crash injury severity using a causal inference approach, treating EV crashes as the treatment group and conventional vehicle crashes as the control group. To robustly address the potential confounding issues with high-dimensional covariates, this study proposes a doubly robust estimator, applying Bayesian Additive Regression Trees in a matching-based approach (inverse probability of treatment weighting) and logistic regression in a regression-based approach. The combination of these methods forms a comprehensively doubly robust estimation framework for binary safety outcomes. The results reveal a significant 14% reduction in the odds of severe injuries in EV crashes compared to conventional vehicle crashes. In addition, the matching-based and regression-based approaches yield consistent casual estimates of the injury severity differences between EV and conventional vehicle crashes, except for the naïve comparison. Methodologically, this study adds to the literature a doubly robust estimator for comparing injury severity of different types of crashes using the differences among log-transformed causal odds ratios. Further, it provides valuable insights for researchers, practitioners, and policymakers to enhance safety management and design for EVs.

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Sponsoring Committee ACS20
Session Number 4073
Session Title **Safety Performance and Analysis for Safe Vehicles**
Paper Number 25-03192
Paper Title **Incorporating the Influence of Vehicle Mix on Crash Frequency and Severity**

Abstract The current approaches for crash frequency and severity prediction in the Highway Safety Manual (HSM) do not employ vehicle mix information. In this research effort, we build advanced alternatives to HSM methods while incorporating vehicle mix information. Two model systems: (a) multivariate Poisson-lognormal model (MVPLN) and (b) negative binomial-ordered probit fractional split model (NB-OPFS) are estimated by incorporating vehicle mix variables. The developed model systems can also capture the influence of observed and unobserved heterogeneity of different independent variables including vehicle mix variables. We estimate the models for three facility types including Urban Arterial 4-Lane Divided segments, Rural 3-Leg STOP Controlled and Rural 4-Leg STOP Controlled intersections using data from four Highway Safety Information System (HSIS) states including California, Illinois, Minnesota, Washington, and three Non-HSIS states including Connecticut, Florida and Texas. For modeling crashes at each facility level, we adopt a pooled modeling technique that accounts for state specific observed and unobserved heterogeneity in the pooled datasets. A comprehensive set of independent variables including traffic volume, vehicle mix indicators, roadway characteristics and state-specific indicators are considered in the analysis. The model comparison exercise is conducted based on a comprehensive set of quantitative and qualitative metrics. The study highlights how different methodological approaches perform better for different facilities. The study findings also underscore how capturing the observed and unobserved impacts of vehicle mix variables improves model performance in crash frequency and severity dimensions across the facility types.

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Sponsoring Committee	ACS20
Session Number	4073
Session Title	**Safety Performance and Analysis for Safe Vehicles**
Paper Number	25-03219
Paper Title	**Investigating Factors Contributing to Autonomous Vehicle Crash Severity Using Machine Learning and Recursive Feature Elimination (RFE)**
Abstract	The safe deployment of autonomous vehicles (AVs) presents significant challenges, requiring a thorough understanding of factors contributing to collisions and injuries. This study examines AV collisions reported to the California Department of Motor Vehicles (CA DMV) from 2018 to 2024, focusing on identifying key features that contribute to crash severity. Various machine learning techniques, including Decision Trees (DT), Logistic Regression (LR), Random Forests (RF), Support Vector Machines (SVM), Naïve Bayes (NB), and K-Nearest Neighbors (KNN), were employed to identify significant predictors of crash severity. Recursive Feature Elimination (RFE) determined the most influential features, while Multi-Distance Augmentation (MDA) addressed minority class imbalances, enhancing model robustness. The findings reveal that SVM and LR models perform exceptionally well, achieving accuracy scores of 92% and 91% respectively, with minimal variability across both original and augmented datasets. This was validated by k-fold cross-validation which demonstrated consistent performance. These models demonstrate strong predictive capabilities, effectively classifying varying severity levels with high precision and recall. Conversely, NB significantly underperforms with high variability, indicating it is not well-suited for this dataset. The results underscore the efficacy of traditional machine learning approaches, particularly SVM and LR, in this domain. Top-ranking features that contributed to these models include vehicle movement and status, specific damage location and collision type, vehicle type, environmental conditions, geographical factors, and vehicle company. Understanding how these key features play a role in collision severity provides insights into the underlying factors that contribute to AV safety.

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Sponsoring Committee	ACS10
Session Number	3039
Session Title	**Transportation Safety Management Systems from Start to Finish**
Paper Number	25-02461
Paper Title	**A Comprehensive Assessment of Pedestrian Fatalities on High-Speed Roads in Rural Areas**
Abstract	This study focuses on a relatively underexplored area: pedestrian fatalities on high-speed roads in rural regions of low- and middle-income countries. Without appropriate datasets, satellite imagery is utilized to estimate land cover and map population density. Pedestrian fatality rates are calculated based on road length and the highly exposed population within a 500-meter buffer along the road. These rates are then modelled using count data models, incorporating various independent variables significantly influencing pedestrian crash occurrences. The findings of this study aim to identify critical roads for pedestrians and key factors contributing to these incidents.

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Sponsoring Committee ACS20

Session Number 4073

Session Title **Safety Performance and Analysis for Safe Vehicles**

Paper Number 25-00341

Paper Title **Identifying Patterns and Risk Factors in SUV-Related Pedestrian Crashes Using Cluster Correspondence Analysis**

Abstract Sports Utility Vehicles (SUVs) have become increasingly popular for their versatility, but they are also known for being involved in more severe pedestrian crashes compared to standard passenger cars due to their mass and design. However, there has been minimal effort to thoroughly understand the unique characteristics of SUV-pedestrian crashes and the associated critical factors. This study utilizes the Cluster Correspondence Analysis (CCA) method, a machine learning-based approach to simultaneously segregate SUV type vehicle (light trucks/vans, and SUVs) and pedestrian crash data into homogeneous groups and extract cluster-specific factors associated with crashes. Specifically, the tool is applied to analyze SUV-pedestrian crashes that occurred in Louisiana between 2017 and 2021. One notable discovery from the CCA is that SUV-related pedestrian crashes often involve children who are identified as inattentive pedestrians. These incidents predominantly occur during daylight. Additionally, it was also identified that SUV-pedestrian crashes mostly occurred at intersections with traffic signals due to driver inattention, posing risks to elderly pedestrians. A detailed cluster-based comparative analysis indicates that crashes involving high-speed SUVs in open country areas under controlled traffic conditions contributed to the highest number of fatal pedestrian injuries. These clusters also present the highest percentage of male pedestrians, the highest incidence of non-collision with a motor vehicle, and a significant involvement of pedestrians aged 25 to 45. The insights drawn from this study are anticipated to provide safety professionals with a deeper understanding of different categories of SUV-pedestrian collisions and the associated factors.

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Sponsoring Committee ACS10

Session Number 2123

Session Title **Creating a Safer System: A Lectern-Poster Session**

Paper Number 25-00232

Paper Title **The Benefits of High-speed Rail on Reducing Traffic Accidents: Evidence from China**

Abstract To assess the nexus between High-Speed Rail (HSR) and road traffic accidents in China, this study analyzes how HSR influences accidents and then conducts a battery of empirical checks using the Difference-in-Differences (DiD) estimator and city-level data from 2005-2017. We find that new HSR routes lead to a 0.417-point reduction in accidents and a 1.511-point reduction in total traffic fatalities, translating to a 20% and 17% decrease respectively after accounting for meteorological variables and fixed effects. Heterogeneity analyses reveal more pronounced effects in economically developed cities with larger urban populations, better public transit infrastructure, and those in western regions. Furthermore, utilizing Tencent migration big data, we demonstrate that these reductions stem from substituting road passenger transport with HSR, especially for medium-to-short journeys. This paper addresses an academic gap in understanding HSR's impact on road safety and provides an idea for future road traffic safety management, that is, should corresponding measures to build an HSR-friendly environment be considered.

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Sponsoring Committee	ACS10
Session Number	2123
Session Title	**Creating a Safer System: A Lectern-Poster Session**
Paper Number	25-03724
Paper Title	**Impact of the 20mph Speed Limit in the UK: What Does the Evidence Show?**
Abstract	Studies on the effectiveness of 20 mph speed limits in the UK vary due to differences in context, methods, data, environments, and schemes. Many do not account for confounding factors like regression-to-the-mean, long-term trends, or changes in traffic volume, making it difficult to generalise their overall impact. This paper addresses these issues by developing a methodology to assess and classify the quality andvalidity of existing studies on 20 mph speed limits. It reviews 24 studies and 224 effect estimates, applying fixed-effects, random-effects, and multi-level meta-analysis models to evaluate the impact on collisions, personal injuries, and speed changes. The analysis shows that 20 mph speed limits reduce traffic collisions by an average of 26.45%, with a 21.6% reduction for schemes with signs only.Casualties decrease by 22.9% for all schemes, compared to 10.9% for sign-only schemes. The introduction of 20 mph speed limits with physical measures results in greater reductions in collisions and casualties than sign-only schemes. Additionally, sign-only schemes reduce mean speed by 1.76 mph. These findings will help policymakers make informed decisions on implementing 20 mph speed limits.

Authors	Ahmed Mohamed, University of Cincinnati Mohamed Ahmed, University of Cincinnati
Sponsoring Committee	ACS10
Session Number	2171
Session Title	**Decision Making with Safety Surrogates**
Paper Number	25-04594
Paper Title	**Assessing Traffic Conflicts Severity Through Simulated Collision Dynamics and Impact Analysis**
Abstract	Traffic conflict analysis is a crucial proactive approach for evaluating roadway safety, particularly at signalized intersections, which are inherently complex due to diverse road users, turning movements, and signal phases. This study introduces an integrated framework for assessing traffic conflict severity by integrating collision mechanisms into the analysis. Initially, the framework identifying conflict instances through time-to-collision (TTC) using accurately represented vehicle polygons. It then evaluates collision mechanisms assuming no evasive actions are taken, extracting forces, kinetic energies (K. E), angles of impact (AOI), and crash influence points (I. Ps) at the anticipated collision time. Eight crash simulation scenarios using an authorized C1500 pickup truck model are performed. The results reveal that for equivalent K. E values, head-on conflicts are significantly more severe compared to angle and rear-end conflicts, based on vehicle damage and sharp drops in K. E post-collision. Analysis also shows that inangle crashes, the amount of energy absorbed increases with the AOI but decreases with higher pre-collision speeds. The proposed framework outperforms traditional methods like Delta-V by offering a more detailed assessment of energy absorption and severity. This method enhances intersection safety evaluations and can optimize resource allocation for effective safety measures at hazardous locations.

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Sponsoring Committee	ACS10
Session Number	3039
Session Title	**Transportation Safety Management Systems from Start to Finish**
Paper Number	25-00080
Paper Title	**Developing Safety Performance Functions for Fatal and Severe Motorcycle Crashes at Intersections**
Abstract	This study developed motorcycle safety performance functions (SPFs) for fatal and severe injury (FSI) crashes at intersections in Kentucky, addressing a gap on intersection safety for motorcyclists. Using Conway-Maxwell-Poisson (CMP) model and its extensions, the study identified key factors affecting FSI motorcycle crash frequency at intersections, including AADT, traffic control type, and intersection layout. Based on study findings, several countermeasures were proposed based on the study results to improve motorcyclist safety andreduce FSI motorcycle crashes at intersections.

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Sponsoring Committee	ACS10
Session Number	3039
Session Title	**Transportation Safety Management Systems from Start to Finish**
Paper Number	25-00102
Paper Title	**Impact of COVID-19 Pandemic on Distraction-Related Motorcycle Crashes**
Abstract	This study identified the factors contributing to the crash injury severity of distraction-related motorcycle crashes in Kentucky, while accounting for the impact of COVID-19. The study findings will inform targeted safety interventions in a post-pandemic context to reduce the severity of distraction-related motorcycle crashes.

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Sponsoring Committee	ACS10
Session Number	3039
Session Title	**Transportation Safety Management Systems from Start to Finish**
Paper Number	25-00607
Paper Title	**How Do EV Crashes Differ from ICEV Crashes: A Comparative Study of Pennsylvania**
Abstract	This presentation will provide valuable insights into understanding the differences between EV and ICEV crashes. Attendees will gain a comprehensive perspective on characteristics of EV crashes in Pennsylvania. This study provides valuable insights into the distinctive patterns of EV crashes and crash severities, thus offering vital references for the development of road safety plans and strategies that accommodate the emergence of EVs.

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Sponsoring Committee	ACS10
Session Number	3039
Session Title	**Transportation Safety Management Systems from Start to Finish**
Paper Number	25-01202
Paper Title	**Analyzing Crash Severity in Texas Piney Woods Rural Areas Using Machine Learning**
Abstract	Every year, crashes in rural towns take lives and alter the dynamics of entire communities. This research seeks to understand a broad scope of factors that determine the severity of crashes that produce either severe or fatal results, particularly in and around the region of Texas known as the “Piney Woods.” In the past ten years, the Piney Woods has accounted for over half of the rural population crashes in the state of Texas, giving specific interest in understanding the influencing factors of crashes that produce severe and fatal injuries in this region. Therefore, to better understand the factors that attribute to such crashes, we have extracted data from the Texas Department of Transportation (TxDOT) Crash Record Information System (CRIS) database, which was then further split into a training and a test data set. Then, five machine learning techniques, namely binary logistic regression, k-nearest neighbors, naïve Bayes, random forest, and an artificial neural network, were all applied to the unseen test data. The random forest model produced the most promising results by predicting non-severe crashes with 99.5% accuracy. The results of this research allow engineers a greater understanding of what influences crashes, specifically severe crashes, within the Piney Woods. In the future, this information could be used to understand roadway hazards and effect changes in design philosophy for our rural communities so that severity of crashes can be reduced, and lives saved, not only in the Piney Woods, but across the state and the U.S.

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Sponsoring Committee	ACS10
Session Number	3039
Session Title	**Transportation Safety Management Systems from Start to Finish**
Paper Number	25-01577
Paper Title	**Getting a “W” for Safety: Flipping the Script on the Safety “Es” in Search of a Winning Strategy**
Abstract	As we enter the second decade of Vision Zero in the US, this paper emphasizes the need to move beyond traditional safety silos and strategies. Historically, transportation safety has relied on the "Es" of safety: engineering, enforcement, education, and emergency services. The Safe System Approach represents a pivotal shift from those silos towards a system-based, proactive paradigm. While this approach has garnered substantial funding and support in the US, its implementation can still revert to the traditional Es mindset, missing the core principle of kinetic energy risk reduction. This paper argues that kinetic energy, the root cause of roadway injuries and deaths, must be central to safety strategies. By focusing on exposure, likelihood, and severity, the Safe System Approach can more effectively mitigate risks. Referencing the Safe Systems Pyramid, this paper explores safety through a public health lens, emphasizing systemic interventions over individual efforts. In alignment with the Pyramid, this paper proposes a "Ws of transportation safety" framework that examines who, what, when, where, why, and which policies influence travel behavior and the environment. This comprehensive view unlocks new safety tools and partnerships, highlighting the importance of upstream interventions such as land use planning, multimodal transportation options, and affordable housing. The paper concludes with practical applications of the Ws framework, illustrating its potential to transform roadway design and safety assessments. By institutionalizing these strategies, transportation practitioners can find a fresh set of tools, and hopefully refreshed motivation, funding, partners, and purpose, in support of Vision Zero 2.0.

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Sponsoring Committee ACS10

Session Number 3039

Session Title **Transportation Safety Management Systems from Start to Finish**

Paper Number 25-02850

Paper Title **Analyzing Injury Severity of School Bus Crashes considering Temporal and Spatial Heterogeneity Using Random Parameters Ordered Probit Model**

Abstract Ensuring the safety of students is a multifaceted task, extending beyond the mere design of vehicles. It involves analyzing crash data related to school buses, which plays a critical role in preventing injuries and fatalities of children both in and around these vehicles. The National Highway Traffic Safety Administration gathers comprehensive data on a wide range of school bus-related crashes, from minor incidents to serious and fatal crashes. The school bus crash data not only educates parents and caregivers but also supports various prevention campaigns. The objective of this study is to investigate the different risk factors that influence the severity of injuries in school bus crashes, considering variations in time and location. To achieve this, a Random thresholds random parameters ordered probit (RPOP) model is used, which is particularly effective in identifying and accounting for unobserved variables that might affect the outcomes. Moreover, the model results suggest that springtime and highway locations significantly impact crash outcomes, considering crash details, vehicle information, and driver-passenger characteristics. These findings enhance our comprehension of the diverse factors that contribute to school bus crashes. This improved understanding aids in the development of effective strategies to reduce the severity of injuries resulting from such crashes.

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Sponsoring Committee ACS10

Session Number 3039

Session Title **Transportation Safety Management Systems from Start to Finish**

Paper Number 25-02841

Paper Title **Comparative Analysis of School Bus Crash Severity on Urban versus Rural Roadways: A Random Parameter Logit Model with Mean Heterogeneity**

Abstract With growing concerns regarding the safety of school-aged children during their commutes, this study delves into an in-depth analysis of the severity of school bus crashes on urban versus rural local roadways. Leveraging a comprehensive dataset from the National Highway Traffic Safety Administration, which encompasses 492 rural and 531 urban crash incidents, the research employs Random Parameter Logit Models with a focus on unobserved heterogeneity in means. This sophisticated methodological approach allows for a nuanced examination of the myriad factors that contribute to crash severity in these divergent environments. The investigation is poised to uncover significant differences in the severity of crashes between urban and rural contexts, attributable to a variety of factors such as roadway infrastructure, traffic congestion, and environmental conditions. The incorporation of unobserved heterogeneity into the analysis underscores the complex nature of crash severity factors, indicating that some determinants may not be directly observable. In rural areas, early morning crashes decrease BC severity by 0.54% while evening crashes increase KA severity by 2.77%, and in urban areas, afternoon crashes decrease BC severity by 16.14% while arterial roads increase it by 25.88%, highlighting the significant influence of temporal and spatial characteristics on injury outcomes and the need for targeted interventions. This study not only delineates the distinct patterns of school bus crash severity between urban and rural settings but also offers concrete data to guide the crafting of specific safety measures aimed at reducing the incidence and impact of school bus crashes in these uniquely defined landscapes.

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Sponsoring Committee	ACS10
Session Number	3039
Session Title	**Transportation Safety Management Systems from Start to Finish**
Paper Number	25-03225
Paper Title	**Effect of Traffic Characteristics on Pedestrian Crash Risk Around School—A Micro-level Pedestrian Casualty Model**
Abstract	Statement of Significance (Relevance of Research): Pedestrians are a vulnerable group of road users who are directly exposed to complex traffic conditions, thereby increasing their risk of injury or death. Traffic characteristics play a crucial role in pedestrian safety, but the impact of micro-scale features has not been fully recognized. To address these issues, this study developed a micro-crash model using pedestrian count data to assess the impact of traffic characteristics on pedestrian injuries. In addition, the effects of spatial dependence and correlation between pedestrian casualties of different injury severities were considered using a multivariate Bayesian spatial approach. The effects of roadway geometry, exposure, traffic characteristics and road conditions were also considered. The results show that exposure characterized by pedestrian counts is significantly and positively correlated with pedestrian casualties. And other values such as speed limits and average speed are positively correlated with pedestrian casualties. Results of the study provide insights for developing traffic management measures to improve pedestrian safety.

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Sponsoring Committee	ACS10
Session Number	3039
Session Title	**Transportation Safety Management Systems from Start to Finish**
Paper Number	25-03313
Paper Title	**Transferability and Temporal Heterogeneityof Motorcyclist Injury Severity in Wet and Dry Season: A Case Studyin Cambodia**
Abstract	Motorcyclists are particularly vulnerable to crashes as they lack sufficient protection, exposing them to a high risk of injury. Despite this, the specific impact of the wet season on motorcyclist injury severity in Southeast Asian developing countries remains largely unexplored. In recent years, the random parameter logit model with heterogeneity in means and variances has emerged as a significant tool in road safety research. To this end, this study investigates factors that influence the severity of motorcycle accidents both in wet and dry season of Cambodia by utilizing the random parameter logit models with heterogeneity in means and variances approach. These models were estimated based on motorcycle crash data of Cambodia, from the year 2015 through 2017. Effects of variables are compared by estimating their marginal effects on the injury severity outcomes. The results indicate that motorcycle-to-motorcycle crashes significantly increase the likelihood of motorcyclist casualties suffering from severe injuries during the wet season. Furthermore, accidents involving elderly motorcyclists are more likely to result in severe and fatal injuries compared to young riders during the wet season. In contrast, during the dry season, riders face a greater risk of severe injury compared to pillion riders, and crashes occurring on national roads have a higher probability of resulting in casualties suffering fatal injuries. Moreover, the transferability and temporal stability tests indicate that the effects of exogenous variables on the motorcyclist injury severity are different across year-wise models. Detailed policy-related recommendations are provided based on these analysis results to improve safety for motorcyclists.

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Sponsoring Committee	ACS10
Session Number	3039
Session Title	**Transportation Safety Management Systems from Start to Finish**
Paper Number	25-03718
Paper Title	**Spatial Variations in the Relationship Between Built Environment and Severe Crashes: A Case Study in Florida**
Abstract	Traffic crashes are known to be one of the significant contributing factors to the fatalities globally, with an increasing pace of accidents occurring in urban areas. This increased pace and higher risk indicate the need to assess the relationship between the built environment and traffic safety. This study focuses on analyzing the relationship between severe traffic crashes and urban built environment by global and local spatial models to reveal the spatial variations in contributing factors. We aim to investigate this relationship at the macroscopic level within a spatial regression modeling framework in which spatial lag (SLM), spatial error (SEM), geographically weighted regression (GWR), multi-scale geographically weighted regression (MGWR), and spatially lagged multi-scale geographically weighted regression (MGWRL) models are employed for a case study of Leon County, Florida. The approach can be used as a route map while investigating the relationship between severe crashes and urban built environment factors within a spatial framework.

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Sponsoring Committee	ACS10
Session Number	3039
Session Title	**Transportation Safety Management Systems from Start to Finish**
Paper Number	25-04271
Paper Title	**Investigating Factors Affecting Pedestrian Fatalities in the US: A Comparative Study of Pre-Pandemic, Pandemic, and Late-Pandemic Periods**
Abstract	The rising pedestrian fatalities were already a public health concern which has been exacerbated by the disruptions caused by the COVID-19 pandemic. The existing literature offers valuable insights into the general trends and factors influencing pedestrian crashes and fatalities, however, there is a significant gap in understanding how these dynamics have changed in the pandemic-affected years. As such, this study aims to conduct a comprehensive analysis to identify the factors that have differential impacts on pedestrian fatalities across three periods: pre-pandemic (2019), pandemic (2020-2021), and late-pandemic period (2022). For this, the data were obtained from various sources including the Fatality Analysis and Reporting System, National Transit Stop Maps, Smart Location Database, and disadvantaged community database. This study utilized a twofold approach, first, the analyses were conducted at the pedestrian level using a mixed effects multinomial logit model, and second, the analyses were conducted at the census tract level using mixed effects negative binomial models. The results showed some variables exhibited a temporal shift and were associated with a higher likelihood of pedestrian fatalities such as pedestrian and driver age (25-45 years), impairment, failure to yield, jaywalking, weekend evenings/nights, proximity to transit stops, population density, and non-intersections. Analyses revealed that urban areas, lower-income neighborhoods, transit stop density, auto-oriented road network density, percent population with poor mental health, and population below 17 years were associated with an incremental increase in pedestrian fatalities across the three periods.

Authors	Weijing Wang, University of California, Davis
Sponsoring Committee	ACS10
Session Number	3039
Session Title	**Transportation Safety Management Systems from Start to Finish**
Paper Number	25-04729
Paper Title	**Safe System for Whom? Quantifying the Impacts of Transport Infrastructure Using a Systematic Analysis**
Abstract	In this paradigm shift to the safe systems, empirical research lacks a systematic analysis of the safety impacts of transport infrastructure. This study contributes to the literature by asking (1) What are the impacts of transport infrastructure on the likelihood of fatalities (versus socioeconomic factors)? (2) What are the heterogeneous effects of transport infrastructure on fatalities for cyclists, pedestrians, relative to vehicle occupants? (3) To what degree does one traveling in areas outside the city boundaries impact the likelihood of fatality, relative to cities? In doing so, I measured the prevalence of transport infrastructure across California using three indicators: the presence, lane miles, and density, and quantified the effects of three types of infrastructure (major roads, residential streets, and cycling infrastructure) on fatalities using the logistic regression. Results show that increases in the lane miles of major roads is associated with increases in the likelihood of fatalities for all - vehicle occupants [ORs: 2-2.4], cyclists [ORs: 1.3-1.4], and pedestrians [ORs: 1.4]; yet, one unit increase in the density of cycling infrastructure is associated with a 6% and 3% decrease in the likelihood of fatality for cyclists and pedestrians, respectively. I also found that a larger proportion of Black and Hispanic residents is associated with increases in the likelihood of fatalities for all [ORs: 1.01-1.02]; cyclist fatalities are 1.3 times as likely to occur in non-cities as in cities. Findings highlight the heterogenous effects of transport infrastructure on fatalities and sociodemographic disparities, which merits attention in the policy intervention processes.

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Sponsoring Committee	ACS10
Session Number	3039
Session Title	**Transportation Safety Management Systems from Start to Finish**
Paper Number	25-04862
Paper Title	**Analyzing School Bus-Related Crashes in New Jersey Using Machine Learning Techniques**
Abstract	Despite various safety initiatives, school bus-related crashes remain a significant concern in the United States. National data from the NHTSA reveals that from 2007 to 2016, 4% of fatal motor vehicle crashes were school-transportation-related, resulting in 1,282 deaths, including 281 school-age children. In 2018, 117 fatalities and 13,000 injuries were reported due to school bus-related crashes in the U.S., with three fatalities in New Jersey. This issue underscores the urgent need to study the safety of school bus passengers and crashes involving school buses. This paper investigates school bus crashes in New Jersey from 2016 to 2024. Advanced machine learning models, including XGBoost, Random Forest (RF), Support Vector Machine (SVM), Decision Tree and AdaBoost, were employed to evaluate the contributing factors to these crashes. The models were trained and tested to predict crash factors, with their effectiveness assessed based on performance metrics and accuracy. Additionally, SHapley Additive exPlanations (SHAP) analysis was conducted to interpret the impact of various factors on different crash outcomes, such as property damage, injury, and fatality. Our findings provide critical insights into the dynamics of school bus-related crashes and offer data-driven recommendations for enhancing safety measures, contributing to the protection of school children, and informing future safety policies and interventions.

Authors	Yazmin Dasgar, Michigan State University Nischal Gupta, Michigan State University Ardeshir Fadaei, Michigan State University Peter Savolainen, Michigan State University
Sponsoring Committee	ACS10
Session Number	3039
Session Title	**Transportation Safety Management Systems from Start to Finish**
Paper Number	25-04997
Paper Title	**Investigating Trends in High-Risk Driving Behaviors Before and After the Onset of the COVID-19 Pandemic**
Abstract	The COVID-19 pandemic brought about significant changes in day-to-day life, including people's travel behavior. This included significant reductions in travel due to travel restrictions that were imposed to contain the pandemic. Surprisingly, despite marked reductions in travel, fatal and severe injuries significantly increased post-pandemic. Various explanations have been provided for this result, including higher travel speeds due to lower levels of congestion, as well as increases in various types of high-risk behaviors, such as impaired driving and the non-use of seatbelts. Interestingly, even after the travel restrictions were relaxed, these negative trends have continued to persist to varying degrees in the subsequent years. This study investigates trends in various high-risk driving behaviors before and after the onset of the COVID-19 pandemic using data from the National Highway Traffic Safety Administration Crash Reporting Sampling System for the years 2018 to 2022. The study examines changes in alcohol-impaired driving, seatbelt usage, and speeding, before and after the pandemic, in addition to evaluating changes in the level of injury sustained by crash-involved drivers. Results indicated a significant increase in each of these high-risk behaviors, which persisted after the pandemic. Several groups of drivers were at elevated risks for these behaviors, particularly male and younger drivers. There were also interesting regional and temporal variations across the United States. The findings underscore the need for targeted road safety interventions to mitigate the long-term impacts of the pandemic on driver behavior and crash outcomes.

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Sponsoring Committee	ACS10
Session Number	3039
Session Title	**Transportation Safety Management Systems from Start to Finish**
Paper Number	25-05800
Paper Title	**Understanding Pedestrian and Bicyclist Safety Trends in the Post-Pandemic Era**
Abstract	This presentation will interest TRB attendees by highlighting post-pandemic trends in pedestrian and bicyclist safety across the U.S. and California. It reveals significant disparities, particularly in disadvantaged communities, and emphasizes the need for targeted interventions to address these safety challenges effectively. Attendees will benefit from evidence-based findings that highlight the urgency for targeted, region-specific interventions to improve safety and reduce disparities, aligning with TRB's mission to enhance transportation systems for all.

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Sponsoring Committee	ACS10
Session Number	3039
Session Title	**Transportation Safety Management Systems from Start to Finish**
Paper Number	25-06361
Paper Title	**Assessment of vehicle age as a contributor to temporal shifts in single-vehicle driver injury severities**
Abstract	Vehicle age plays a crucial role in crash occurrence and occupant injury severity, with older vehicles historically associated with more severe injury outcomes compared to newer models. This study investigates the temporal instability of specific injury-contributing factors for single-vehicle, single-occupant crashes involving vehicles less than 5 years old at the time of the crash, using data from Alabama's Critical Analysis Reporting Environment (CARE) system. The analysis spans four time points: 2010, 2014, 2018, and 2022. Preliminary data analysis indicates a reduction in new vehicle severe injury crashes from 8.63% in 2010 to 3.99% in 2022. Random parameters multinomial logit models with heterogeneity in means were developed to identify crash factors significantly related to injury outcomes. Key findings highlight the consistent trend of higher severity in crashes involving completely damaged vehicles. However, there was a notable decrease in severe injuries for 5-year-old vehicles involved in crashes in 2022 compared to previous years. Similarly, the reduced impact of deployed frontal airbags on severe injury outcomes points to significant improvements in occupant protection. The results further revealed that this benefit is particularly evident in the reduced likelihood of severe injury among drivers older than 65 years over the years. The study indicates the importance of advancements in vehicle technology in enhancing occupant safety. It also emphasizes the need for ongoing research into driver behavior, road conditions, and the evolution of safety standards to fully leverage these technological improvements. The findings suggest that continuous updates to driver education and awareness programs are essential to reflect new technologies and changing driving environments, ensuring drivers can effectively utilize advanced safety features.

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Sponsoring Committee	ACS10
Session Number	3039
Session Title	**Transportation Safety Management Systems from Start to Finish**
Paper Number	25-06437
Paper Title	**Investigating the Association of Post-Crash Medical Conditions and Human Factors with Motorcyclists Injuries: Insights from Fine Injury Data From Hospital Records**
Abstract	This study investigates the factors influencing the Injury Severity Score (ISS) in motorcycle crashes, utilizing a comprehensive dataset from the Road Traffic Injury Research and Prevention Centre (RTIRPC) in Karachi, Pakistan. The analysis focuses on the post-crash medical conditions of crash victims as well as factors related to the roadway, environment, crash, and post-crash events. Specifically, the study examines the post-crash medical health conditions including Glasgow Coma Score (GCS), Systolic Blood Pressure (SBP), and Respiratory Rate (RR) and their association with the ISS. Based on the distribution of dependent variable (ISS), after addressing the issues related to missing or inappropriate values in the dataset with synthetic data generation, a Tobit regression model was employed in a corner solution setup. The findings indicate that decreased GCS and SBP levels have a significant impact on the ISS, signifying a more severe injury. Additionally, a positive association between prehospital time and ISS was established, underscoring the critical influence of emergency response times on injury outcomes. The study also highlights several significant characteristics contributing to the severity of injuries in motorcycle crashes, such as overspeeding, wrong-way driving, nighttime crashes, and crashes involving multiple vehicles. Furthermore, the study emphasizes the significance of specific actions, including focused interventions, improved enforcement of traffic laws, and enhanced emergency medical services, in mitigating injury severity in motorcycle crashes. It also calls for future research to consider real-time data collection at crash sites and account for socio-economic elements in formulating comprehensive safety measures.

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Sponsoring Committee	AMR00, ACP10, ACS10, ACS30, AMR20
Session Number	4081
Session Title	**Advancements in Emergency Response, Incident Management, and Post-Crash Care: Innovative Approaches to Enhancing First Responder Safety and Efficiency**
Paper Number	25-00712
Paper Title	**How Do Motorists' Pre-Crash Behaviors Contribute to the Injury Severity of Police Officers? Using Interpretable Machine Learning to Untangle the Behavioral Pathways in Police-Involved Crashes**
Abstract	This presentation will provide valuable insights into the behavioral pathway leading to police injury severities. Attendees will gain a comprehensive perspective on the behavioral pathways from contributing factors to motorists' pre-crash behaviors, ultimately leading to the injury severity of police officers in Alabama. The findings offer an overview of how variables affect police injury severity directly and indirectly. The presentation aims to contribute to the ongoing discussions on the injury severity of police officers and the potential solutions for protecting police officers on the roadway.

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Sponsoring Committee	AMR00, ACP10, ACS10, ACS30, AMR20
Session Number	4081
Session Title	**Advancements in Emergency Response, Incident Management, and Post-Crash Care: Innovative Approaches to Enhancing First Responder Safety and Efficiency**
Paper Number	25-02845
Paper Title	**Examining the Spatially Varying Correlates of Police Injury Severity: A Study of Pennsylvania**
Abstract	This study addresses the critical issue of police officer safety in traffic incidents by exploring the spatially 38 varying factors contributing to injury severity in police-involved crashes across Pennsylvania. The application of a Geographically Weighted Ordered Logistic Regression (GWOLR) model uncovers significant spatial heterogeneity, offering valuable insights for localized, data-driven interventions to enhance officer safety.

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Sponsoring Committee	AMR00, ACP10, ACS10, ACS30, AMR20
Session Number	4081
Session Title	**Advancements in Emergency Response, Incident Management, and Post-Crash Care: Innovative Approaches to Enhancing First Responder Safety and Efficiency**
Paper Number	25-04781
Paper Title	**Data Driven Analysis to Inform National Strategies on Improving Post-Crash Care**
Abstract	Reducing prehospital emergency medical service (EMS) time is essential for decreasing the severity of crash outcomes. Recently, South Korea has faced prolonged prehospital EMS time, prompting the Korea National Fire Agency (KFA) to announce strategies to reduce prehospital EMS time. This study aimed to provide a methodological process and quantitative basis for implementing the KFA's strategies. To achieve this, the study employed an XGBoost approach with SHAP value analysis to identify key factors influencing crash severity and to examine their global and local impacts. The resultant key factors included spatiotemporal attributes, including on-scene time, freeway mainline, and nighttime, which were used to quantitatively validate the KFA's strategies. This research is the first attempt to apply an interpretable machine learning algorithm to improve post-crash care, using crash data and EMS infrastructure information from an entire country. The methodology employed can be applied to quantitatively support decision- making on similar issues in various regions and countries.

6 Crash Modification Factors and Functions

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This year, the subcommittee identified **10 papers** based on research dealing with crash modification factors (CMF) and did not identify any dealing with crash modification functions. This review only includes CMFs estimated using collision data analysis. For studies using surrogate safety measures, the readers are referred to Section 7.

Below, for each of the 10 papers involving Crash Modification Factors_, the following information is provided: authors, sponsoring committee, session number, session title, paper number, paper title, and abstract or Introduction.

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Sponsoring Committee	AKP50-Standing Committee on Pavement Surface Properties and Vehicle Interaction
Session Number	Lectern Session 4087
Session Title	**Texture Evaluation and Friction Response: The Rub on Safety**
Paper Number	TRBAM-25-01444
Paper Title	**How Does Pavement Friction Impact Motorcycle Crashes? A Florida Analysis**
Abstract	Pavement friction performance is crucial to motorcycle safety due to motorcycles' unique dynamics and vulnerabilities compared to other vehicles. Maintaining adequate pavement friction prevents motorcyclists from losing control and reduces motorcycle crashes. However, the relationship between motorcycle crashes and friction characteristics is not well quantified due to the absence of reliable friction data. The Florida Department of Transportation (FDOT) District 7 utilized the Sideway-force Coefficient Routine Investigation Machine (SCRIM) to collect continuous pavement friction measurement (CPFM) data for over 2,000 lane miles on its state roads. Based on the SCRIM data, this study developed safety performance functions (SPFs) and crash modification functions (CMFs) for motorcycles considering facility types and pavement types. The modeling results indicate that increased friction is more likely to reduce motorcycle crash frequencies, while intensified friction variation tends to increase crash frequencies in specific scenarios. Other pavement characteristics affecting motorcycle crash frequencies include macrotexture and pavement conditions (roughness, cracks, and ruts). Investigatory Levels (ILs) for friction and macrotexture were developed based on the SPFs to determine the friction demand for motorcycle safety. The study outcomes, such as SPFs, CMFs, and ILs, can be integrated into motorcycle safety management and select resurfacing, restoration, and rehabilitation (3R) projects for motorcycle safety improvement.

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Sponsoring Committee	AKP50-Standing Committee on Pavement Surface Properties and Vehicle Interaction
Session Number	Lectern Session 4087
Session Title	**Texture Evaluation and Friction Response: The Rub on Safety**
Paper Number	TRBAM-25-00955
Paper Title	**Safety Performance Functions and Crash Modification Factors for Skid Resistance on Interstate and Non-Interstate Highways**

Abstract

Pavement friction is crucial for road safety, especially in adverse weather. This study investigates the relationship between pavement friction—measured as Skid Number (SN) —and crash frequency on Utah highways. Using data from 2016–2019 for I-15 (interstate) and US-89 (non-interstate), negative binomial models were estimated to establish safety performance functions (SPFs) and crash modification factors (CMFs). The models accounted for traffic volume, segment length, and roadway geometric characteristics, examining various crash types, including dry and wet weather, property damage only, and injury-related crashes. Results show a significant negative association between SN and crash frequency for all crash types on both highway types. Higher SN values (more friction) were linked to fewer crashes. A 10-unit increase in SN was associated with a 7–8% reduction in dry weather crashes on both highway segments. For wet weather crashes, the same increase in SN resulted in a 13% decrease on non-interstate and a 21% decrease on interstate highways. The impact of SN on reducing crashes was particularly strong on interstate highways during wet conditions, indicating that pavement friction is vital for safety in these scenarios. Additionally, the safety impact of skid resistance was greater on segments with more curved portions. These findings suggest that enhancing pavement friction through measures like high-friction surface treatments could significantly improve traffic safety. The results support the continued collection of skid data by transportation agencies to identify high-risk locations and prioritize friction improvement efforts to enhance roadway safety.

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Sponsoring Committee ACS20

Session Number Poster Session 2206

Session Title Safety Performance and Analysis with Crash Predictions

Paper Number TRBAM-25-03413

Paper Title **Safety Performance Functions for Rural Two-Lane Two Way Roadways in New Jersey**

Introduction

The Highway Safety Manual (HSM), published in 2010, provides a comprehensive approach and a set of analytical tools and methods for roadway safety analysis (1). The HSM's predictive methods are based on safety performance functions (SPF), which have the following general form for the mean crash counts of roadway segments ($N_{spf,s}$) and intersections ($N_{spf,x}$) in the HSM:

$$\log(N_{spf,s}) = a_0 + a_1.\log(AADT) + a_2.\log(L) \quad (1)$$

$$\log(N_{spf,x}) = b_0 + b_1.\log(AADT_{maj}) + b_2.\log(AADT_{min}) \quad (2)$$

Where, $AADT$, $AADT_{maj}$ and $AADT_{min}$ are the annual average daily traffic on road segments, and on the major and minor approaches of intersections, respectively; L is roadway segment length in miles, and a 1nd b are the model coefficients. These functions yield the mean crash frequency under specific base geometric and operational conditions. Crash modification factors (CMFs) are then used to adjust the mean to account for the differences between the base and site-specific conditions, as follows:

$$N_{e\,i} = N_{spf\,i} \prod CMF_{k\,i} \quad (3)$$

Where, $N_{spf\,i}$ is mean crash count at site i for base conditions, similar in form to equations (1) and (2), $N_{e\,i}$ is the adjusted mean crash count at site i, and $CMF_{k\,i}$ is calculated for specific geometric or operational feature k for site i. To utilize these functions for other states one could either (1) calibrate the generic SPF provided in the HSM and (2) develop new SPF using local data. In the calibration process, a calibration factor C is calculated using historical local crash counts N_o collected from similar sites, as follows:

$$C = \sum_{\forall i} N_{o\,i} \Big/ \sum_{\forall i} N_{e\,i} \quad (4)$$

C is then adopted in future safety analyses when predicting the mean crash count of a similar site by calibrating the adjusted mean crash count N_e as $N_{pred} = C.N_e$. Numerous studies have been dedicated to the calibration and development of SPF. A comprehensive review of these studies can be found in Ozbay et al. (2). It is evident from the review of these studies that a significant portion of the research effort was directed towards identifying and compiling the required data from multiple sources, as well as manually extracting data to complement missing information. The objectives of this paper are twofold. The first objective is to present a detailed discussion of data needs and availability, data processing methods, and approaches to gather the required data for the calibration and development of SPF. For this purpose, rural two-lane two-way (R2) segments and intersections in New Jersey (NJ) were used as a case study.

The paper demonstrates that datasets are rarely free of errors and inconsistencies, and that generating a usable dataset from various data sources is a rigorous task of data compiling, cleaning, and processing, requiring significant computer programming effort. The second objective of the paper is to examine the functional form of C in Equation (4) and to propose maximum likelihood (ML) estimation for a more statistically sound estimate of C. It is shown that ML estimation restores the current form of C in Equation (4) only when crash counts follow a Poisson distribution.

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Sponsoring Committee	ACS20
Session Number	Poster Session 2240
Session Title	**Safety Performance and Analysis for Safe Roads**
Paper Number	TRBAM-25-04300
Paper Title	**Crash Modification Factors and Functions for Management of Pavement Friction for Safety for Roadway Segments**

Abstract The paper documents the development of safety performance functions (SPFs) that include friction and macrotexture on a variety of roadway facility types and categories (i.e., segments, intersections, curves, and ramps). The main objective is to apply those SPFs to develop crash modification factors (CMFs), or crash modification functions (CMFx) that make it possible to evaluate the effect of pavement friction changes on safety performance, which can be used to assess the cost-effectiveness of pavement friction enhancements. The analysis confirmed a strong statistical association between pavement surface frictional properties (friction and macrotexture) and crash rates; lower crash rates were observed with higher friction and macrotexture. The Safety Performance Functions (SPFs), which included friction and macrotexture measurement, were developed for total crashes using traditional negative binomial models. Friction was found to have a statistically significant effect for predicting total crashes on all the roadway facility types; and macrotexture was found to have a statistically significant effect for predicting total crashes on all roadway facility types except rural two-lane/two-way roads. These SPFs were then used to develop CMF/CMFx for relatively straight segments and with areas of higher friction demand (curves and intersections) on each type of facility. The CMFx obtained generally follows the expected trends and show, for example, that a potential reduction of up to 30 percent of total crashes can be achieved with a 10-point increase in friction (SFN40). Keywords: Pavement Friction Management Program, Continuous Friction Measurement Equipment, Continuous Pavement Friction Measurement, Skid Resistance, Macrotexture, Mean Profile Depth, Safety Performance Function, Crash Modification Function, Crash Modification Factor.

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Sponsoring Committee	ACS20
Session Number	Poster Session 2240
Session Title	**Safety Performance and Analysis for Safe Roads**
Paper Number	TRBAM-25-04389
Paper Title	**Safety Effectiveness of Rumble Strips on Indiana Rural Roads**

Abstract Rumble strips are designed and deployed to reduce run-off-road crashes by alerting drivers about near lane departures. Although they have been widely used, their operational safety effectiveness still needed to be investigated in states with their specific weather and driving population. Rumble strips may have different lengths (transversal) and be installed on edge, shoulder, center, or in any combination of these locations. To perform a comprehensive analysis of rumble strips' safety effect on rural two-lanes undivided roads across Indiana, this study extracted and assembled a dataset for road segments with installed rumble strips including crash data, strips' locations, types, dimensions, and road geometry for 4,782 miles-years. For comparison, data for reference road segments without rumble strips installed were collected for 16,955 miles-years. The 2015-2022 crash data was assigned to over 5,600 road segments with homogeneous rumble strip arrangement (including no strips), traffic, and cross-section. To account for the potential overdispersion of crash counts and heterogeneity among segments from the same road, the random effect negative binomial model was estimated. The estimation results indicated that rumble strips significantly reduced the crash rates. The overall Crash Modification Factors (CMFs) for roadside only design and for center only design was both 0.87, while the CMF for combined roadside and center design was 0.79. The likelihood ratio tests showed that rumble strips length (12-inch and 16-inch) and installation location (edge and shoulder) have insignificant effects on rumble strips' safety performance.

104th ANNUAL MEETING
January 5–9, 2025 • Washington, DC

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Sponsoring Committee ACS20
Session Number Poster Session 2240
Session Title **Safety Performance and Analysis for Safe Roads**
Paper Number TRBAM-25-04741
Paper Title **Effect of Roadway Lighting on Safety in Utah**

Introduction Nighttime conditions introduce significant problems to roadway safety due to reduced visibility, including a disproportionate number of severe crashes. Increasing street lighting is generally assumed to mitigate these risks. While many studies have established that the presence of lighting generally improves road safety, there is limited research on how specific photometric properties, such as average illuminance (quantity of light) and uniformity (consistency of light distribution), impact crash rates. The Utah Department of Transportation (UDOT) commissioned this research to examine the impact of lighting quality and quantity on nighttime crashes along urban arterials and to develop Utah-specific crash modification factors (CMFs) which quantify the effect of lighting changes on nighttime crash rates. Current lighting standards from organizations such as the Illuminating Engineering Society (IES) and American Association of State Highway and Transportation Officials (AASHTO) set baseline illuminance and uniformity levels for various roadway environments. Many state DOTs, including those in Utah, Texas, and New York, adopt these national guidelines, while Florida and Washington have developed state-specific standards (1-7). Most CMFs based on fixed street lighting were developed only with the presence of street lighting in mind without accounting for photometric properties (8-14). However, research from Florida found that CMFs associated with varying levels of illuminance and uniformity could provide more insight into nighttime crash risks (15-18). For example, while these studies suggest a relationship between increased average illuminance levels and reduced nighttime crash risk, these and other studies have also found that the relationship does not extend to high levels of illuminance (15; 16; 18-21). This study enhances existing research on the effects of lighting quantity (average illuminance) and quality (uniformity) on nighttime crashes using data from Utah arterials. The analysis was conducted as a cross-sectional study using a negative binomial structure with log link function. This structure was applied to two different methodologies for calculating CMFs: 1) a bivariate, single-cutoff approach that explored interactions between illuminance and uniformity; and 2) a two-cutoff approach that classified lighting levels as "low," "medium," or "high" based on existing standards. The two-cutoff approach applied a Bayesian model to account for increased variability across lighting categories. The results indicated that while some lighting (above 3.2 lux) correlates to reduced crash rates, increasing existing light levels did not produce significant additional benefits. CMFs for uniformity showed that less uniformity correlated with fewer crashes at low illuminance levels, but with more crashes at higher levels. This may show that it is more important to light specific locations than to light entire road segments evenly, unless light levels are already high. These findings advance both theory and practice by providing Utah-specific CMFs that address both lighting quality and quantity. The insights support transportation agencies in designing standards that prioritize effective, location-specific lighting over simply increasing light levels. Future research could expand on these results with pedestrian-specific lighting studies and advanced tools, like eye-tracking, to assess optimal nighttime visibility.

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Sponsoring Committee	ACS20
Session Number	Poster Session 2240
Session Title	**Safety Performance and Analysis for Safe Roads**
Paper Number	TRBAM-25-04787
Paper Title	**Examining the Impact of Centerline Rumble Strips on Reducing Rural Two-Lane Head-On Collisions in Maine**
Introduction	Rumble strips are a common and relatively low-cost countermeasure (1–3) used to alert drivers about a possible lane departure through noise and vibration (4, 5). Centerline rumble strips are commonly used on undivided roadways to prevent head-on and opposite-direction sideswipe collisions (4). In Maine, 511 miles of centerline rumble strips were installed on bidirectional and undivided rural two-lane roadways. Additionally, two types of rumble strips were installed: conventional and sinusoidal. Evaluations showed that the sinusoidal rumble strips generate lower noise levels compared to the conventional ones (6, 7). Maine experiences the highest crash fatality rate among New England states (8) and the majority of these crash fatalities result from lane-departure crashes. In fact, according to crash records from 2010 to 2022, lane departure crashes resulted in approximately twice as many (or more) fatalities as all other types of crashes combined. Additionally, Maine's lane-departure crashes accounted for approximately 73% of the fatalities, even though only 30% of the total number of crashes in the state were lane departure crashes. Head-on and opposite sideswipe collisions represented approximately 20% of the total lane departure crashes in the state. Moreover, the fatality rate per 100 million vehicle miles traveled (VMT) was 1.7 times higher in rural compared to urban areas (9), and Maine is mainly a rural state where approximately 80% of its roadways are in rural areas (10). Therefore, this study aims to assess the effectiveness of centerline rumble strips installed in Maine on preventing total and fatal injury (KABC) head-on and opposite sideswipe collisions on rural two-lane roadways. The terms fatal and injury crashes and KABC crashes are used interchangeably referring to the following crash severities defined by the Highway Safety Manual (HSM) (11). The effectiveness of the centerline rumble strips is assessed using before-and-after studies with two methods: comparison group, and empirical Bayes (EB) comparison group. Crash modification factors (CMFs) and the percentage of change in crash frequency are computed. Also, safety performance functions (SPFs) are estimated for the rural two-lane roadways. In addition, economic analysis is performed to determine the economic benefits of installing centerline rumble strip for the same roadway type. The installations of centerline rumble strips are associated with reductions of 28%-48% of head-on and opposite sideswipe collisions on rural two-lane roads, and the benefits of the rumble strips are at least 14 times the cost. The centerline rumble strips are cost-effective countermeasures to reduce head-on collisions on rural two-lane roadways in Maine.

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Sponsoring Committee ACS20
Session Number Poster Session

Session Title **Safety Performance and Analysis for Safe Roads**
Paper Number TRBAM-25-05914
Paper Title **Safety Impact Assessment of Median Cable Barriers on Four and Six-Lane Interstates: Utilizing Safety Performance Functions and the Empirical Bayes Method**

Abstract This paper estimates the impacts of median cable barriers in Louisiana by developing Safety Performance Functions (SPFs) for rural 4-lane, urban 4-lane, and urban 6-lane interstates. The SPFs were developed for both total and median-related crashes, considering variables such as segment length, Average Annual Daily Traffic (AADT), median width, lane width, and shoulder width. Empirical Bayes (EB) estimates of Crash Modification Factors (CMFs) strongly support the installation of median cable barriers, particularly for reducing visible injury crashes (KAB). The CMFs derived from EB results indicate a 54% reduction in total KAB crashes overall, with large reductions of 48% for rural 4-lane, 64% for urban 4-lane, and 35% for urban 6-lane interstates. Median-related KAB crashes experienced substantial reductions, with reductions of 55% for rural 4-lane, 77% for urban 4-lane, and 69% for urban 6-lane interstates, leading to an overall reduction of 65%. Besides developing SPFs that should facilitate future analyses of the safety impacts of median cable barriers and similar interventions, this study demonstrates the effectiveness of median cable barriers in reducing visible injury crashes, potentially aiding in the strategic implementation of such interventions on interstates.

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Sponsoring Committee ACS20
Session Number Poster Session 2240
Session Title **Safety Performance and Analysis for Safe Roads**
Paper Number TRBAM-25-02956
Paper Title **Framework for Applying Highway Safety Manual Methods During Project Alternatives Analysis**

Abstract The Highway Safety Manual (HSM) provides methods for transportation agencies to quantify and compare safety performance of project alternatives in terms of estimated average crash frequency. When applicable, the HSM promotes the use of the empirical Bayes (EB) method to combine predicted average crash frequency and observed crash frequency to obtain a more reliable estimate of expected average crash frequency. In cases where the EB method does not apply to one or more alternatives, the HSM recommends not using the EB method within the Part C predictive method and relying solely on predicted crashes for comparing alternatives. This has led agencies to avoid using the EB method, including for “future no-build” scenarios. The objective of this research was to consolidate best practices and research findings to develop a reliable and consistent approach supporting project alternatives analysis using HSM-recommended methodologies. This paper provides a five step alternatives analysis approach prioritizing methods based on reliability and consistency. This approach establishes an estimated baseline average annual crash frequency for the no-build condition in the design year. This approach then recommends identifying appropriate crash modification factors (CMFs), including pseudo-CMFs determined based on the HSM predictive method. The results of this research highlight the importance of calibrating national SPFs or developing jurisdiction-specific SPFs. Additionally, this research demonstrated a need for consistency when applying the EB method based on external CMFs and pseudo-CMFs, particularly when evaluating whether historic crash data are applicable to project alternatives that do not change HSM facility type.

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Sponsoring Committee ACS20
Session Number Poster Session 2240
Session Title **Safety Performance and Analysis for Safe Roads**
Paper Number TRBAM-25-01365
Paper Title **Developing Combined Crash Modification Factors (CMFs): Challenges, Lessons Learned and Recommendations**

Abstract
Combining Crash Modification Factors (CMFs) often involves merging multiple CMFs to establish a unified CMF for either the same safety treatment or the overall effect of implementing multiple safety treatments simultaneously. This paper reports the combined CMF results for five safety countermeasures: change signal phasing, convert intersection to roundabout, install bicycle lane, change shoulder width, and change posted speed. More importantly, this paper discusses four challenges from the effort to create combined CMFs from the CMFs available in the CMF Clearinghouse that are related to CMF applicability, CMFs of different magnitudes with some showing a safety improvement and some showing non-improvement, the need of information beyond the CMF Clearinghouse, and issues with multiple CMFs from the same study. Based on the lessons learned, the paper also provides suggestions to mitigate these challenges in future research efforts to create combined CMFs, as well as recommendations to researchers who develop CMFs so that key information is reported and made available to facilitate similar work in the future.

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Sponsoring Committee ACS20
Session Number Poster Session 2240
Session Title **Safety Performance and Analysis for Safe Roads**
Paper Number TRBAM-25-05030
Paper Title **Safety Evaluation of Dilemma Zone Protection System for Rural, High-Speed Signalized Intersections Using Empirical Bayes Method**

Abstract
This study employed the Empirical Bayes (EB) method to conduct a before-and-after safety analysis of a radar sensor-based dilemma zone protection (DZP) system deployed at rural, high-speed signalized intersections in Alabama. Six intersections treated with the DZP system were selected as the treatment group, while 33 untreated intersections with similar characteristics in terms of traffic, geometric, and speed-limit conditions were selected as the reference group. Safety performance functions (SPFs) and crash modification factors (CMFs) were developed using police-reported crash data. Red-light running (RLR) crashes were chosen and categorized into two groups (strict definition (SD-RLR) and extended definition (ED-RLR) crashes) for a comprehensive safety analysis. The analysis results showed that SD-RLR and ED-RLR crashes would decrease by 35% (CMF = 0.65, SE = 0.06) and 24% (CMF = 0.76, SE = 0.05), respectively if a rural high-speed intersection is treated with the radar sensor-based DZP system.

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Sponsoring Committee ACS20
Session Number Poster Session 3213
Session Title **Safety Performance and Analysis for Safe Road Users and Safe Speeds**
Paper Number TRBAM-25-05580
Paper Title **Analysis of Crashes Involving Micromobility Devices**

Introduction

Shared micromobility systems have rapidly emerged as a popular transportation option for short distances, with 133 million trips made in the US alone in 2023, a 16% increase from 2022 (1). These systems have shown significant potential in alleviating traffic congestion by reducing the number of vehicle trips, facilitating short-distance travel, extending the reach to public transportation, and addressing first and last-mile travel challenges (2, 3). This potential to alleviate traffic congestion is a promising aspect of shared micromobility systems in urban areas. Micromobility devices are motorized transportation devices that are mainly designed not to exceed 20 miles per hour (mph) on level ground (4). These devices can be privately owned and operated or used as part of a shared system. Examples of micromobility devices include electric bikes (e-bikes), electric scooters (e-scooters), shared bicycles, and electric pedal-assisted bicycles.

The spread of micromobility use has brought about a rapid increase in micromobility crashes. In the United States, the number of crashes involving e-scooters increased from 8,016 in 2017 to 14,641 in 2018 (5). Transportation agencies have implemented diverse strategies to combat micromobility crash occurrences and severity, such as ensuring bike facilities such as installing bike lanes, bicycle boulevards, proper parking corrals, and reducing speed limits. However, the specific impact of such strategies on reducing micromobility-related crashes remains uncertain, highlighting the need for further research in this area.

This study aims to assess the safety implications of various on-street facilities on micromobility users by analyzing crash data and evaluating the effectiveness of different infrastructure elements. The study will utilize statistical models to identify significant factors contributing to micromobility-related crashes and estimate crash modification factors (CMFs) to quantify the impact of each variable. The findings of this study will provide valuable insights to urban planners and transportation engineers, assisting them design safer streets and implement effective strategies to reduce the risk of crashes involving micromobility users.

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Sponsoring Committee	ACS20
Session Number	Poster Session 3213
Session Title	**Safety Performance and Analysis for Safe Road Users and Safe Speeds**
Paper Number	TRBAM-25-03811
Paper Title	**An Analysis of the Safety Impact of Changing Speed Limit From 55 MPH to 60 MPH on Two-Lane, Two-Way Road Segments In Minnesota**

Abstract

The objective of this study was to evaluate the safety impacts of increasing the speed limit from 55 mph to 60 mph on rural two-lane, two-way state highway road segments in Minnesota. An empirical Bayes (EB) before-after analysis was used to estimate crash modification factors (CMFs) for both segments and intersections. The segment analysis showed an 8 percent reduction in total crashes that was statistically significant, alongside a significant 15 percent increase in KAB injury crashes. The aggregate CMFs for all intersections show on average between 10% to 20% statistically significant reduction in total and injury crashes. The investigation of speed data showed some evidence of a larger increase in KAB crashes in segments with a larger increase in mean speed after the speed limits were increased. The aggregate estimated crash safety effects (for total and injury crashes) for combined segments and intersection sites show a reduction in total crashes but an increase in the KAB injury crashes.

7 Surrogate Measures of Safety

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This year, **sixty-two papers** that use surrogate measures of safety (SMoS) were identified. In these studies, the surrogate measures are used either as the primary approach to safety analysis or as a complement to the traditional crash-based approach.

The papers can be summarized into the following **six** topics: **interactions**, **vulnerable road users (pedestrians, scooter riders, etc.)**, **SMoS**, **connected and autonomous vehicles (CAV)**, **real time safety monitoring** and **safety simulation**.

Twenty papers analyze safety at **intersections**: 25-04897, 25-04039, 25-00294, 25-06160, 25-02695, 25-01266, 25-02110, 25-03794, 25-02234, 25-06465, 25-06028, 25-00157, 25-01181, 25-03684, 25-02053, 25-05314, 25-03841, 25-06266, 25-02287 and 25-01252.

Pedestrians and non-motorized users were investigated in sixteen papers: 25-01356, 25-04897, 25-00294, 25-06160, 25-03898, 25-01266, 25-02110, 25-03794, 25-05787, 25-06028, 25-02053, 25-05314, 25-06266, 25-06304, 25-03364 and 25-01181.

Various **SMoS applications** were presented in **thirty-seven** papers: 25-03364, 25-01356, 25-03242, 25-02179, 25-06304, 25-03910, 25-03369, 25-02148, 25-02431, 25-02912, 25-04897, 25-02956, 25-00294, 25-06160, 25-02280, 25-02695, 25-03898, 25-01266, 25-02110, 25-04100, 25-02234, 25-01271, 25-06465, 25-06028, 25-05130, 25-01181, 25-05230, 25-04520, 25-02053, 25-04982, 25-05008, 25-03841, 25-00926, 25-02890, 25-02287, 25-04901 and 25-01356.

Real time safety analysis or monitoring is highlighted in **sixteen** papers: 25-01960, 25-03910, 25-03369, 25-03070, 25-02280, 25-02695, 25-05976, 25-03898, 25-02234, 25-05130, 25-03684, 25-04982, 25-06266, 25-00443, 25-02287 and 25-04901.

Safety Simulation was performed in **seventeen** papers: 25-00906, 25-03242, 25-01387, 25-02431, 25-03070, 25-04039, 25-02695, 25-01271, 25-06028, 25-05365, 25-05130, 25-01181, 25-04523, 25-05314, 25-02287, 25-05379 and 25-01252

Finally, **CAV** applications are discussed in **ten** papers: 25-00906, 25-00842, 25-03070, 25-02695, 25-04100, 25-06465, 25-06028, 25-05743, 25-01181 and 25-05314.

Concerning **SMoS**, we found that **traffic conflicts** are used in **twenty-four** papers:

25-01356, 25-03242, 25-02179, 25-06304, 25-02431, 25-02070, 25-02695, 25-05976, 25-03898, 25-04100, 25-01768, 25-05787, 25-06028, 25-05743, 25-00157, 25-01767, 25-03684, 25-05230, 25-04520, 25-05696, 25-06266, 25-00926, 25-02287 and 25-04901.

In terms of conflict indicators, the **time-to-collision (TTC)** and its variants such as modified time to collision (MTTC), generalized time to collision (GTTC) are used in forty-seven papers: 25-00906, 25-01356, 25-03242, 25-00842, 25-02179, 25-06304, 25-01387, 25-01960, 25-02148, 25-02431, 25-03070, 25-04897, 25-04039, 25-06160, 25-02695, 25-05976, 25-03898, 25-01266, 25-02110, 25-04100, 25-03794, 25-02234, 25-05277, 25-05787, 25-06028, 25-05743, 25-00157, 25-01767, 25-05365, 25-05130, 25-01181, 25-03684, 25-05230, 25-04520, 25-02053, 25-05696, 25-04523, 25-05008, 25-06266, 25-02388, 25-00926, 25-00443, 25-02890, 25-03251, 25-02287, 25-05379 and 25-04901. The second most popular is the **post-encroachment time (PET)**, which is applied in **thirteen** papers: 25-00906, 25-00842, 25-04897, 25-02695, 25-03898, 25-01266, 25-02110, 25-04100, 25-06465, 25-04520, 25-05314, 25-06266 and 25-02287. Indicators related to deceleration such as deceleration rate to avoid crash (DRAC) were used in **six** papers: 25-02179, 25-06304, 25-02148, 25-03070, 25-04520 and 25-00926.

Alternatively, **speed statistics** were used in **seven** papers: 25-01266, 25-01356, 25-02110, 25-03898, 25-03910, 25-05286 and 25-06304.

In terms of input data, user **trajectories** derived from **video** was the most common sources of input data used for analysis in nineteen papers: 25-01356, 25-03242, 25-06304, 25-01960, 25-02431, 25-02912, 25-04897, 25-00294, 25-06160, 25-02695, 25-03898, 25-01266, 25-02110, 25-01271, 25-03684, 25-04520, 25-06266, 25-02388 and 25-02890. Of these, seven papers used **UAVs** to record **video:** 25-03242, 25-01960, 25-02431, 25-02912, 25-02110, 25-01271 and 25-02890. LIDARs were used in three papers (25-03898, 25-03684 and 25-00926).

SMoS are used in some **car-following** and **lane changing** maneuvers as well**. Car following** scenarios which include **rear end** conflicts were analyzed in seven papers: 25-00842, 25-02179, 25-02148, 25-04039, 25-04100, 25-06465 and 25-05379. **Lane change** maneuvers were investigated in nine papers: 25-00842, 25-06304, 25-01387, 25-02912, 25-01271, 25-05277, 25-06028, 25-02890 and 25-05379.

Regarding data analysis, **statistical regression models** were used in **twenty-six** papers: 25-01356, 25-03910, 25-03369, 25-06160, 25-01271, 25-05743, 25-05365, 25-05130, 25-02053, 25-04982, 25-05696, 25-00926, 25-01252, 25-01960, 25-02912, 25-03070, 25-06160, 25-02280, 25-03898, 25-02234, 25-01181, 25-04520, 25-03841, 25-06266, 25-00926 and 25-00443. **Machine learning** methods, in particular **deep learning**, were used in **fourteen** papers: 25-01960, 25-02912, 25-03070, 25-06160, 25-02280, 25-03898, 25-02234, 25-01181, 25-04520, 25-03841, 25-06266, 25-00926, 25-00443 and 25-01960.

To conclude, it is relevant to highlight that the **crash risk** or probability of **crash** was estimated in **twenty-two** papers: 25-00906, 25-03242, 25-06304, 25-03910, 25-02431, 25-03070, 25-04039, 25-06160, 25-03898, 25-04100, 25-02234, 25-05365, 25-01181, 25-05230, 25-04520, 25-04982, 25-05314, 25-05008, 25-03841, 25-02287 and 25-04901.

The papers dealing with surrogate measures of safety ordered by their paper number are listed below. For each paper, the following information is provided: authors, sponsoring committee, session number, session title, paper number, paper title, and abstract.

Authors	Khashayar Kazemzadeh, University of Cambridge Frances Sprei, Chalmers tekniska hogskola Pontus Wallgren, Chalmers University of Technology
Sponsoring Committee	Standing Committee on Transportation Safety Management Systems (ACS10)
Session Number	3039
Session Title	Transportation Safety Management Systems from Start to Finish
Paper Number	TRBAM-25-00294
Paper Title	**Assessing E-scooter Rider Safety Perceptions in Shared Spaces: Insights from Sweden**
Abstract	Shared spaces prioritise the role of micromobility in urban environments by separating vulnerable road users from motorised vehicles, aiming to enhance actual objective and subjective safety perceptions. However, various modes of transport with differing navigation characteristics impact road users' perception of safety. Despite the rise of emerging transport modes such as e-scooters, there is a lack of theoretical and empirical evidence regarding their safety perception in shared spaces. In response, we conducted an online video experiment and polled 920 e-scooter users in Sweden to assess their safety perceptions. We collected data on socio-demographics, travel habits, crash history, and responses to hypothetical video scenarios depicting interactions where riders overtake or meet cyclists in shared spaces. We then employed a random effect latent class ordered logit model to quantify the determinants of e-scooter riders' safety perceptions. The findings indicate that women feel less safe in shared spaces compared to men. Additionally, the direction of encounters significantly affected young adults, who perceived meeting other users as more unsafe than overtaking them. These findings highlight the importance of accounting for unobserved heterogeneity in safety perceptions, emphasise the significant role of demographic variables in understanding users' safety perceptions, and reinforce the need for inclusive design of shared spaces for all road users.

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Sponsoring Committee	Standing Committee on Transportation Safety Management Systems (ACS10)
Session Number	3039
Session Title	Transportation Safety Management Systems from Start to Finish
Paper Number	TRBAM-25-04039
Paper Title	**Motorcycle Following Distance and its Relationship to the Risk of Rear-End Collisions**
Abstract	This study classified motorcycle (MC) following distance based on trajectory traffic data and validated results using actual MC rear-end collisions. A total of 8,223 events of a MC following a vehicle were investigated in Pathum Thani, Thailand, and 41 cases of MC rear-end crashes were analyzed between 2017 and 2021. Time headway (TH), safe stopping distance (SSD) and time to collision (TTC) were applied to the proposed concept to determine safe following distance (SFD). Speed and following distance for actual rear-end crashes were applied to validate SFD. Results showed that the proposed SFD model identified the causes of MC rear-end collision events as mostly due to longitudinal critical area (38 cases, 92.68%), implying insufficient MC rider reaction and decision time for evasive action. The longitudinal warning area had relatively few chances for rear-end collisions to occur, with only 3 cases recorded. VDO clip extracts from MC rear-end crashes illustrated 11 cases (26.83%) of rider fatality. The study findings revealed that the SFD concept can help to prevent MC rear-end collision events by developing reminder systems when the rider reached the following distances of both warning and critical areas.

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Sponsoring Committee	Standing Committee on Transportation Safety Management Systems (ACS10)
Session Number	3039
Session Title	Transportation Safety Management Systems from Start to Finish
Paper Number	TRBAM-25-06465
Paper Title	**Characterizing Behavioral Differences and Adaptations of Automated Vehicles and Human Drivers at Unsignalized Intersections: Insights from Waymo and Lyft Open Datasets**
Abstract	The integration of autonomous vehicles (AVs) into transportation systems presents an unprecedented opportunity to enhance road safety and efficiency. However, understanding the interactions between AVs and human-driven vehicles (HVs) at intersections remains an open research question. This study aims to bridge this gap by examining behavioral differences and adaptations of AVs and HVs at unsignalized intersections by utilizing two comprehensive AV datasets from Waymo and Lyft. Using a systematic methodology, the research identifies and analyzes merging and crossing conflicts by calculating key safety and efficiency metrics, including time to collision (TTC), post-encroachment time (PET), maximum required deceleration (MRD), time advantage (TA), and speed and acceleration profiles. The findings reveal a paradox in mixed traffic flow: while AVs maintain larger safety margins, their conservative approach can lead to unexpected situations for human drivers, potentially causing unsafe conditions. From a performance point of view, human drivers exhibit more consistent behavior when interacting with AVs versus other HVs, suggesting AVs may contribute to harmonizing traffic flow patterns. Moreover, notable differences were observed between Waymo and Lyft vehicles, which highlights the importance of considering manufacturer-specific AV behavior in traffic modeling and management strategies for the safe integration of AVs. The processed dataset utilized in this study is openly published to foster the research on AV-HV interactions.

Authors	Jaikishan Damani, Indian Institute of Technology, Bombay Perumal Vedagiri, Indian Institute of Technology, Bombay
Sponsoring Committee	Standing Committee on Transportation Safety Management Systems (ACS10)
Session Number	3039
Session Title	Transportation Safety Management Systems from Start to Finish
Paper Number	TRBAM-25-03364
Paper Title	**Development of Composite Risk Index (CORSI) to evaluate risky situations while MTWs decide whether to follow or filter**
Abstract	Since Motorized Two Wheelers (MTWs) are compact and highly maneuverable, they often exhibit filtering behavior in mixed traffic conditions. However, owing to their low visibility and lack of physical protection, this behavior poses substantial risks. This study proposes the development of an index to quantify and evaluate the risks that MTWs face when choosing whether to follow or filter through mixed traffic. The Composite Risk Index (CORSI) is a normalized index ranging from 0 (safest interactions) to 1 (riskiest interactions) and is calculated using key parameters: Clear Lateral Gap (CLG), Relative Speed, Speed of MTW, and Acceleration of MTW. Each parameter is normalized between 0 and 1, and the weights assigned to them represent how much of an impact they have on risk. Based on CORSI values, the study uses the K-means clustering technique to classify 803 interactions into "Safe," "Moderately Risky," and "Risky" clusters. According to the data, younger riders, men, and non-helmet wearers are more likely to engage in dangerous exchanges, which also tend to involve filtering behavior and higher accelerations and speeds. Safer encounters are correlated with larger leader vehicles. This research contributes to better safety tactics by improving the understanding of MTW behavior in urban mixed traffic and offering a robust tool for real-time risk assessment.

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Sponsoring Committee Standing Committee on Safety Performance and Analysis (ACS20)
Session Number 2206
Session Title Safety Performance and Analysis with Crash Predictions
Paper Number TRBAM-25-00926
Paper Title **Development of a New Safety Indicator for Predictive Safety Analysis Based on Different Arbitrary Surrogate Safety Measures Using LiDAR Sensor Data.**

Abstract Traffic accidents pose a significant global health challenge with profound impacts on human life and economic development. The World Health Organization (WHO) reports that approximately 1.25 million people die annually from traffic accidents, with an additional 20 to 50 million suffering non-fatal injuries. These accidents not only result in loss of life but also have substantial economic consequences, costing countries about 5% of their gross domestic product (GDP).

Traditional road safety evaluations based on historical accident rates have proven inadequate due to various limitations, including time-consuming data collection, underreporting of accidents, and insufficient information on pre-accident events. Consequently, there has been a shift towards using traffic conflicts and surrogate safety measures (SSMs) for more comprehensive and predictive safety assessments.

While SSMs offer a more integrated approach to understanding specific risks, the correlation between different types of SSMs and actual accident rates remains debatable. Various SSMs employ different definitions and assumptions, resulting in diverse scenarios for potentially dangerous traffic situations. A thorough evaluation of these measures is crucial to refine their use in traffic safety assessments.

This study's primary contribution lies in comparing SSMs and establishing their relationship with traffic accidents to define their characteristics for accident risk computation. The research introduces the Overall Indicator as a common characteristic of individual SSMs and employs machine learning algorithms to predict values of specific SSMs and the Overall Indicator. This approach aims to enhance the reliability and accuracy of traffic safety estimates by combining new computational methods with conventional safety indicators.

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Sponsoring Committee	Standing Committee on Safety Performance and Analysis (ACS20)
Session Number	2206
Session Title	Safety Performance and Analysis with Crash Predictions
Paper Number	TRBAM-25-01271
Paper Title	**Collision Risk Prediction in the First Phase of Overtaking on Two-lane Highway Based on Nearest Distance Risk Indicator**

Abstract Overtaking on two-lane highway is a complex and hazardous task particularly in the first phase. In order to make up for the shortcomings of earlier studies on the risk prediction of the first phase on two-lane highway, this study presented a two-dimensional risk indicator considering the nearest distance between vehicles during overtaking and built short-time risk prediction models by non-parametric methods. Firstly, based on the overtaking trajectory obtained by the dual UAV observation method, this study analyzed the behaviors in the first phase of overtaking in various scenarios. Secondly the risk indicator dis_TTC was proposed which had been proved the superiority in the task of collision risk assessment by comparing it with TTC. Finally, the top five most important characteristic variables which were screened by Random Forest were selected to construct the non-parametric short-term risk prediction model. The findings demonstrate that overtaking behavior was quite variable in different conditions and the potential psychological cost to drivers is larger when there were a reversing car and overtaking trucks. According to the results of risk assessment, the 85% quantile risk threshold of dis_TTC was 2.00s. With the average R2 values of 0.97 and 0.82, respectively, the non-parametric model represented by Extra Trees and K-Nearest Neighbors performs best on the time scales of 0.5s, 1.0s, and 1.5s compared with parametric model. The research's conclusions show promise for proactive risk aversion on two-lane highways.

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Sponsoring Committee	Standing Committee on Safety Performance and Analysis (ACS20)
Session Number	2206
Session Title	Safety Performance and Analysis with Crash Predictions
Paper Number	TRBAM-25-01768

Paper Title <u>**Time-Varying Causality Analysis of Successive Secondary Conflicts Using Hazard-Based Duration Models**</u>

Abstract

Secondary crashes within chain collisions represent a significant yet underexplored area in traffic safety. According to the U.S. Department of Transportation, secondary crashes account for approximately 20% of traffic-related fatalities. These crashes are generally categorized into two types: those caused by queuing effects following a primary crash and those occurring within the influence zone of a primary crash due to successive vehicle conflicts. This study emphasizes the latter type, as chain collisions are increasingly common in modern traffic systems. Since traditional crash databases often lack sufficient or unbiased records, secondary conflicts are examined as proxies to understand the spread of secondary crashes.

The primary challenges lie in identifying secondary conflicts, quantifying their risks, and accounting for uncertainties. Existing studies have recognized secondary conflicts in various road conditions but have not fully explored the factors influencing their propagation or considered unobserved heterogeneity. This research employs a high-precision vehicle trajectory dataset to construct a chain conflict identification model that detects mutually influential conflicts. Secondary conflicts are then extracted and analyzed through a multi-level variable system encompassing macro-level factors (road segment type, traffic status), meso-level factors (front chain conflict patterns), and micro-level factors (vehicle statuses).

Using Kaplan-Meier analysis and the Log-Rank test, significant factors influencing secondary conflicts are identified. Additionally, a Weibull Accelerated Failure Time model with random parameters is developed to analyze the combined effects of multiple factors on secondary conflict occurrences, accounting for unobserved heterogeneity. This approach yields a survival probability curve that highlights key risks during chain conflict propagation.

The study introduces four key innovations:

1. Proposing a multi-level variable framework for quantifying factors influencing successive secondary conflicts.
2. Developing a Kaplan-Meier model to compare the heterogeneous effects of different segment types, traffic statuses, and front chain conflict types on secondary conflicts.
3. Constructing a hazard-based duration model with random parameters to determine the survival probability curve and influencing factors during chain conflict propagation.
4. Introducing the concept of a critical post-supervision period, emphasizing the need for close monitoring shortly after a conflict to prevent further chain conflicts.

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Sponsoring Committee	Standing Committee on Safety Performance and Analysis (ACS20)
Session Number	2206
Session Title	Safety Performance and Analysis with Crash Predictions
Paper Number	TRBAM-25-01960
Paper Title	**Study on Regional Risk Evaluation Model of Mountainous Secondary Highway Based on BN-DS**

Abstract

This study investigates driving safety on mountainous secondary highways, focusing on sections, intersections, sharp curves, and slopes. Risk levels are quantitatively assessed by analyzing traffic characteristics and constructing evaluation indexes based on conflict rates and serious conflicts per vehicle-kilometer. A risk evaluation model is introduced, combining Bayesian Network (BN) and Dempster-Shafer (DS) theory, considering factors from vehicle conditions, road environment, and weather.

First, UAV aerial photography data is processed using optical flow methods, identifying eight key causal risk factors through correlation analysis. The risk evaluation model is then developed using machine learning to construct the Bayesian Network and integrate DS theory. Next, the highway is segmented using ArcGIS, with traffic risk levels and conflict locations visualized through a risk level map. When applied to practical scenarios, the model demonstrates its effectiveness in assessing traffic risk distribution across various road environments. It accurately identifies high-risk points, enabling targeted adjustments and laying a foundation for future risk prevention and control.

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Sponsoring Committee Standing Committee on Safety Performance and Analysis (ACS20)
Session Number 2206
Session Title Safety Performance and Analysis with Crash Predictions
Paper Number TRBAM-25-02280
Paper Title **Two-level Real-time Prediction of Rear-end Conflict Risk Levels and Drivers' Longitudinal Evasive Styles on the Expressway**

Abstract Expressways, as the backbone of urban transportation, handle significant intra-city traffic, with operational efficiency directly affecting the entire network. In China, the high speeds and large traffic volumes on expressways often lead to crashes, impacting network efficiency. For instance, in 2022, Shanghai expressways recorded 6,951 traffic events, with side-wipe and rear-end conflicts comprising 20.5%. Understanding expressway traffic safety is thus crucial for improving urban road network service levels.

Traffic conflicts are widely used as crash surrogates in safety research. While previous studies have examined the mechanisms and factors of traffic conflicts, most focus on external road and traffic factors, neglecting driver behavior due to data limitations. Traditional datasets like NGSIM and highD lack data on multiple traffic states and transitions, emphasizing the need for broader datasets to capture driver behaviors across different conditions.

Advanced Driver Assistance Systems (ADAS) provide safety functions but often lack personalization, which has become a key research direction in recent years. Personalized ADAS can enhance safety by considering individual driver behaviors. Research into traffic conflicts and driver heterogeneity, using historical data, can improve the reliability of such systems.

(1) Traffic Conflict Classification

Surrogate Safety Measures (SSM) are commonly used to evaluate traffic events based on spatial or temporal proximity and evasive behavior. SSMs like Time-to-Collision (TTC) help classify conflicts by severity. However, current research often overlooks detailed conflict descriptions, and further study is needed to account for risk variation and evasive behaviors within the same risk level.

(2) Traffic Conflict Prediction

Many prediction models have been developed to forecast traffic conflicts using statistical and machine learning approaches. Statistical models like Binary Logit and Poisson regression are widely used to predict conflict occurrences and frequencies. Machine learning models, including Neural Networks and Hidden Markov Models, have also been applied, showing better performance than statistical models, though their interpretability remains a challenge. Despite the rise of machine learning, statistical models remain valuable for their transparency and ease of variable interpretation.

(3) Driving Styles

Driving style refers to a driver's approach to completing driving tasks, with safety research often focusing on aggressive behavior. Research suggests that driving decisions depend on both historical behavior and current traffic conditions. Most studies explore driving styles during normal conditions, examining behaviors such as car-following and lane-changing. However, relatively few studies have investigated driving styles during conflicts, despite evidence that driving style indicators can predict accident risk. Further research is needed to quantify the relationship between driving styles and conflict risks.

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Sponsoring Committee	Standing Committee on Safety Performance and Analysis (ACS20)
Session Number	2206
Session Title	Safety Performance and Analysis with Crash Predictions
Paper Number	TRBAM-25-02287
Paper Title	**Validation Analysis of Traffic Simulation Safety Metrics with Real-World Crash Data**
Abstract	Assessing safety using traffic simulation is becoming increasingly feasible with advancements in methodological frameworks and tools, emphasizing the critical importance of accuracy and reliability. This study aims to bridge the gap between simulation models and real-world safety observations, contributing to the advancement of more robust safety assessment methodologies. It presents a comprehensive comparative analysis of traffic safety metrics derived from both simulated and real-world data, employing clustering techniques to identify safety patterns. Using Aimsun Next, simulation data was analyzed in the Safety Assessment Model (SSAM) to extract traffic conflicts, which were then converted into crash risk levels. Real-world crash data from the Hellenic Statistical Authority (ELSTAT) encompassed various crash types involving at least one slightly injured individual between 2017 and 2019. Specifically, observational data included speed limits, road lengths, injuries, vehicles involved, and crash counts, while simulation metrics included flow, capacity, and crash risk. The analysis of simulation and observational data revealed two distinct clusters: roads with low and high crash risks, clearly distinguished with minimal overlap. Comparison of clustering results demonstrated approximately 87.7% accuracy in predicting road crash risk classifications through traffic simulation, confirming its reliability for safety assessment. The study also highlights the importance of thorough calibration; roads inaccurately predicted lacked sufficient traffic data, underscoring the need for robust calibration to enhance safety assessment. This study validates a framework ready for future research applications in scenarios where direct observation is impractical, enhancing road safety and guiding interventions amid evolving traffic conditions and technologies.

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Sponsoring Committee Standing Committee on Safety Performance and Analysis (ACS20)

Session Number 2206

Session Title Safety Performance and Analysis with Crash Predictions

Paper Number TRBAM-25-03242

Paper Title **Predicting Crash Frequency at Upstream Diverging Section of Toll Plaza in Heterogenous Traffic**

Abstract The presence of Electronic Toll Collection (ETC) lanes at toll plazas can increase crash risks, particularly in upstream diverging sections, due to the frequency of lane-changing maneuvers in heterogeneous traffic. This study aims to predict crash probabilities of mixed lane-changing traffic conflicts using extreme value theory (EVT) at the upstream toll plaza region.

High-resolution (4K) video data were acquired using Unmanned Aerial Vehicle (UAV) technology, covering a 240-meter road segment to capture morning rush hour traffic (8 to 9 a.m.) at the Jewar Toll Plaza on the Yamuna Expressway (YE) in India. Vehicle trajectories and surrogate measures such as Time to Collision (TTC) were extracted using advanced AI-driven video analysis via the DataFromSky platform.

Furthermore, the proposed Lane Changing Time-to-Collision (LTTC) was analyzed using the Peak Over Threshold (POT) approach. The Mean Residual Life (MRL) plot, along with the scale and shape parameter stability plots of the Generalized Pareto Distribution (GPD), identified the threshold as -1.25 seconds.

The results indicate that the collision risk (R) for Cars, Two Wheelers (2W), Trucks, Buses, and Light Commercial Vehicles (LCV) are 0.0084, 0.0068, 0.0073, 0.0057, and 0.0034, respectively. The annual crash frequency (N) for all vehicle types at the section was calculated to be 41 incidents. The correlation heatmap between vehicle type, collision risk, sample size, and mean vehicle speed indicates that smaller vehicle types should be prioritized in traffic safety measures, as they are associated with higher collision risks and travel speeds.

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Sponsoring Committee	Standing Committee on Safety Performance and Analysis (ACS20)
Session Number	2206
Session Title	Safety Performance and Analysis with Crash Predictions
Paper Number	TRBAM-25-04901
Paper Title	**Applying Extreme Value Theory to Road Safety Evaluation using Safety Pilot Model Deployment (SPMD) Data**
Abstract	Road safety assessment faces a critical challenge: traditional measures based on crash frequency and injury severity are often limited by data availability and quality issues. These limitations manifest in two key ways: (1) small sample sizes and underreporting due to predetermined reporting thresholds or voluntary non-reporting, and (2) insufficient detail to fully understand crash mechanisms, leading to inconclusive or conflicting analyses. To address these challenges, researchers have developed surrogate safety measures that evaluate traffic safety without relying on crash data. These measures identify traffic conflicts, defined as situations where two or more road users approach each other in space and time with a crash risk unless they alter their movements. Surrogate measures offer several advantages over traditional crash-based analysis: they enable proactive safety assessment, allow rapid evaluation of innovative intersection designs and traffic control strategies, and can effectively measure safety improvements for rare crash types such as pedestrian or bicycle incidents. While traditional collection methods for surrogate safety measures relied on field observations—which are time-consuming, labor-intensive, and potentially inaccurate—recent technological advances have revolutionized data collection approaches. Automated techniques, traffic simulations, and emerging data sources such as naturalistic driving studies and the Safety Pilot Model Deployment (SPMD) study now provide more efficient and accurate means of gathering surrogate safety data. Of particular interest is the SPMD study, which collected comprehensive vehicle-to-vehicle and vehicle-to-infrastructure communication data from approximately 3,000 vehicles across 73 lane-miles in Ann Arbor, Michigan. The goal of this study was to: 1. Provide a framework for utilizing the in-vehicle SPMD data to extract surrogate safety measures and evaluate road safety. 2. Apply extreme value theory models in road safety evaluation and illustrate possible applications using in-vehicle data. The findings contribute both theoretical and practical value: theoretically, they extend the application of extreme value theory to in-vehicle connected vehicle data analysis; practically, they provide transportation agencies with a more robust methodology for proactive safety assessment using in-vehicle data.

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Sponsoring Committee Standing Committee on Safety Performance and Analysis (ACS20)
Session Number 2206
Session Title Safety Performance and Analysis with Crash Predictions
Paper Number TRBAM-25-04982

Paper Title **Adopting Individual Vehicle Motion Patterns for Real-time Crash Risk Prediction Based on Empirical Vehicle Trajectories Prior to Crashes**

Abstract Real-time crash risk prediction research typically determines hazardous traffic conditions by linking crash likelihood with various features, such as traffic flow, weather, and road conditions. These features are often aggregated over a segment and a time period, with crash timing accuracy recorded in minutes. Consequently, the absence of high-precision, individual-level information poses a challenge for developing vehicle-specific real-time crash prediction models.

With advancements in sensor and perception technologies, high-resolution vehicle trajectory data are becoming more accessible. However, due to the infrequent and random nature of crash events, significant effort is required to obtain precise empirical vehicle trajectories preceding crashes. As a result, the relationship between individual vehicle motion patterns and crash risk remains unclear.

In many instances, surrogate safety measures (SSMs) serve as crucial alternatives for developing reliable statistical safety models due to the absence of historical crash data. From the perspective of individual vehicles, these indicators have been used to assess the specific vehicles' real-time crash risk in recent years. While they have shown promising results, there are many cases where vehicles are identified as risky by SSMs, but crashes do not occur. Crashes are caused by specific vehicle motions.

Consequently, observing more pre-crash trajectories and non-crash instances under similar high-risk conditions, as indicated by SSMs, would enable researchers to establish statistical relationships that pinpoint the factors leading to crashes. Such insights could enhance collision avoidance systems, allowing for the early and efficient identification of crash-prone vehicles and the implementation of timely control measures.

The primary objective of this study is to utilize vehicle motion patterns for real-time crash risk prediction at the individual vehicle level. To achieve this, the researchers developed a framework for collecting real-world pre-crash vehicle trajectory data in Chengdu, China, obtaining 68 rear-end crashes for modeling and prediction. A matched case-control structure was employed to assess the influence of individual vehicle motion patterns on crash risk. A Bayesian logistic regression model was established to identify significant crash precursors and evaluate real-time crash risks. The effectiveness of this approach in early warning was thoroughly examined, and crash precursors at different early warning times were subsequently discussed.

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Sponsoring Committee Standing Committee on Safety Performance and Analysis (ACS20)

Session Number 2240

Session Title Safety Performance and Analysis with Crash Predictions

Paper Number TRBAM-25-00157

Paper Title **Analysis of Factors Influencing the Severity of Lateral and Longitudinal Conflicts in Diverging Areas: A Correlated Mixed Logit Approach with Heterogeneity in Means**

Abstract
Diverging areas, such as intersections and interchanges, present a high risk of traffic conflicts. These conflicts are often linked to the geometric layout of the road, the flow of traffic, and vehicle movement characteristics. To mitigate these risks, identifying the key safety factors in such areas and implementing effective corrective or preventive measures is crucial for improving traffic safety.

Previous studies have predominantly focused on specific factors influencing traffic conflicts, but many have overlooked a comprehensive analysis that incorporates static factors (e.g., road geometry), quasi-dynamic factors (e.g., weather conditions), and dynamic factors (e.g., traffic flow characteristics). Additionally, unobserved or unmeasurable factors can still affect the relationship between observed variables and conflicts, adding complexity to safety assessments. Addressing this heterogeneity typically involves incorporating variability in the data, allowing variables to differ across individual observations or grouped sets of data. This approach leads to the development of mixed logit models, including dynamic random parameters mixed logit frameworks.

In this study, the researchers construct correlated mixed multinomial logit models with heterogeneity in means to analyze the causal relationships between varying conflict severities and a range of contributing factors, including traffic flow, road conditions, driving behaviors, and environmental conditions. By accounting for these factors and the heterogeneity in their effects, the study aims to offer a more accurate understanding of how these elements influence conflict risk and severity in diverging areas.

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Sponsoring Committee Standing Committee on Safety Performance and Analysis (ACS20)

Session Number 2240

Session Title Safety Performance and Analysis with Crash Predictions

Paper Number TRBAM-25-02179

Paper Title **The Improvement of Surrogate Safety Measures for Highway Merging Scenarios Based on Buffer Areas**

Abstract Merging behavior, especially in areas where vehicles must integrate into existing traffic flows, often leads to recurrent bottlenecks, traffic conflicts, and even accidents, making it a critical issue in traffic conflict studies. Traditional surrogate safety measures (SSMs), such as Time-to-Collision (TTC), can sometimes be inadequate for assessing conflict risk in scenarios involving significant lateral and longitudinal movements, such as merging or cut-in situations. In these cases, drivers may perceive a situation as dangerous, but traditional one-dimensional TTC might misclassify these situations as safe, failing to account for the complexities of two-dimensional traffic interactions.

To address this gap, this study introduces a novel method for calculating two-dimensional TTC based on buffer areas. A buffer area is defined as the space surrounding a vehicle that the driver prefers to remain unobstructed by other vehicles. The study uses merging scenario data from the exiD dataset and compares the validity of three TTC methods: the traditional one-dimensional TTC, a two-dimensional TTC extended to account for lateral movements, and the proposed two-dimensional TTC calculated using buffer areas.

The study also applies the Dynamic Time Warping (DTW) method to assess the similarity between these three surrogate safety measures and the acceleration change trends of merging vehicles. By comparing how well these measures reflect actual conflict risks, the study finds that the proposed two-dimensional TTC based on buffer areas provides a more accurate reflection of merging vehicle conflicts than the traditional one-dimensional TTC or the extended two-dimensional TTC.

This research contributes a methodology for comparing different surrogate safety measures, offering a more precise approach for evaluating conflict risk in complex traffic scenarios, particularly those involving merging behavior.

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Sponsoring Committee Standing Committee on Safety Performance and Analysis (ACS20)

Session Number 2240

Session Title Safety Performance and Analysis with Crash Predictions

Paper Number TRBAM-25-02431

Paper Title **Evaluation of Traffic Conflicts at Approaching Section of Toll Plaza using Extreme Value Theory**

Abstract The approach to toll plazas, characterized by a gradual increase in the number of lanes and frequent lane-changing behavior, significantly heightens the risk of traffic conflicts and collisions. This study aimed to assess the potential risks of traffic conflicts at a toll plaza on National Highway-44 in Haryana, India, during the morning rush hour. Traffic data was collected using an Unmanned Aerial Vehicle (UAV), and vehicle trajectory data was processed through fully automated image processing software.

To evaluate collision risks, the study employed Extreme Value Theory (EVT) alongside Time to Collision (TTC), a Surrogate Safety Measure (SSM) indicator. The findings revealed that the TTC threshold in this section of the toll plaza was 1.25 seconds, which was used as the key marker for identifying risky situations. The study also explored the relationship between collision risks and various vehicle types, uncovering a negative correlation between vehicle size and collision risk. Specifically, larger vehicles, such as trucks, buses, and light commercial vehicles (LCVs), had a lower likelihood of being involved in collisions compared to smaller vehicles like cars and two-wheelers.

Additionally, the study found that vehicle speed positively correlated with collision risk. Vehicles traveling at higher average speeds were more likely to be involved in collisions, indicating that speed management could be a crucial factor in reducing risks.

These findings provide valuable insights that can guide toll plaza operators and engineers in selecting appropriate traffic control measures to improve safety at toll plaza approaches, particularly during high-traffic periods such as the morning rush hour.

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Sponsoring Committee Standing Committee on Safety Performance and Analysis (ACS20)

Session Number 2240

Session Title Safety Performance and Analysis with Crash Predictions

Paper Number TRBAM-25-02890

Paper Title **The Existence and Impacts of Sequential Traffic Conflicts: Investigation of Traffic Conflict in Sequences encountered by Left-turning Vehicles at Signalized Intersections**

Abstract The global sales of light electric vehicles (EVs) have been steadily increasing since 2010, signaling a shift toward electrification in the automotive industry. One key distinction between EVs and traditional fuel-powered vehicles lies in their powertrains: while the electric motor in EVs allows for higher acceleration performance, especially at lower operating speeds, it also presents new safety challenges, particularly in traffic scenarios such as signalized intersections. The acceleration capabilities of EVs can be up to 136% greater than those of traditional vehicles, which could lead to increased traffic safety risks.

At signalized intersections, the frequent changes in traffic signals create complex acceleration and deceleration patterns that heighten safety risks. Drivers are typically more willing to accelerate straight ahead than when making left or right turns, which contributes to higher hazard levels in straight-ahead traffic. Given this, the strong acceleration of EVs could make such traffic even more dangerous, potentially increasing the likelihood of accidents.

While previous studies on EVs have focused mainly on accident analysis—such as those examining accident probability due to EVs' low noise or their severity due to their explosive nature—there is a gap in research regarding the impact of EVs' acceleration performance on traffic safety. This study aims to address this gap by investigating the safety risks posed by EVs at signalized intersections, with a particular focus on their acceleration characteristics.

To achieve this, the study uses UAVs and roadside cameras to collect data on vehicle trajectories, creating a comprehensive trajectory database. A two-dimensional safety surrogate indicator is proposed, considering both collision probability and severity, to automatically quantify the traffic safety risks associated with EVs at signalized intersections. The study then compares the safety risks of straight-ahead traffic for both electric and fuel-powered vehicles, considering factors like individual driving behavior and the interaction between vehicles.

By analyzing these factors, the study aims to better understand how the acceleration performance of EVs influences safety at signalized intersections and provide insights for developing targeted traffic safety measures for these vehicles.

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Sponsoring Committee	Standing Committee on Safety Performance and Analysis (ACS20)
Session Number	2240
Session Title	Safety Performance and Analysis with Crash Predictions
Paper Number	TRBAM-25-02956
Paper Title	**Framework for Applying Highway Safety Manual Methods During Project Alternatives Analysis**
Abstract	The Highway Safety Manual (HSM) provides methods for transportation agencies to quantify and compare safety performance of project alternatives in terms of estimated average crash frequency. When applicable, the HSM promotes the use of the empirical Bayes (EB) method to combine predicted average crash frequency and observed crash frequency to obtain a more reliable estimate of expected average crash frequency. In cases where the EB method does not apply to one or more alternatives, the HSM recommends not using the EB method within the Part C predictive method and relying solely on predicted crashes for comparing alternatives. This has led agencies to avoid using the EB method, including for “future no-build” scenarios. The objective of this research was to consolidate best practices and research findings to develop a reliable and consistent approach supporting project alternatives analysis using HSM-recommended methodologies. This paper provides a five step alternatives analysis approach prioritizing methods based on reliability and consistency. This approach establishes an estimated baseline average annual crash frequency for the no-build condition in the design year. This approach then recommends identifying appropriate crash modification factors (CMFs), including pseudo-CMFs determined based on the HSM predictive method. The results of this research highlight the importance of calibrating national SPFs or developing jurisdiction-specific SPFs. Additionally, this research demonstrated a need for consistency when applying the EB method based on external CMFs and pseudo-CMFs, particularly when evaluating whether historic crash data are applicable to project alternatives that do not change HSM facility type.

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Sponsoring Committee Standing Committee on Safety Performance and Analysis (ACS20)

Session Number 2240

Session Title Safety Performance and Analysis with Crash Predictions

Paper Number TRBAM-25-03684

Paper Title **Deriving Minimum Dynamic Time-To-Collision Between Vehicles Key Conflicting Points at Signalized Intersections**

Abstract Analyzing vehicle-to-vehicle conflicts at signalized intersections is a crucial aspect of traffic safety research, with computer vision techniques playing an important role in detecting and tracking vehicles to assess potential safety hazards. However, current methods face challenges, including errors in identifying traffic conflict instances due to empirical assumptions, inaccurate vehicle dimension estimations, and the inflexibility of conflict indicator formulas, which fail to adapt to the dynamic nature of vehicle interactions across different timestamps.

To address these limitations, this study proposes a novel traffic conflict identification framework that uses a deep neural network-based pose estimation algorithm, followed by a refinement technique that adjusts vehicle key points based on imagery perspectives to accurately represent the positions in a plan view. The study then analyzes traffic conflicts by investigating the continuous motion states of vehicle pairs and extracting the minimum dynamic time-to-collision (mDTTC) at the key points level. The mDTTC is calculated between both structured and unstructured key point pairs, and an optimized curve is plotted to assess collision risk.

The results reveal that the traditional Time-to-Collision (TTC) equation significantly underestimates the minimum TTC value for head-on and angle conflicts, creating a false indication of a severe need for evasive action. On the other hand, rear-end conflicts show a relative decrease in mDTTC values when the leading vehicle makes a left turn and suddenly reduces speed. This highlights the traditional TTC function’s limitations in accurately assessing such dynamic and complex conflict scenarios.

By incorporating the mDTTC approach, this study improves the accuracy of intersection safety assessments, offering a more precise depiction of vehicle interactions. This approach can reduce false detections of hazardous situations and provide more reliable data for traffic safety analysis, ultimately enhancing the effectiveness of traffic management systems and safety interventions at signalized intersections.

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Sponsoring Committee	Standing Committee on Safety Performance and Analysis (ACS20)
Session Number	2240
Session Title	Safety Performance and Analysis with Crash Predictions
Paper Number	TRBAM-25-04897
Paper Title	**That Was Close: A Video-Based Safety Assessment of Signalized Traffic Intersections along a High-Speed Corridor**
Abstract	Intersections are critical junctures in urban traffic networks, frequently identified as hotspots for traffic-related injuries and fatalities due to their complex vehicle-to-vehicle (V2V) and pedestrian-to-vehicle (P2V) conflict points. This study presents a comprehensive case study focusing on the utilization of video analytics and artificial intelligence (AI) to enhance intersection safety in Broward County, Florida. By leveraging traffic cameras and AI-based methods, the research aims to measure and track pedestrian and vehicle movements, providing crucial insights into traffic behaviors and potential risks. The study employs surrogate safety measures such as Time-to-Collision (TTC) and Post-Encroachment Time (PET) and uses an event filter to determine severe events (1). Key findings reveal significant conflict points, especially during left-turn movements, and underscore the role of driver and pedestrian behaviors in contributing to these conflicts. Specifically, along the high-speed corridor of Stirling Road in Davie, Florida, the most frequently occurring type of P2V conflict involved a northbound left vehicle. To address issues such as this, the research proposes a range of countermeasures, including the addition of standardized signage, crosswalk visibility improvements, and walk signal timing adjustments. These strategies aim to improve driver awareness and ultimately reduce the frequency of accidents at intersections. The findings and recommendations of this study provide a data-driven foundation for traffic engineers, urban planners, and policymakers to implement effective safety measures, thereby enhancing the overall safety and performance of traffic intersections.

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Sponsoring Committee Standing Committee on Safety Performance and Analysis (ACS20)
Session Number 2240
Session Title Safety Performance and Analysis with Crash Predictions
Paper Number TRBAM-25-05008

Paper Title **Surrogate safety measure with consideration of maximum stopping distance based onempirical vehicle trajectories prior to crashes**

Abstract Road traffic crashes result in approximately 1.35 million deaths annually, highlighting the urgent need for improved road safety measures. Rear-end crashes are particularly prevalent, accounting for about 29% of all vehicle crashes, according to the NHTSA report. Surrogate safety measures (SSMs), which act as proxies for actual crashes, are widely used to assess crash risks. However, many existing SSMs are based on assumptions such as constant velocities, unchanged trajectories, and predefined deceleration rates, which do not accurately capture the actual risk-avoidance behaviors and braking mechanisms of traffic participants, especially in rear-end crash scenarios.

To address this gap, this study introduces a novel SSM for detecting the risk of rear-end crashes, which accounts for the actual deceleration process of vehicles in a platoon. The proposed method utilizes the Maximum Stopping Distance (MSD), derived from the deceleration process of both the leading and following vehicles. This metric quantifies the crash risk of each following vehicle in the platoon, considering the variable deceleration rates during braking. The deceleration process is modeled using large-scale empirical vehicle trajectory data associated with rear-end crashes.

The study compares the crash detection performance of the MSD with traditional SSMs, such as the RSS safe distance, Time-to-Collision (TTC), and Minimum Time-to-Collision (MTTC). The analysis focuses on balancing the recall and false-alarm rates in crash detection, assessing the ability of each measure to accurately predict rear-end crash risk. The MSD approach, by incorporating actual braking behaviors, is expected to improve the reliability of rear-end crash risk predictions, offering a more realistic and practical tool for traffic safety analysis and intervention.

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Sponsoring Committee	Standing Committee on Safety Performance and Analysis (ACS20)
Session Number	2240
Session Title	Safety Performance and Analysis with Crash Predictions
Paper Number	TRBAM-25-05277
Paper Title	**Analyze Impacts of Lane-change on Highway Safety Risk with Safety Risk Potential Field and Multi-State Survival Analysis**
Abstract	The effect of vehicles' lane changes on the de-escalation of safety risks, specifically how safety conditions return to normal after a potential conflict, has not been thoroughly explored in existing literature. Understanding the impact of lane changes on the de-escalation process of traffic risks is crucial for gaining insights into the overall evolution of traffic risk and improving highway safety. Survival analysis, a statistical method used to examine time-to-event data, is well-suited for investigating how lane-changing behaviors influence the recurrent transitions of vehicle safety risks. However, current survival models for vehicle safety have certain limitations when applied to lane-change risk analysis: 1. Oversimplified risk transition: Many existing survival models use binary states (such as "no-conflict" vs. "conflict" or "crash" vs. "no-crash"), which oversimplify the risk transition process. This approach fails to capture the complexity of traffic risks and does not account for the various stages of risk progression and de-escalation. 2. Missing recurrent risk nature: Some models consider multi-state transitions but overlook the recurrent nature of risks. They often assume a one-directional risk progression (e.g., risk continuously increases or decreases), which does not capture the possibility of risks escalating and de-escalating multiple times within a single driving scenario. 3. Limited incorporation of multi-directional risks: Traditional models typically focus on longitudinal risks (e.g., following distance, time-to-collision) and rely on surrogate safety measures like minimum gap, time-to-collision (TTC), and modified time-to-collision (MTTC). These models often neglect other important risk factors, such as lateral movements, which are particularly relevant in lane-changing scenarios. To address these challenges, this study proposes multi-state survival models combined with an innovative surrogate safety measure, the Potential Field Risk Index (PFRI), which is based on safety potential field theory. This approach is an extension of the researchers' previous framework, where safety risks are discretized into four hierarchical states of severity: "crash," "near-crash," "risky," and "safe", based on PFRI values. The PFRI-survival models incorporate multi-directional risks and better capture the dynamic and recurrent nature of safety risk transitions. By comparing the survival analysis of PFRI and MTTC, the study identifies which types of risks (multi-directional or longitudinal) are predominantly affected by vehicles' lane changes and other risk factors under different driving conditions. This improved model offers a more comprehensive understanding of traffic risk dynamics and can guide more effective safety interventions, particularly in scenarios where lane-changing behavior plays a significant role in risk mitigation or escalation.

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Sponsoring Committee	Standing Committee on Safety Performance and Analysis (ACS20)
Session Number	3147
Session Title	Safety Performance and Analysis Using Machine Learning or Artificial Intelligence
Paper Number	TRBAM-25-00443
Paper Title	**Ensemble-based Machine Learning Approach to Prioritize Driving Safety Indicators Using Connected Vehicle System Data for Proactive Safety Analytics**

Abstract

The advancement of vehicle detection technology has revolutionized traffic safety analysis by enabling the collection of individual vehicle trajectory data. This data can be used to derive a variety of driving safety indicators, which are essential for real-time traffic safety evaluation and crash prediction. By analyzing these indicators, hazardous road sections can be identified immediately, contributing to the development of proactive accident prevention measures.

For effective identification of hazardous road sections, it is crucial to select the driving safety indicators that have the most significant impact on determining the presence of hazards. The selection of salient indicators is key to reducing the complexity of safety models and maximizing their efficiency.

While many studies have attempted to prioritize safety indicators for model development, a common limitation is the reliance on a single machine learning model for this task. However, the importance of variables can differ across models due to the inherent algorithmic differences in machine learning methods. This study aims to address this limitation by combining multiple models to prioritize driving safety indicators more effectively.

To implement this, three well-known machine learning methods—support vector machine (SVM), artificial neural network (ANN), and K-nearest neighbor (KNN)—are used in the hazardous section identification model. In this model, driving safety indicators serve as input variables, and the output consists of hazardous and normal road sections. The study compares the performance of an ensemble learning model (which combines the outputs of the individual models) with that of the individual models (SVM, ANN, KNN).

To determine the priority of the indicators, the study adopts permutation importance, a model-agnostic feature importance method. This method helps assess the contribution of each safety indicator to the model's performance, allowing for a more accurate identification of hazardous road sections and enhancing the effectiveness of the overall safety model.

By combining multiple machine learning models and prioritizing safety indicators using permutation importance, the study aims to improve the identification of hazardous road sections, thereby enhancing road safety measures and reducing crash risks.

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Sponsoring Committee	Standing Committee on Safety Performance and Analysis (ACS20)
Session Number	3147
Session Title	Safety Performance and Analysis Using Machine Learning or Artificial Intelligence
Paper Number	TRBAM-25-01181
Paper Title	**Generating Risky and Realistic Scenarios for Autonomous Vehicle Tests Involving Powered Two-Wheelers: A Novel Reinforcement Learning Framework**
Abstract	Emerging technologies have the potential to revolutionize transportation, with Autonomous Vehicles (AVs) enhancing traffic safety, improving efficiency, and reducing emissions by optimizing driving patterns and minimizing idling time. However, despite their great potential, the actual utility and functionality of AVs have yet to be fully realized. Testing remains a critical method for advancing AV adoption, and given that Powered Two-Wheelers (PTWs) are a major contributor to crashes, this paper proposes a novel scenario generation method for PTWs interactions with AVs. First, we extracted 314 car-to-PTWs crashes from the China In-depth Mobility Safety Study-Traffic Accident (CIMSS-TA) database as the initial state of the test scenarios. Subsequently, Reinforcement Learning (RL) was employed to control PTWs, using a reward function guided by a potential energy function that mirrors human driving characteristics to enhance the risk and realism of the generated scenarios. Finally, the effectiveness and scientific validity of the generated scenarios are verified by comparing and analyzing the risk, realism, and crash severity through multiple indicators. The results demonstrate that our proposed method increases riskiness while maintaining a high level of realism. It is hoped that this process will be applied in the future to not only test AV functions but also encourage AVs to be more mindful of crash severity.

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Sponsoring Committee Standing Committee on Safety Performance and Analysis (ACS20)

Session Number 3147

Session Title Safety Performance and Analysis Using Machine Learning or Artificial Intelligence

Paper Number TRBAM-25-01767

Paper Title **Evolution Pattern Analysis Using a Rule-Based Road Chain Conflict Identification Algorithm**

Abstract Recently, chain traffic crashes have occurred frequently on continuous flow facilities such as expressways and highways. Chain traffic crashes involve multiple vehicles and typically occur on high-capacity and high-speed roads. These crashes often result in high fatality rates and difficulties in rescue, seriously endangering the reliability of road transportation system. Existing studies on multi-vehicle collisions mainly explore the identification method, influencing factors, and risk control strategies of chain conflicts or chain crashes. However, current research is not sufficient to understand the risk pattern of multi-vehicle chain conflicts under diverse road segments or traffic conditions, and it is difficult to effectively break the chain conflicts. Therefore, it is of great significance for traffic managers to identify and analyze the development patterns of chain crashes before they occur, as this can help predict the risks and control the risk conditions of chain crashes, highlighting the potential benefits in the era of connected and automated vehicles. This study firstly identifies conflicts of vehicle pairs based on a large-scale and multi-period vehicle trajectory dataset. Secondly, this study matches conflicts between different vehicle pairs to identify chain conflicts, taking into account the randomness of the moment of conflict occurrence and the fluctuation of the duration of conflict impact. Thirdly, a series of chain conflict risk quantification indicators are constructed, including risk intensity, risk volatility, risk trend, propagation speed, propagation direction, and propagation length. Then, the chain conflict risk pattern recognition is carried out, and three patterns of chain conflict patterns are finally identified, i.e., Longitudinal Risk Decrease Pattern, Longitudinal Risk Increase Pattern, and Comprehensive High-risk Persistent Pattern. Furthermore, the analysis of transition probabilities of different chain conflict patterns yields a series of meaningful inferences that are crucial in improving traffic system safety. This study proposes three innovations: (1) It proposes a nonlinear mapping relationship between modified time-to-collision (MTTC) and potential conflict risks, and constructs chain conflict risk quantification indicators; (2) It constructs a rule-based chain conflict extraction algorithm by matching conflicts between different vehicle pairs, further identifies different patterns of chain conflicts, and calculates the probability of pattern transition in the chain conflict micro system; (3) It compares the performance of different chain conflict patterns and transition probability under different traffic conditions and road segments based on a vehicle trajectory dataset.

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Sponsoring Committee	Standing Committee on Safety Performance and Analysis (ACS20)
Session Number	3147
Session Title	Safety Performance and Analysis Using Machine Learning or Artificial Intelligence
Paper Number	TRBAM-25-02234
Paper Title	**Dynamic Traffic Risk Assessment at Highway Tunnel Entrances Using Optimized Neural Network Models**
Abstract	Tunnel entrances are critical areas with frequent accidents. This study provides management suggestions for tunnel entrance traffic operations by analyzing the impact of driver behavior and vehicle movement on traffic safety risks. Using a long tunnel on a mountainous highway in Yunnan Province, China, high-altitude video data were collected by drones at the tunnel entrance to obtain vehicle trajectory data. The Modified Time-to-Collision (MTTC) was used as a surrogate safety measure to quantify risks. Risk thresholds were defined using the cumulative frequency method. Six optimization algorithms (BBO, PSO, GA, ACO, ES, and PBIL) optimized the convergence speed and classification accuracy of the multilayer perceptron (MLP) neural network model. The optimized model then classified traffic risk levels. Results indicated that traffic risk in the fast lane significantly increases within 100 meters before the tunnel entrance, while the slow lane shows a cyclical risk pattern, with both lanes exhibiting the highest risk levels at the entrance. “Distance to the tunnel entrance” and “Following distance” were key factors influencing traffic risk. Additionally, the BBO-MLP model demonstrated superior performance in convergence speed and accuracy compared to other models. These findings provide valuable references for traffic management authorities to develop targeted measures, such as clear signage and warning systems at various distances from the tunnel entrance, to remind drivers to maintain safe distances and appropriate speeds, thereby minimizing traffic risks before the tunnel entrance.

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Sponsoring Committee	Standing Committee on Safety Performance and Analysis (ACS20)
Session Number	3147
Session Title	Safety Performance and Analysis Using Machine Learning or Artificial Intelligence
Paper Number	TRBAM-25-02912
Paper Title	**The Impact of Electric Vehicle's Strong Acceleration Performance on Traffic Safety Risks at Signalized Intersections**
Abstract	Since 2010, the global sales of light electric vehicles (EVs) have been consistently increasing, marking electrification as a major trend in the automotive industry (1). The electric motor in EVs differs from the engine in traditional fuel-powered vehicles (2). For instance, when the rotation speed of an EV's motor reaches 5000 revolutions per minute, the power can reach 300 kW, with a power-to-speed ratio of approximately 0.06 kW·min/rev. In contrast, a traditional fuel-powered vehicle at 5000 revolutions per minute has a power of less than 220 kW, with a power-to-speed ratio of 0.044 kW·min/rev. With the same transmission ratio, overall vehicle mass, and tire diameter, vehicle acceleration is proportional to the power-to-speed ratio. EVs can achieve accelerations 130% to 136% greater than traditional fuel-powered vehicles, potentially posing adverse effects on traffic safety (3). The strong acceleration performance of EVs is particularly evident at lower operating speeds (4). Among various low-speed scenarios, signalized intersections are integral components of the road network (5). Due to frequent changes in traffic signals, the acceleration and deceleration of traffic flows at these intersections are complex, leading to greater safety risks (6). Drivers' willingness to accelerate is typically higher for straight-ahead traffic compared to left or right turns, which makes straight-ahead traffic at signalized intersections more hazardous (7). Most studies on EVs are based on accident analysis, focusing on the characteristics and causes of EV accidents (8). Some researchers have analyzed the impact of EVs on traffic safety from the perspective of accident probability due to their low noise or from the perspective of accident severity due to their flammable and explosive nature (9, 10). Existing studies are based on limited accident data and rarely consider the impact of EVs' strong acceleration performance. This study aims to investigate the impact of the strong acceleration performance of electric vehicles on traffic safety risks at signalized intersections. For this purpose, UAVs and roadside cameras are used to obtain vehicle information and construct a trajectory database containing different types of vehicles. A two-dimensional comprehensive safety surrogate indicator, considering both collision probability and severity, is proposed to achieve automatic quantification of traffic safety risks based on trajectory data. The study compares the straight-ahead traffic safety risks of electric vehicles and fuel-powered vehicles at signalized intersections from the perspectives of individual driving behavior and interactive behavior.

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Sponsoring Committee	Standing Committee on Safety Performance and Analysis (ACS20)
Session Number	3147
Session Title	Safety Performance and Analysis Using Machine Learning or Artificial Intelligence
Paper Number	TRBAM-25-04520
Paper Title	**ProSafeAV: Enhancing Proactive Safety Performance of AVs using World Model-Based Reinforcement Learning and Extreme Value Theory**
Abstract	The increasing deployment of autonomous vehicles (AVs) necessitates robust safety mechanisms to navigate complex traffic scenarios. This study introduces ProSafeAV, a novel framework integrating Extreme Value Theory (EVT) with world model-based reinforcement learning (RL) to enhance AVs' proactive safety and performance. Traditional approaches often rely on reactive safety measures, leaving AVs vulnerable to traffic conflicts. ProSafeAV addresses this limitation by emphasizing prediction and prevention of high-risk traffic situations. Our methodology integrates EVT with world model-based RL in a comprehensive architecture. The system processes environmental data through sensor fusion and safety indicators to predict and avoid potential conflicts. Key components include a perception module for sensor data fusion, a world model for efficient latent space representation, and an RL module for decision-making. The EVT module analyzes tail behavior of conflict-related metrics, enhancing risk assessment. We evaluated ProSafeAV using the CARLA simulation platform and CarDreamer model, focusing on challenging scenarios such as overtaking tasks. Our experiments compared ProSafeAV against benchmark models DreamerV2 and DreamerV3. Results demonstrate ProSafeAV's significant outperformance in key metrics including average Time-to-Collision (TTC), collision avoidance, and overall driving score. ProSafeAV achieved higher TTCs while maintaining competitive speeds, indicating a balanced approach to safety and efficiency. The integration of EVT with RL frameworks enables enhanced risk assessment and decision-making, allowing AVs to anticipate and mitigate potential conflicts effectively. These findings suggest that ProSafeAV's approach could significantly advance AV safety and reliability in dynamic, complex environments.

TRB 104th ANNUAL MEETING January 5–9, 2025 • Washington, DC

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Sponsoring Committee	Standing Committee on Safety Performance and Analysis (ACS20)
Session Number	3147
Session Title	Safety Performance and Analysis Using Machine Learning or Artificial Intelligence
Paper Number	TRBAM-25-05976
Paper Title	**AI Conflict Observer: Severity and Scenario Identification for Multi-type Vehicle-to-Vehicle Conflict at Intersection Based on Transformer**
Abstract	Intersections are potential crash hotspots within road networks. Crash data consistently indicate that safety issues at intersections warrant focused attention (1; 2). Traffic Conflict Technique (TCT) is an effective method for analyzing intersection operational safety. Compared to low-probability crash data analysis, TCT offers a larger sample size, shorter observation periods, easier monitoring, and real-time capabilities (3). However, traditional manual conflict observation methods suffer from high costs, subjectivity, and low accuracy (4). Sensing technologies offer solutions for automated traffic conflict research, exemplified by the deployment of numerous smart intersections in cities such as Detroit, USA (5), and Shanghai, China (6). Using video and point cloud data from cameras and radar (7; 8), tracking algorithms capture vehicle trajectories to compute Surrogate Safety Measures (SSM) like Time to Collision (TTC) (9) and Post Encroachment Time (PET) (10). Threshold-based methods assess conflict severity, while semantic rules describe spatial relationships to identify conflict scenarios. However, these methods face challenges: 1) Threshold methods fail to capture motion state changes and behavioral differences, leading to misjudgments of conflict severity; 2) Semantic rules struggle with diverse intersection designs, limiting generalizability of conflict scenarios; 3) Large-scale data processing is difficult due to the heterogeneity of data from different intersections. To address these issues, this study combines the kinematic features of trajectory data from seven holographic intersections and labels the conflict severity and scenarios for 21,110 vehicle pairs. Four different Transformer encoder models with varying heads and layers were trained. A 2-layer Transformer with 8 heads was selected as the benchmark, leading to the development of the AI Conflict Observer (AICO) model. The AICO model achieves weighted F1 scores of 0.723 for conflict severity and 0.873 for scenario recognition. Compared to manually verified results, the model's detection outcomes differ by only 3.97%, with high consistency in temporal and spatial distribution. It uses relative coordinates, driving angles, and speeds of conflicting vehicles to identify conflict severity and scenarios, without relying on thresholds or lane information. The model overcomes traditional methods' limitations, enabling large-scale conflict detection and providing a quantitative reference for improving intersection safety. It can integrate with edge computing devices for real-time risk assessment and safety management.

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Sponsoring Committee	Standing Committee on Safety Performance and Analysis (ACS20)
Session Number	3147
Session Title	Safety Performance and Analysis Using Machine Learning or Artificial Intelligence
Paper Number	TRBAM-25-06160
Paper Title	**Causality Modeling and Analysis of Crash Risk during Interactions Between Motorized and Non-Motorized Vehicles Based on Double Machine Learning**
Abstract	The mixing of motorized and non-motorized vehicles in the central area of the intersection with a high density of interaction behavior leads to a high risk of collision that seriously endangers users. To devise effective control strategies for risky driving behavior, it is crucial to model how risk evolves during these interactions. This study presents a novel analytical framework grounded in causal inference theory to assess accident risk and uncover the causal links between driving behavior and risk. Initially, risk during the interaction between motorized and non-motorized vehicles is quantified using a modified measure known as Anticipated Collision Time (ACT). Next, a double machine learning model (DML) is employed to explore the relationship between vehicle motion characteristics, environmental conditions, and collision risk. The findings demonstrate that this causal analysis framework effectively examines micro-level interaction behavior and reveals that the impact of driving behavior on interaction risk varies significantly across different scenarios. These insights enhance our understanding of interaction processes and their potential to lead to accidents, offering valuable information for developing driver assistance systems.

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Sponsoring Committee	Standing Committee on Safety Performance and Analysis (ACS20)
Session Number	3213
Session Title	Safety Performance and Analysis for Safe Road Users and Safe Speeds
Paper Number	TRBAM-25-01266
Paper Title	**Evaluating the Safety Impact of Mid-block Pedestrian Signals (MPS)**
Abstract	The Florida Department of Transportation (FDOT) has recently started implementing a new signal system at mid-blocks called Mid-block Pedestrian Signals (MPS). This study aims to evaluate the effectiveness of these newly implemented MPSs. A total of 260 hours of video data were collected from five locations across Florida, with 130 hours recorded before MPS installation and 130 hours after installation. State-of-the-art computer vision technology was employed to detect and track various road users. A random parameters multinomial logit model with heterogeneity in the means was implemented to assess safety of vehicle-pedestrian interaction by three conflict categories: No Conflict, Moderate Conflict, and Serious Conflict. Relative-Time-to-Collision (RTTC) values were utilized to classify these level of conflicts. The analysis demonstrates that the presence of MPS significantly enhances safety outcomes by increasing the likelihood of avoiding conflicts and reducing the probabilities of both moderate and serious conflicts. Key factors influencing conflict probabilities were identified, including pedestrian and vehicle counts, average leading vehicle speed, standard deviation of leading vehicle speeds, and land-use mix, all of which increase the probability of serious conflicts. Interestingly, the analysis identified three significant interaction variables with MPS: average leading vehicle speed, standard deviation of leading vehicle speeds, and land-use mix. While these factors individually had a higher probability of leading to serious conflicts, the presence of MPS effectively mitigates these risks by moderating their adverse effects, increasing the likelihood of no conflicts. These results underscore the importance of MPS as an effective measure to improve safety at mid-block crossings.

Authors Right-Turn Safety for Pedestrians: Insights from Multilevel Models of Conflicts in Utah
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Sponsoring Committee Standing Committee on Safety Performance and Analysis (ACS20)
Session Number 3213
Session Title Safety Performance and Analysis for Safe Road Users and Safe Speeds
Paper Number TRBAM-25-01356
Paper Title <u>**Right-Turn Safety for Pedestrians: Insights from Multilevel Models of Conflicts in Utah**</u>

Abstract Pedestrians and vehicles frequently interact at signalized intersections, and a significant portion of recent pedestrian crashes at intersections involve right-turning vehicles. There is a need to proactively understand right-turn safety for pedestrians, without waiting for crashes to occur. Using the severity of conflicts between pedestrians and right turning vehicles as a surrogate safety measure, the purpose of this study was to investigate associations of various conflict- and location-specific factors with pedestrian conflict severity, and ascertain variations across locations. First, data were collected for 1,640 pedestrian–right turn conflicts observed from over 1,000 hours of video at 34 intersections in Utah. Next, multilevel models (conflicts nested within intersections) were estimated to analyze the data. The results reveal an increase in conflict severity for pedestrians crossing when the signal was solid don't walk and for bicyclists using the crosswalk. Conflicts tended to be less severe: when more pedestrians were in the group, pedestrians were using a wheelchair or pushing a stroller, fewer vehicles were waiting to turn right; for large vehicles, vehicles turning right on red, conflicts during evening peak hours; and during hours with precipitation. Conflicts in the first crosswalk encountered by right-turning vehicles had longer encroachment times than conflicts in the second crosswalk. Similarly, when pedestrians approached the curb, higher encroachment time and pre-encroachment time were observed, while post-encroachment time was shorter. Crosswalk offset distance (from the outside edge of the right-most lane to the nearest line of the parallel crosswalk) and household size were negatively associated with conflict severity.

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Sponsoring Committee Standing Committee on Safety Performance and Analysis (ACS20)
Session Number 3213
Session Title Safety Performance and Analysis for Safe Road Users and Safe Speeds
Paper Number TRBAM-25-02110
Paper Title <u>**Assessing the Safety Nature of Pedestrian-Vehicle Interaction at Non-signalized Crosswalks**</u>

Abstract Uncontrolled crosswalks frequently contribute to pedestrian crashes. Despite extensive studies on pedestrian crossing safety, the dynamic state of pedestrian-vehicle interactions (PVI) and its impact on collisions have received little attention. This study investigates how the dynamic behavior of PVI influences pedestrian crossing safety from a novel perspective. A methodology is put forth that leverages computer vision and clustering techniques to gain insight into pedestrian-vehicle interactions. This is accomplished by extracting trajectory data from unmanned aerial vehicle (UAV) videos and calculating the representation of PVI. The resultant pattern of interactions is then clustered. Additionally, two novel interaction indicators are devised to evaluate the dynamics of the interaction state. A risk prediction test assesses the efficiency of the proposed indicators. Further analysis examines pedestrian crossing safety and decision-making from the perspective of interaction dynamics, considering differences among interaction clusters. While collision exposure might increase crash probability, it can also improve risk perception. Frequent changes in passing priority increase the possibility of serious conflicts. The risk prediction model incorporating the proposed dynamic interaction indicators outperforms other models. Our findings reveal that complex interaction experiences encourage vehicles to yield and influence potential conflict risks.

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Sponsoring Committee Standing Committee on Safety Performance and Analysis (ACS20)

Session Number 3213

Session Title Safety Performance and Analysis for Safe Road Users and Safe Speeds

Paper Number TRBAM-25-03898

Paper Title **A Novel Approach for Instantaneous Traffic Near-Miss Identification Based On Vehicle Speeds And Proximity At Signalized Intersections**

Abstract Traffic near misses refer to a situation when conflict drivers or vulnerable road users (VRU) and vehicles are about to crash but travellers take evasive actions to avoid. Previous research reveals a strong correlation between frequent traffic near misses and actual crashes. Therefore, it is desired to use the number of identified traffic near misses as a proactive indicator of crash possibility. Identifying the near misses is based on conflict vehicles' maneuvers and therefore it is common to analyze the vehicle trajectories and capture those near misses. However, this approach faces a few challenges in real-time applications. Identifying near misses from vehicle trajectories is computing-intensive and so cannot be achieved both quickly and cost-effectively. In the meantime, roadside sensors like video, radar, or LiDAR have inherent positioning errors (e.g., parallax). A tiny position error can be easily amplified into wrong speed estimation and therefore the near-miss identification. To address the above issues, a proximity-based method is presented in this paper. The idea is that a near miss will occur whenever conflicting vehicles are close at dangerously high speeds. The conflict zones are designed in a way that, if conflicting fast vehicles appear in the zone at the same time, they must take evasive maneuvers to avoid collisions, defined as a traffic near miss. Capturing instantaneous near misses with this new method only needs to capture isolated events instead of continuously tracking all vehicles. Therefore, it can be implemented for real-time applications. The presented method was tested at an intersection equipped with LiDAR tracking sensors in Salt Lake City, Utah, USA, and the results were demonstrated in the end.

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Sponsoring Committee Standing Committee on Safety Performance and Analysis (ACS20)

Session Number 3213

Session Title Safety Performance and Analysis for Safe Road Users and Safe Speeds

Paper Number TRBAM-25-03910

Paper Title **Developing a Short-Term and Rapid Road Traffic Safety Assessment Indicator: Copula-Based Joint Modeling of Crash and Risky Driving Behavior Count**

Abstract Crash data is crucial for evaluating road safety, but its randomness limits the ability to conduct prompt road safety assessments. Additionally, property damage-only crashes may go unreported, leading to biased estimates. Alternative safety measures are used in road safety analysis since they can capture more frequent "near-miss" situations. However, concerns about their predictive accuracy persist. This study aims to jointly model crash and risky driving behavior count to develop a short-term, rapid road safety assessment indicator. Panel data, including crash and risky driving behaviors (such as sharp acceleration, deceleration, and turning) recorded at 1-hour intervals across 22 segments of the Yongtaiwen freeway, is utilized. Zero-inflated negative binomial (ZINB) models and negative binomial (NB) models are employed for the marginal regression modeling of crash and risky driving behavior frequency. A copula-based approach jointly models the marginal distributions, describing the nonlinear dependency structure between the variables. Comparing Gaussian and five one-parameter Archimedean copulas reveals that the Gumbel copula is the best fit. Finally, the joint cumulative distribution function (joint CDF) values of crash and risky driving behavior count were derived under the Gaussian copula joint distribution. The modified total rank differences test (TRDT) indicates that the ranks based on joint CDF values are more consistent with those based on risky driving behavior count than with those based on crash count alone. This demonstrates that the joint CDF values provide a more accurate and stable identification of high-risk freeway segments, showcasing the effectiveness of copula-based data fusion for road safety assessment.

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Sponsoring Committee	Standing Committee on Safety Performance and Analysis (ACS20)
Session Number	3213
Session Title	Safety Performance and Analysis for Safe Road Users and Safe Speeds
Paper Number	TRBAM-25-05286
Paper Title	**Comprehensive Safety Impacts Analyses of the Augmented Reality Warning and Navigation System**
Abstract	Due to the serious consequences of road crashes on property and human life, road safety has been widely studied by relevant researchers for decades. To improve driving behavior and safety, certain navigation companies like Amap and Sogou have developed Augmented Reality Warning and Navigation Systems (ARWNS) and implemented them in real-world use. The fundamental function of ARWNS is to offer drivers audio-visual interactive driving assistance by analyzing the surrounding external environment in real time. Though previous experiments suggest that AR navigation will reduce the driver’s load and improve driving behavior, real-world evidence that characterizes the safety impacts of ARWNS is still limited. Most of the studies conducted driving simulator experiments and identified optimal AR navigation designs in terms of specific aspects such as display mode (audio, visual, audio-visual, etc.), stereoscopic display, interface symbols, and so on. Driving simulator experiments were also conducted to compare AR navigation and conventional navigation and explore whether it would distract drivers’ attention or increase the driving load. The research results show that AR navigation systems can benefit driving performance, reduce uncertainty, and hesitation in unfamiliar areas. Furthermore, some studies have investigated the effects of AR navigation integrated with pedestrian conflict warnings on driver behavior and performance. Based on the above literature review, previous research primarily focuses on either ADAS or AR navigation. While the ARWNS, as a deployed alternative ADAS, has received limited attention in the literature, there is a notable research gap regarding the safety impacts of ARWNS under the new “navigation+warning” assistance form. However, the safety effects of ARWNS have not been thoroughly investigated, particularly in diverse scenarios of real road environments.

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Sponsoring Committee	Standing Committee on Safety Performance and Analysis (ACS20)
Session Number	3213
Session Title	Safety Performance and Analysis for Safe Road Users and Safe Speeds
Paper Number	TRBAM-25-06304
Paper Title	**Effect of Rider Kinematics and Expected Speed Differences on the Sideswipe Crash Risk of Powered Two-Wheelers: A Copula-Based Proactive Safety Approach**
Abstract	For designing effective rider assistance systems for powered two-wheeler (PTW) safety, studying the relationship between rider kinematics and safety-critical events is essential since it explains the rider’s workload in mitigating the crash risk. However, such relationships must also consider the expected speed differences of post-crash occurrences, as it is indirectly related to the injury risk of PTWs. Hence, the present study investigates the relationship between rider kinematics, expected speed differences, and PTW safety margins. Using the detailed PTW conflict data obtained from microscopic trajectories, the study analyzes the relationship between safety margins, rider kinematics, and expected speed differences. The study employs a copula-based approach for modeling the association between safety margin, rider kinematics, and injury risk related to sideswipe PTW conflicts. Three surrogate safety measures (SSMs) were considered for this purpose: anticipated collision time (measures safety margin), yaw rate (measures rider kinematics), and DeltaV (measures injury risk). Using an unmanned aerial vehicle (UAV), video data were collected from a four-lane highway in India covering an extended road length. It was found that a bivariate Gumbel Copula fits the safety margin, rider kinematics, and expected speed differences. The safety margin thresholds were found to be smaller than those of car drivers, and the high fluctuations in the yaw rate values signify the application of rapid evasive maneuvers. Understanding this inter-relationship between these three characteristics will help in better designing rider assistance systems.

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Sponsoring Committee	Standing Committee on Safety Performance and Analysis (ACS20)
Session Number	4073
Session Title	Safety Performance and Analysis for Safe Vehicles
Paper Number	TRBAM-25-00906
Paper Title	**Crash-based Safety Testing of Autonomous Vehicle: Insights from Generating Safety-Critical Scenario based on In-Depth Crash Data**
Abstract	Safety is a paramount concern in the development of Autonomous Vehicles (AVs) within the automotive industry. Ensuring AVs' reliable performance requires the development of varied and realistic testing scenarios. Identifying unknown hazardous scenarios presents a notable challenge in the testing process. To address a wider spectrum of unknown hazardous scenarios, this study introduces a novel methodology for generating safety-critical scenarios for AV safety testing based on in-depth crash data. First, we utilized the China In-depth Mobility Safety Study-Traffic Accident (CIMSS-TA) database to decompose crash scenarios into static and dynamic variable tuples. Subsequently, the time series Generative Adversarial Networks (TimeGAN) was employed to capture temporal features and generate safety-critical scenarios using the original dataset. The synthesized scenarios were then assessed in terms of similarity, usability, and risk. Finally, a well-known autonomous driving system, Baidu Apollo, was tested in both original and synthesized scenarios. The experimental results demonstrate that safety-critical scenarios derived from in-depth crashes preserve the essential risk characteristics. Furthermore, Baidu Apollo exhibits superior safety performance in hazardous situations compared to human drivers. The synthesized scenarios provide a comprehensive dataset for testing AVs in high-risk situations. This method addresses the challenge of limited crash data, broadens the scope of safety-critical scenarios, and enhances the assessment and advancement of AV technology.

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Sponsoring Committee	Standing Committee on Safety Performance and Analysis (ACS20)
Session Number	4073
Session Title	Safety Performance and Analysis for Safe Vehicles
Paper Number	TRBAM-25-02148
Paper Title	**A Comprehensive Risk Metric for Freeway Vehicles Based on Predicted Positions**
Abstract	Freeways are the arteries of road traffic, bearing the majority of the nation's traffic load and playing an indispensable role in the transportation system. However, with the significant increase in the number of vehicles and the expansion of freeway networks, the safety pressure on freeways has been intensifying. Compared to urban roads, freeway accidents often result in more severe casualties and substantial property damage. Quantifying driving risks is a crucial component of proactive traffic safety management and remains a hot topic in traffic safety research. As a core component of traffic conflict techniques, Surrogate Safety Measures (SSMs) have been proposed and widely applied to quantify driving risks and identify hazardous driving behaviors. Nonetheless, these SSMs often assume that vehicles maintain their current state of motion, with constant speed or acceleration. They only consider the current state of the vehicles, ignoring variations in speed or acceleration during operation and potential future changes, thus limiting the accuracy of risk assessment. In recent years, the development of intelligent and connected transportation systems has garnered significant attention. Connected and Automated Vehicles (CAVs) are capable of comprehensively sensing and acquiring information about the road environment and traffic conditions. Constructing surrogate safety measures based on predicted vehicle position distribution can more comprehensively and accurately reflect the operational risks of road traffic. This study establishes a Generalized Dynamic Graph Convolutional Network (GDGCN) to predict vehicle position distributions. Subsequently, it calculates the risk between vehicles by evaluating the overlapping areas of their predicted position distributions. This serves as a new indicator for assessing inter-vehicle risk, contributing to the safety management of freeway traffic. The main contributions of this paper are as follows: 1. Harmonization of vehicle risk calculations for car-following and lane-changing scenarios: This study develops a methodology that harmonizes risk calculations for both car-following and lane-changing scenarios by utilizing vehicle position predictions. This approach ensures consistent and reliable risk assessments across different driving conditions. 2. Integration of temporal and spatial proximity in risk metrics: This research enhances risk assessment accuracy by incorporating both temporal and spatial proximity into vehicle risk metrics. The developed GDGCN predicts vehicle positions and evaluates risk based on overlapping areas of predicted position distributions, accounting for variations and fluctuations in vehicle dynamics. This approach overcomes the inaccuracies associated with the assumption of constant vehicle motion.

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Sponsoring Committee Standing Committee on Safety Performance and Analysis (ACS20)

Session Number 4073

Session Title Safety Performance and Analysis for Safe Vehicles

Paper Number TRBAM-25-03841

Paper Title **Improving Representative Accuracy of Connected Vehicles' Hard-Braking Events for Crashes Through Maximizing their Spatio-temporal Correlation**

Abstract Historically, traffic safety solutions have been based on crash records, which means that traffic safety improvements often come only after crashes have occurred. However, emerging connected vehicle (CV) data, particularly hard-braking events, offers a preventive surrogate for crashes. The assumption is that if a location becomes prone to crashes, vehicles passing through it will experience frequent hard-braking events before a crash actually occurs. The relationship between hard-braking events in CV data and crashes has been examined, and while previous studies report a strong correlation, a fundamental question remains: What is the optimal spatio-temporal coverage of hard-braking events to best represent the crash potential?

Different spatio-temporal coverage—such as the distance from the crash site and the time before and after the crash—can result in varying characteristics of hard-braking events. This, in turn, affects the representative accuracy of these events in predicting crashes. To address this, we developed a multi-objective analysis framework to optimize the spatio-temporal coverage of hard brakes in order to best represent crashes. This approach involves a data reduction algorithm and the establishment of a set of measures of effectiveness (MOEs) by correlating hard-braking events with crashes.

Through multi-objective optimization, the optimal time and space thresholds for maximizing crash-brake correlation factors are identified. In a case study conducted in the Dallas-Fort Worth area, it was found that a 1.25-hour time interval (before and after the crash) and a 300-foot distance threshold effectively correlate a crash with the corresponding hard-braking events.

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Sponsoring Committee Standing Committee on Safety Performance and Analysis (ACS20)

Session Number 4073

Session Title Safety Performance and Analysis for Safe Vehicles

Paper Number TRBAM-25-04100

Paper Title **Safety Evaluation of Automated Vehicles Using Surrogate Safety Measures**

Abstract In recent years, automated vehicles (AVs) have been increasingly integrated into road networks with the primary goal of reducing driver error. Since around 94% of traffic crashes are attributed to driver error, AVs have the potential to significantly improve road safety by eliminating the need for human drivers. Researchers have often used surrogate safety measures, such as Time-to-Collision (TTC), to quantify near-crash occurrences, with a typical TTC threshold of 1.5 seconds for manually-driven vehicles.

However, while AVs can travel with shorter headways due to their enhanced safety features, many studies continue to use the same TTC threshold for both manually-driven and automated vehicles. The purpose of this study was to measure the reaction time of AVs currently available in the market as they travel in car-following mode on road networks. These findings aim to establish the critical TTC for AVs and assess potential conflicts on the road.

To achieve this, two approaches were employed: cross-correlation and the visibility graph algorithm. These methods were used to determine the reaction time of AVs on both freeways and arterial roads. The results showed that the mean reaction time of AVs was 0.95 seconds on freeways and 1.05 seconds on arterials. By using these values as critical TTC thresholds, the study found no incidents of potential conflicts in the provided dataset. These findings align with previous studies and support the notion that AVs offer significant safety benefits, particularly in terms of conflict prevention.

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Sponsoring Committee	Standing Committee on Safety Performance and Analysis (ACS20)
Session Number	4073
Session Title	Safety Performance and Analysis for Safe Vehicles
Paper Number	TRBAM-25-05230
Paper Title	**Integrating Connected Vehicle Hard Braking Event Data for Proactive Road Network Safety Screening**
Abstract	Advancing road safety requires moving beyond the traditional reliance on historical crash data and integrating alternative measures to proactively improve safety. This study explores the potential integration of hard braking events (HBE) from connected vehicles (CV) as crash surrogates for network screening. The study first performed spatial autocorrelation and Spearman correlation analyses to assess the suitability of HBE as a surrogate safety measure for different crash types, including all crashes, rear-end crashes, no-injury crashes, and severe crashes. The analysis of common hotspots revealed that a significant proportion of the crash-based hotspots were also identified using HBE, with the following results:All crashes: 86.25%, Rear-end crashes: 96.83%, No-injury crashes: 85.37%, Severe injury crashes: 78.22% Comparing the ranking of common hotspots based on crash data and HBE showed that rear-end crashes had the least Total Rank Difference (TRD) for the top 20 and 30 hotspots. Additionally, the average ranking difference decreased as the number of top hotspots increased, with the exception of severe crashes. These findings suggest that HBE could be more effective for identifying locations with elevated risks of rear-end crashes compared to other crash types. The study provides valuable insights into the potential of HBE as a surrogate measure for crash prediction, which could help safety management agencies conduct timely evaluations of road network performance and identify areas that could benefit from advanced safety improvements to reduce the risk of traffic conflicts leading to crashes.

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Sponsoring Committee	Standing Committee on Safety Performance and Analysis (ACS20)
Session Number	4073
Session Title	Safety Performance and Analysis for Safe Vehicles
Paper Number	TRBAM-25-05379
Paper Title	**Safety Validation of Automated Vehicles Using Aggregate Markov Chain Theory**
Abstract	AV safety testing requires the evaluation of the occurrence and evolution of safety-critical rare states. Existing scenario-based methods use designed episodes of limited lengths to estimate accident rates, which fails to address how vehicles transition into dangerous states over time. This paper proposes a new perspective that analyzes the occur probabilities of various states over an infinite driving process, providing a comprehensive analysis of the distribution and evolution of near-collision states. By employing Markov Chain steady-state probability theory, state probability distributions are derived from state transition matrices, which can be directly extracted from AV action models, thus avoiding the "curse of rarity." To address the high-dimensional state space issue, aggregate Markov Chain theory is introduced to cluster the state space for effective estimation. We aggregate microscopic states into macroscopic blocks, simplifying the high-dimensional microscopic state transition relationships into macroscopic block transition probability estimation to reduce the complexity. An iterative steady-state sampling method is designed to estimate transition patterns across states of varying danger levels. Simulation experiments compare the proposed method with the Monte Carlo benchmark, showing that the proposed method can estimate dangerous state probabilities using just 0.03% of the sample size and provide more valuable assessment insights than existing studies.

Authors	Song Wang, Chongqing Jiaotong University Zhixia Li, University of Cincinnati Zhengxin Liu, Chongqing Jiaotong University Wenjing Zhao, Hong Kong Polytechnic University Tangzhi Liu, Chongqing Jiaotong University
Sponsoring Committee	Standing Committee on Safety Performance and Analysis (ACS20)
Session Number	4073
Session Title	Safety Performance and Analysis for Safe Vehicles
Paper Number	TRBAM-25-05696
Paper Title	**Leveraging Automated Vehicle Technology to Enhance Driving Safety in Dilemma Zones: A Validation Study**
Abstract	Existing research primarily employs signal-based approaches or Connected Vehicle-based technologies to alleviate the negative impacts of the yellow-light Dilemma Zone (DZ) on safety. However, these methods either reduce the mobility performance at the intersection level or challenge the driver to perform multiple tasks. Emerging Automated Vehicle (AV) technology has the potential to enhance DZ driving safety without involving human drivers if full automation is achieved. Until then, drivers are needed in the automated driving environment to handle AV disengagements. Therefore, how drivers will behave and respond when driving an AV to proceed through the intersection at the onset of yellow remains unknown. More importantly, whether AV is the ultimate answer to DZ driving safety remains unanswered. To address these issues, this research aims to validate whether AV technology is effective in improving DZ safety and identify the characteristics that make AV effective in enhancing safety performance at DZ. A driving simulator study was conducted by inviting 45 participants to drive through a signalized intersection at the onset of yellow under Levels 0, 3, and 4, respectively. Demographical information, driving behavior, and safety performance were collected. The research concludes that as the level of automated driving increases, the probability of traffic conflicts significantly decreases in the DZ scenario. Individuals with high income and education levels but do not believe AV's safety benefits are at a high level can benefit from Level 4 automation in enhancing driving safety through the signalized intersection. The conclusions will benefit AV deployment in urban scenarios.

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Sponsoring Committee	Standing Committee on Safety Performance and Analysis (ACS20)
Session Number	4073
Session Title	Safety Performance and Analysis for Safe Vehicles
Paper Number	TRBAM-25-06028
Paper Title	**Evaluating Safety Benefits of Various Automation Levels and Penetration Rates of Automated Vehicles: A Case Study from the Netherlands**
Abstract	Road traffic crashes result in approximately 1.19 million deaths annually, with vulnerable road users (VRUs) accounting for over half of these fatalities. With human error responsible for over 90% of crashes, the potential of connected and automated vehicles (CAVs) to enhance road safety by minimizing such errors is significant. This study aims to comprehensively analyze the safety impacts of different levels of CAV market penetration using traffic microsimulation based surrogate safety assessment. A calibrated and validated microsimulation model (developed in AIMSUN Next) of Veenendaal city in the Netherlands was used to perform the simulation experiments. The driving characteristics of CAVs in the microsimulation model were defined based on various previous research studies and the safety impacts were examined under a range of mixed scenarios with different levels of automation and CAVs market penetration. Results indicate that with high dominance of CAVs, conflicts can be reduced significantly. These findings suggest that the integration of CAVs can substantially enhance road safety, provided there is a sufficient market penetration of higher-level automated vehicles.

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Sponsoring Committee Standing Committee on Pedestrians (ACH10)

Session Number 2096

Session Title Pedestrian Technology and Data-Driven Safety Measures

Paper Number TRBAM-25-03794

Paper Title **Day and Night Performance Differences in Detection and Deceleration by Pedestrian Automatic Emergency Braking Systems**

Abstract Pedestrian crashes, particularly at night, account for 75% of fatalities among vulnerable road users (VRUs), highlighting the urgent need for effective technological interventions. Pedestrian Automatic Emergency Braking (P-AEB) systems, a feature in Level 2 Autonomous Vehicles (AVs), offer promising solutions by leveraging advanced sensors such as cameras, LiDAR, and radar to detect pedestrians and initiate braking. Studies suggest that P-AEB systems can reduce pedestrian crashes by up to 52%, with combined sensor technologies achieving up to 90% effectiveness. However, the effectiveness of these systems varies due to factors such as lighting conditions, vehicle features, and pedestrian movement, with significant gaps remaining in our understanding of their performance under diverse scenarios.

This study aims to assess P-AEB performance in both daytime and nighttime conditions under controlled settings, focusing on detection and deceleration capabilities while identifying influential vehicle and environmental factors. By addressing sensor limitations and braking response variability, the research seeks to offer new insights into P-AEB functionality, enhance pedestrian safety through improved technology, and inform effective policy-making.

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Sponsoring Committee Standing Committee on Pedestrians (ACH10)

Session Number 2096

Session Title Pedestrian Technology and Data-Driven Safety Measures

Paper Number TRBAM-25-05314

Paper Title **Investigating Pedestrians' Crossing Behavior and Trust towards Human-Driven and Autonomous Vehicles on High-Speed Arterials: Insights from a Virtual Reality Study**

Abstract With the advancement of autonomous vehicles (AVs) technology, the road environment is expected to be mixed between AVs, human-driven vehicles (HDVs), and other road users (e.g., pedestrians). The purpose of this study was to thoroughly investigate pedestrians' crossing behaviors and trust towards AVs at high-speed arterial roads in a virtual reality (VR) environment and examine how such behaviors are comparable to their interactions with HDVs. It also sought to examine significant factors such as demographics, past behaviors/experiences, along with visibility conditions, affecting various pedestrian behaviors and safety measures.

Fifty-six adults participated in six different pedestrian crossing VR scenarios (336 crossings analyzed). Participants also responded to a survey asking about their confidence, predictability, dependability, responsibility, reliability, and faith with both HDVs and AVs. The survey results indicated higher confidence in HDVs, while AVs were rated higher in predictability, dependability, responsibility, and reliability. Several Generalized Linear Mixed Models were developed.

The results revealed significant differences in pedestrian behaviors towards AVs and HDVs. Overall, pedestrians experienced longer post-encroachment times (PET) with AVs compared to HDVs. Pedestrians also showed shorter waiting times at the curb and median and faster overall crossing times when dealing with AVs. Furthermore, AVs were associated with fewer pedestrian crashes compared to HDVs. Age and gender significantly influenced crossing behavior, in that pedestrians aged ≥25 took longer to cross, and males waited longer at the median. Familiarity with AVs reduced curb waiting times. Finally, low visibility resulted in longer waiting times and decreased safety, reflected by shorter PET.

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Sponsoring Committee	Standing Committee on Pedestrians (ACH10)
Session Number	2097
Session Title	Pedestrian Perceptions, Health, and Environment
Paper Number	TRBAM-25-02053
Paper Title	**Modeling Cyclist-Pedestrian Interactions at a Zebra Crossing in Germany**
Abstract	Previous research has examined vehicle-pedestrian and vehicle-cyclist interactions, but there have been few studies that examined cyclist-pedestrian interactions, specifically at intersections. This study investigates cyclist-pedestrian interactions at an unsignalized intersection in Germany using frame-by-frame analysis of 4K drone video recordings. The objectives are to identify variables influencing cyclist yielding behavior and obstructed travel time (OTT) within a predefined zone at a zebra crossing and to categorize the behavior of cyclists. Logistic and linear regression models were employed to analyze predictors such as cyclist speed, deceleration, trajectory changes, pedestrian time-to-conflict-point (TTCP), and interaction type (close or far). Results of the logistic regression indicate that higher cyclist speeds and trajectory changes decrease the likelihood of yielding, while speed reduction and the presence of pedestrians on the crossing increase it. The linear regression analysis reveals that faster cyclists and abrupt deceleration correlate with shorter OTT, suggesting less yielding behavior, whereas speed reduction is positively associated with OTT, promoting yielding. Clustering analysis using Mclust and ClustMD identified two distinct groups: Cluster 1 cyclists exhibit shorter OTT suggesting less yielding, while Cluster 2 cyclists display longer OTT suggesting more yielding behavior and more respect to pedestrian right-of-way at zebra crossings. These findings underscore the need for targeted interventions, such as speed reduction measures, enhanced signage, and improved pedestrian visibility, to ensure cyclist compliance with yielding laws. The study highlights the importance of designing safer crossing environments. This proactive approach offers valuable insights for traffic management and pedestrian safety enhancement at unsignalized intersections.

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Sponsoring Committee	Standing Committee on Pedestrians (ACH10)
Session Number	2097
Session Title	Pedestrian Perceptions, Health, and Environment
Paper Number	TRBAM-25-05743
Paper Title	**Does Shorter Takeover Time Guarantee Safer Performance? Exploring Optimal Takeover Performance in Vehicle-Pedestrian Interaction Scenarios**
Abstract	In responding to the Automated Vehicle (AV) disengagement, drivers must switch to manual driving to control the vehicle. In such cases, two potential driving risk scenarios may arise: (a) the driver takes a long time to react but quickly completes the driving control, and (b) the driver quickly recognizes the takeover request but takes a long time to complete the driving control. While past studies extensively explored the impact of Takeover Time (TOT) on safety performance, Action Time (AT) has rarely been discussed, let alone revealing the mechanism of how TOT and AT influence driving safety under automated driving. Therefore, this research aims to further explore the mechanisms of how the takeover process affects driving safety in response to AV disengagement by integrating both the takeover and action processes. A driving simulator study was conducted by recruiting drivers to experience automated driving under Level 3 automation. Drivers must complete driving through two scenarios where jaywalking occurs with takeover actions needed via the “visual-only” and “visual & audible” takeover warning types. As a result, the takeover warning type is the most crucial factor affecting takeover performance. Specifically, when the “visual + audible” warning is used, none of the participants experienced a traffic conflict. On the other hand, under the “visual-only” warning, the optimized time windows for TOT and AT that achieve no traffic conflicts are identified. In summary, this research contributes to further understanding of the relationship between the takeover process and safety performance.

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Sponsoring Committee	Standing Committee on Pedestrians (ACH10)
Session Number	2097
Session Title	Pedestrian Perceptions, Health, and Environment
Paper Number	TRBAM-25-06266
Paper Title	**Predicting Pedestrian-Vehicle Interaction Severity in Mixed Traffic Conditions: A Feature-Based Long Short-Term Memory Neural Network Approach**
Abstract	This study introduces a novel feature-based Long Short-Term Memory (LSTM) neural network designed to predict the severity of pedestrian-vehicle interactions at unsignalized intersections, aiming to enhance traffic safety significantly. The LSTM model dynamically integrates real-time data variables such as pedestrian and vehicle speeds, distances, and types, enabling it to accurately predict potential hazardous interactions in mixed traffic conditions. Utilizing a comprehensive dataset of over 4,300 pedestrian-vehicle interactions, the interactions were meticulously categorized from ‘Safe Passage’ to ‘Conflict’ based on detailed behavioral analyses. Training and validation of the LSTM model with this data demonstrated robust predictive capabilities. Specifically, the model achieved a precision of 94%, a recall of 87%, and an F1-score of 90% for Safe Passage interactions. For Critical Events, precision was 79%, recall 92%, and F1-score 85%. For Conflicts, precision reached 96%, recall 88%, and an F1-score of 92%. Further validation on external datasets from different urban settings confirmed the model’s effectiveness and generalizability. These tests showed the model maintaining high performance metrics, with overall accuracy improving from 75% initially to 89% after iterative retraining with external data, indicating strong adaptability. The successful deployment of this LSTM model marks a significant advancement in real-time traffic safety technology. Its ability to provide accurate predictions of interaction severity offers a proactive tool for providing real-time warnings to mitigate pedestrian-vehicle collisions, highlighting its potential for integration into traffic management and autonomous vehicle systems. This study underscores the model’s applicability across various traffic environments, making it a vital asset for urban safety enhancements.

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Sponsoring Committee	Standing Committee on Human Factors of Vehicles (ACH30)
Session Number	2231
Session Title	Human Factors of Vehicles: Road User Behavior
Paper Number	TRBAM-25-00842
Paper Title	**An Empirical Study for Investigating Human Drivers' Heterogeneity in Lane-changing Maneuvers from Naturalistic Trajectory Datasets**
Abstract	The emergence of autonomous vehicles can hopefully improve system safety and efficiency levels while they may encounter challenges in interacting with human-driven vehicles, especially during lane-changing maneuvers. This study aims to investigate the effects of driving style heterogeneity with respect to vehicle compositions consisting of lane-changing vehicles (LCV) and vehicles driving behind in the target lane (FV). Discretionary (DLC) and mandatory lane-changing (MLC) events in six-lane dual highways are extracted from highD and exiD datasets. By comparing several commonly used clustering methods, the K-means method is finally selected to categorize LCV-FV compositions into multiple clusters during lane-changing interactions and to capture driving styles (e.g., aggressive and mild) corresponding to LCVs and FVs in each cluster. The impacts of these clusters are expounded upon through analysis of variance and post-hoc paired tests. After that, we evaluate traffic safety, efficiency, and comfort for different compositions and compare their respective performance. The results demonstrate some similarities in driving styles between DLC and MLC, with an aggressive-aggressive LCV-FV composition leading to greater lane-changing risk and reduced comfort compared to other types, while aggressive-mild compositions prioritize interaction efficiency. Moreover, FVs are more likely not to yield to LCVs in DLC maneuvers, and their consideration for efficiency is more pronounced compared to those in MLC. Based on the comparison of different interaction compositions, the findings of this paper could guide the future design of advanced driver assistance systems and autonomous vehicles operating in highly interactive scenarios.

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Sponsoring Committee Standing Committee on Human Factors of Vehicles (ACH30)
Session Number 2231
Session Title Human Factors of Vehicles: Road User Behavior
Paper Number TRBAM-25-01387
Paper Title **Evaluating Lane Change Dynamics: A Study of Camera-Based vs. Mirror-Based Systems in Traffic Safety**

Abstract Lane changing is frequently associated with a high incidence of traffic crashes. This study evaluated the effectiveness of camera-based systems compared to traditional mirror-based systems in enhancing lane-change safety. Utilizing naturalistic driving data, it employed Association Rules Mining (ARM) techniques to analyze driver behavior under different conditions. The findings revealed that camera-based systems lead to safer lane-change behaviors with higher mean Time-to-Collision (TTC) values, especially for left lane changes. In contrast, mirror-based systems encouraged more cautious behavior during right lane changes with higher TTC values. Additionally, the ARM analysis uncovered specific patterns in driver behavior, indicating that drivers using camera-based systems rely on enhanced visibility to make safer and more confident lane changes. These results suggested that integrating camera-based systems in vehicles could significantly enhance driver safety by providing a broader field of view and reducing blind spots, ultimately contributing to more informed and confident lane changes. Future research should explore a broader range of conditions and further investigate the long-term impacts of these systems on driver behavior and safety.

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Sponsoring Committee Standing Committee on Human Factors of Vehicles (ACH30)
Session Number 2231
Session Title Human Factors of Vehicles: Road User Behavior
Paper Number TRBAM-25-02388
Paper Title **Turn In Path Same Crashes- Driver Behavior and Perception Response Time from the SHRP-2 Naturalistic Database**

Abstract This study aims to better understand the triggering thresholds that prompt human drivers to respond urgently in emergency situations, particularly in Turn-In-Path (TIP) scenarios where another vehicle turns into the path of a straight-moving subject vehicle (SV) at an intersection. Building on previous research, this phase expands the scope to include a larger dataset with vehicles turning from both the right and left. Using the Second Strategic Highway Research Program (SHRP2) naturalistic dataset, we identified 167 real-world incidents, including crashes and near-crashes, fitting the study criteria. We measured driver perception response time (PRT) from the moment the principal other vehicle (POV) entered the SV's lane. Our analysis considered various factors, including POV direction, time to conflict, POV behavior, and SV driver engagement in secondary tasks. The findings highlight the conditions under which human drivers are likely to initiate emergency responses, providing valuable insights into the differences between human and a hypothetical automated vehicle reactions, particularly in scenarios with longer onset times. This research offers critical data to inform the design of more effective crash avoidance and driver assistance systems, ensuring that both human drivers and automated systems can respond appropriately to potential hazards.

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Sponsoring Committee	Standing Committee on Human Factors of Vehicles (ACH30)
Session Number	2231
Session Title	Human Factors of Vehicles: Road User Behavior
Paper Number	TRBAM-25-03251
Paper Title	**Study on Takeover Failure Prediction Model Based on Extreme Value Theory and Copula Function**
Abstract	Conditional automated driving is gradually becoming a reality. According to the extreme value theory (EVT), the safe takeover can be used as a normal sample, while the takeover failure can be used as an extreme value sample. EVT can then be used to establish the correlation between safe takeovers and takeover failures. Therefore, based on EVT, it is feasible to characterize takeover failure risk using non-failed takeover data, which offers unique advantages for takeover safety evaluation and failure risk prediction. Many studies indicate that takeover time and Minimum Time to Collision (MTTC) are representative indicators of takeover safety. EVT and Copula theory can be applied to assess takeover safety and failure risk based on non-failed takeover data. The current industry and academic communities still face challenges in assessing takeover safety and failure risk. First, takeover failure data is difficult to obtain due to its rarity and sporadic nature. Second, previous studies have focused on the assessment of takeover failure risk, but there is insufficient prediction of takeover failure events. Therefore, this study aims to construct a takeover failure risk prediction model based on extreme value theory and Copula theory, and compare the performance of unary and binary extreme value models in predicting takeover failure events.

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Sponsoring Committee	Standing Committee on Human Factors of Vehicles (ACH30)
Session Number	2231
Session Title	Human Factors of Vehicles: Road User Behavior
Paper Number	TRBAM-25-03369
Paper Title	**Drivers' Rear-end Conflict Risk Avoidance Behaviors Prediction Based on Natural Driving Data**
Abstract	Previous research mainly focuses on calculating the risk of conflicts using surrogate safety measures. However, these studies have primarily considered the likelihood of conflict occurrence, neglecting how conflict risk evolves after an event. The driver's risk avoidance behavior in conflicts is also crucial, as it determines whether a conflict will escalate into a crash. Identifying significant contributing factors is essential for building traffic conflict prediction models. Traffic flow characteristics, road geometric features, and weather conditions have been thoroughly researched, yet the factors related to driving style have received less attention. A driver's usual driving style could be linked to risk avoidance behavior during conflicts, as it reflects the driver's attitude—for example, whether the driver is aggressive in car-following behavior by keeping a short headway distance. This study incorporates the driver's usual driving behaviors into the predictive model to explore the mechanism of conflict risk avoidance behaviors more effectively. Based on the analyses above, the study focuses on answering two key questions: 1. What is the mechanism of heterogeneity in a driver's risk avoidance behavior during conflicts? 2. Does the driver's usual driving style significantly impact risk avoidance behavior? To address these questions, the study will focus on the following key aspects: • Predicting the driver's rear-end risk avoidance behavior in conflicts using a logistic regression model. • Incorporating the driver's usual driving style into the model to better predict rear-end risk avoidance behavior.

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Sponsoring Committee Standing Committee on Human Factors of Vehicles (ACH30)
Session Number 2231
Session Title Human Factors of Vehicles: Road User Behavior
Paper Number TRBAM-25-04523
Paper Title **Using Physiological Data to Understand Drivers' Performance and Workload under Warning Uncertainty: A Driving Simulation Study at Roundabouts**

Abstract Previous studies have demonstrated that an accurate and properly designed Advanced Driving Assistance System (ADAS) can significantly improve drivers' performance (Ren et al., 2023; D. Zhang et al., 2022). However, ADAS systems can be prone to errors due to human perception variations (Feng et al., 2023; Reinmueller & Steinhauser, 2019) and technical limitations like sensor failures (Cao et al., 2022). Despite this, the effect of human drivers' responses, including driving performance and workload, under warnings with uncertainties, has not been extensively studied.

Driver workload is an effective indicator of future performance, and monitoring workload can help avoid both extremely low and high workload conditions, which can impair driving performance. Previous studies have mostly employed questionnaire-based methods, such as NASA-TLX, to monitor workload (Chen et al., 2022) or focused on time-domain and frequency-domain heart rate variability (HRV) features. However, non-linear features, such as HRV_ShanEn, have not been thoroughly examined (Martin et al., 2016).

This paper presents a driving simulation study aimed at investigating how drivers' performance and workload are affected by a warning system with varying levels of uncertainty at roundabouts. Roundabouts are challenging for human drivers due to the complex information they require to navigate. The study area was the roundabout at Ellsworth and State St, Ann Arbor, Michigan, where 534 crashes occurred between 2018 and 2022 (Southeast Michigan Council of Governments, 2023). Analyzing crash records revealed that 53% of the crashes were caused by "failure to yield" during merging scenarios (C. Zhang et al., 2023).

The study specifically investigates drivers' responses to "failed to yield" cases in merging scenarios. Using a driving simulator, the study examines driver behavior under warning systems with two levels of uncertainty. Drivers' safety performance was measured using the minimum Time to Collision (TTC) between the ego vehicle and interacting vehicles. Physiological data, including eye movements, heart rate, and skin conductivity, were collected for analysis. An XGBoost model was developed for workload prediction, with the SHAP method used to explain the model's outcomes (Lundberg, 2017).

The findings suggest that:

1. Drivers perform better and experience lower workload under conditions of low warning uncertainty.
2. Psychological features effectively reflect changes in drivers' workload under warnings with uncertainties.
3. The XGBoost regressor performs well in predicting drivers' workload.

These insights could help improve the design of warning systems and provide better understanding of how uncertainty affects driver performance and workload.

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Sponsoring Committee Standing Committee on Human Factors of Vehicles (ACH30)

Session Number 2231

Session Title Human Factors of Vehicles: Road User Behavior

Paper Number TRBAM-25-05130

Paper Title **Modeling Dynamic Vehicle-Driver Complex Behaviors at Signalized Intersections Under Cyberattacks**

Abstract Recent studies highlight the need for advanced models that address the complex impacts of cyberattacks on vehicular dynamics, particularly at intersections. Traditional approaches often overlook the integration of dynamic human factors and adaptive behaviors. This research presents a comprehensive modeling framework designed to capture the behavior of vehicles and drivers under cyberattack conditions at signalized intersections.

The proposed framework includes key elements such as dynamic perception-reaction time (PRT), variable braking intensity based on situational urgency, and adaptive velocity adjustments that account for intersection boundaries and signal phases. The primary component of the framework is a trajectory reconstruction model, which integrates vehicle kinematics, the Perception-Identification-Emotion-Volition (PIEV) processes of drivers, and cyber-psychological perspectives.

The model was validated using data from the miniSim driving simulator, and results demonstrate its superior accuracy and explainability compared to the Intelligent Driver Model (IDM) and Long Short-Term Memory (LSTM) models. The findings show that the new model aligns closely with ground truth data under both normal and cyberattack conditions.

The study also explores how factors such as age, gender, driving experience, and trust in connected vehicle technology influence driver responses to cyberattacks. A critical aspect of the research is the identification of a scenario-based timestamp, which distinguishes proactive responses (taking timely action to mitigate risks) from reactive responses (reacting only after the event unfolds). The research emphasizes the importance of timely driver reactions to mitigate the impacts of cyberattacks on traffic safety.

This framework offers valuable insights for improving vehicular safety in environments vulnerable to cyber threats, paving the way for more resilient autonomous and connected vehicle systems.

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Sponsoring Committee	Standing Committee on Human Factors of Vehicles (ACH30)
Session Number	2231
Session Title	Human Factors of Vehicles: Road User Behavior
Paper Number	TRBAM-25-05365
Paper Title	**Exploring the Effectiveness of Connected Vehicle Technology in Enhancing Driver Behavior and Safety During Hurricane Evacuation**

Abstract

Connected vehicle (CV) technology has the potential to enhance driving safety, especially during evacuation scenarios, by providing real-time communication through vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I), and vehicle-to-everything (V2X) systems. While previous research has focused on numerical simulations, human factors in evacuation scenarios have often been overlooked. This study addresses this gap by assessing the impact of CV technology on driver behavior and safety during hurricane evacuations.

A driving simulator experiment was designed to simulate four critical evacuation scenarios—rain, congestion, blocked shoulder, and potential crash—under two conditions: with and without CV warnings. In the “with warning” condition, both text and audio alerts were provided, while the “without warning” condition had no such alerts. The results showed that over 87% of drivers complied with the warnings, slowing down in each event.

Factors influencing driver compliance included prior crash history and familiarity with CV technology. The study used generalized linear mixed models to analyze the data, revealing that warnings significantly improved safety metrics. Specifically, drivers in the “with warning” scenario had approximately 20% lower maximum speed, 16% lower maximum deceleration, 22% higher time-to-collision, and 14% lower standard deviation of acceleration/deceleration compared to those in the “without warning” scenario.

These findings highlight the effectiveness of CV technology in promoting safer driving behaviors during evacuations and provide insights for automotive manufacturers on designing safety features for connected and autonomous vehicles. The results suggest that advanced warning systems can play a crucial role in improving safety during emergency evacuations, benefiting both individual drivers and broader traffic management strategies.

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Sponsoring Committee Standing Committee on Human Factors of Vehicles (ACH30)

Session Number 2232

Session Title Human Factors of Vehicles: Connected and Automated Vehicles and Intelligent Systems

Paper Number TRBAM-25-01252

Paper Title **Time-Dependent Effect of Advanced Driver Assistance Systems on Driver Behavior Based on Connected Vehicle Data**

Abstract This paper introduces a novel functional data analysis (FDA) approach to better understand the time-dependent effects of advanced driver assistance systems (ADAS) on driver behavior. Existing aggregate measures used in studying driver behavior tend to overlook the temporal dynamics of how drivers respond to ADAS, and often compress important time-based data. The proposed FDA approach addresses this gap by utilizing functional representation methods to capture the underlying patterns in driver behavior in response to warning messages, while also handling irregularly spaced observations and measurement errors.

The study employs functional principal component analysis (FPCA) with the bootstrap-enhanced Kaiser-Guttman method to identify key patterns in driver response behaviors. Additionally, a nonparametric functional varying coefficient regression model is developed, which accounts for vehicle initial motions and drivers' acceleration styles. This model uses coefficient functions to estimate the time-dependent effects of ADAS on driver behavior.

The FDA approach is evaluated using a dataset from New York City connected vehicle records, specifically examining forward collision warning (FCW) event records. Results indicate that the effect of FCW is time-dependent, with initial increases in driver response followed by a progressive decrease over time. The study identifies distinct phases in driver responses, including reaction time (1.3 seconds), brake adjustment time (1.3 seconds), progressive braking duration (2.7 seconds), and effective treatment duration (4.0 seconds). Additionally, the time-dependent bootstrap confidence interval highlights significant driver heterogeneity across these phases.

This novel FDA approach offers a valuable method for quantifying the treatment effects of ADAS and can be applied to other ADAS applications as well. The findings contribute to improving ADAS design and developing more accurate driver behavior models that take ADAS into account.

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Sponsoring Committee Standing Committee on Human Factors of Vehicles (ACH30)

Session Number 2232

Session Title Human Factors of Vehicles: Connected and Automated Vehicles and Intelligent Systems

Paper Number TRBAM-25-02695

Paper Title **Safety Performance of Drivers in Connected and Automated Vehicles During Safety-Critical Events: A Networked Driving Simulation Study**

Abstract

This study investigates factors influencing driver safety performance in connected and automated vehicles (CAVs) during safety-critical events that require drivers to take over control. The research utilizes networked driving simulators, where two drivers interact within a synchronized virtual driving environment. The experiment intentionally creates safety-critical events, such as running red lights or stop signs at intersections and highway merging situations.

The drivers' safety performance during these events was assessed using post-encroachment time (PET), a surrogate safety measure that quantifies the time to potential collision. Logit models with participant-specific random effects were developed to explore the relationship between the presence of traffic conflict (as categorized by PET values) and several factors, including the presence of connected vehicle (CV) warnings, obstructions, automation level (Level 2 vs Level 3), traffic control (e.g., stop signs, traffic lights), and time of day (daytime vs nighttime).

The study's analysis showed that random effects logit models outperformed standard logit models in terms of model fit, with better performance based on AIC and BIC measures. The results indicated that CV warnings significantly reduced the likelihood of traffic conflicts, with a statistical significance of 0.064 for intersection scenarios and 0.073 for highway merging scenarios.

The findings highlight the importance of improving human-machine interactions within CAV systems to enhance safety during critical events. These insights are valuable for the future development of CAV technologies, especially in scenarios requiring driver intervention.

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Sponsoring Committee Standing Committee on Human Factors of Vehicles (ACH30)

Session Number 2232

Session Title Human Factors of Vehicles: Connected and Automated Vehicles and Intelligent Systems

Paper Number TRBAM-25-05787

Paper Title **Integrating Human Factors in Evaluating Safety and Operational Efficiency of Automated Vehicles: Insights for Global Robotaxi Services**

Abstract This research investigates how human factors influence the safety and efficiency of Automated Vehicles (AVs), considering various driving behaviors within automated environments. While there is significant anticipation that AVs will improve driving safety and efficiency, the involvement of human drivers remains crucial until full automation is achieved. Existing studies often focus on optimizing safety and efficiency through simulations, but they do not adequately consider human drivers’ participation in the process.

The study involved sixty participants who completed driving tasks on a simulator at different levels of automation (Levels 0, 2, 3, and 4). The research aimed to evaluate safety performance based on human driving behaviors, understand the distribution of traffic conflicts, uncover the reasons behind safety preferences for different automation levels, and explore the tradeoff between AV safety and operational efficiency.

The findings revealed that appropriate driving behaviors significantly enhance safety performance compared to inappropriate ones. Level 4 automation was the most preferred level by participants, mainly because it reduced traffic conflicts caused by human errors. To assess the balance between safety and efficiency, the study introduced a benefit-cost ratio, which compared safety with travel delay. The results showed that Level 2 automation had a significantly higher benefit-cost ratio than Levels 3 and 4.

This research provides valuable insights for AV specialists, helping them better understand how human factors influence AV safety and efficiency, particularly in environments with varying levels of automation. The study emphasizes the importance of integrating human behavior into the design and optimization of AV systems.

8 Real-Time Safety Prediction

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Studies related to real-time safety prediction aim to enhance traffic safety by identifying the real-time locations with high probability of crashes. The studies focus on predicting safety related parameters in real-time such as crash frequency, crash likelihood, and vehicle conflicts. The subcommittee identified **fifteen papers** that are related to real-time safety prediction. The papers are classified by the outcomes of the predictive models, data sources, and methodologies.

Considering the **outcomes of predictive models**, multiple papers explored various aspects of real-time crash likelihood and roadway safety prediction. Papers (25-02171, 25-01393, 25-05553) focused on predicting crash likelihood and conflict risks across different traffic conditions, emphasizing the importance of adapting models to specific roadway and segment types. Paper (25-02415) expanded the scope to intersection-level crash likelihood prediction, addressing challenges such as data imbalance and variability in traffic dynamics. Similarly, paper (25-04982) examined crash risk at the individual vehicle level, offering insights into the temporal progression of crash precursors and the role of vehicle motion patterns in predicting risk. Additionally, some studies leveraged innovative frameworks to address emerging safety challenges (25-04901, 25-00443). Paper (25-04901) applied Extreme Value Theory (EVT) to quantify crash probabilities using surrogate safety metrics, such as Time-to-Collision (TTC), providing a proactive approach to identifying high-potential scenarios. Meanwhile, paper (25-00443) utilized ensemble modeling techniques to prioritize driving safety indicators, integrating diverse methodologies to identify hazardous traffic conditions. Collectively, these studies demonstrate a comprehensive approach to crash likelihood prediction, highlighting the integration of advanced modeling techniques with real-time data to support proactive traffic safety management.

Some studies introduced **distinct data sources** into the real-time safety prediction. Specifically, papers (25-02797, 25-01152) utilized crowdsourced vehicle movement and UAV-based monitoring data to assess real-time traffic safety. Furthermore, papers (25-04901, 25-03318) relied on connected vehicle data, including INRIX speed segment data, to predict crash potential and identify hotspots. Moreover, paper (25-02405) combined Waze crowdsourced alerts with NJDOT crash data, improving incident detection accuracy in real-time scenarios. Extending to mixed traffic conditions, paper (25-03364) utilized rider-specific parameters such as acceleration and speed to quantify motorized two-wheeler risks, highlighting the diverse application of data sources in modern traffic safety research.

These studies also adopted various **methodologies** to enhance the accuracy and applicability of safety predictions. Machine learning and ensemble models dominated the landscape, with Random Forest and hybrid approaches with high predictive performance (25-05553, 25-01393). Paper (25-02415) shows the integration of deep learning techniques, combining Transformers and GANs to overcome data challenges. Meanwhile, paper (25-04901) introduced EVT to estimate crash probabilities based on surrogate safety metrics, offering a statistical perspective. In another effort, paper (25-00443) demonstrated the effectiveness of ensemble models by integrating SVM, ANN, and KNN for driving safety indicator prioritization, highlighting the importance of combining diverse methodologies for improved results.

Below, for each of the fifteen papers involving real-time safety prediction, the following information is provided: authors, sponsoring committee, session number, session title, paper number, paper title, and abstract.

Authors	Yunting Miao, University of Hong Kong Ling Wang, Tongji University Wanjing Ma, Tongji University Jiangping Zhou, University of Hong Kong
Sponsoring Committee	Standing Committee on Safety Performance and Analysis (ACS20)
Session Number	2206
Session Title	**Safety Performance and Analysis with Crash Predictions**
Paper Number	TRBAM-25-02280
Paper Title	**Two-level Real-time Prediction of Rear-end Conflict Risk Levels and Drivers' Longitudinal Evasive Styles on the Expressway**
Abstract	This study introduces an approach to understanding expressway rear-end conflicts by integrating driving style research with traffic safety. By proposing the concept of longitudinal evasive styles and using a two-level Nested Logit model, it offers a method to predict conflict risk and driver behavior. The findings are crucial for developing personalized Advanced Driver Assistance Systems (ADAS), allowing for tailored safety interventions based on individual driving styles. This research provides valuable insights for improving road safety and enhancing driver experience, with potential applications in broader traffic safety and ADAS development.

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Sponsoring Committee Standing Committee on Safety Performance and Analysis (ACS20)

Session Number 2206

Session Title **Safety Performance and Analysis with Crash Predictions**

Paper Number TRBAM-25-02171

Paper Title **Large-Scale Real-time Crash Prediction: A Comprehensive System and Analyses**

Abstract The rapid increase in traffic volume and complexity necessitates advanced real-time crash prediction systems to enhance road safety. This study introduces a comprehensive crash risk prediction system that integrates real-time traffic and weather data, using advanced machine learning techniques. The system features a modular architecture, including crash prediction, CCTV integration and user-friendly GUI modules, providing precise and timely predictions. Segment-specific models tailored to different segment types ensure accuracy and relevance. The system's performance was thoroughly evaluated, achieving high sensitivity and low false alarm rates. Specifically, the best model configuration achieved sensitivity improvements in the range of 0.839-0.918 and false alarm rate reductions to 0.073-0.208, depending on the segment type. The results demonstrate that the system can accurately predict crashes and provide timely warnings, enabling traffic operators to take preemptive actions such as adjusting traffic management systems, deploying emergency response teams, or providing real-time warnings to drivers. By predicting both the occurrence and severity of crashes, as well as the risk of secondary crashes, the system enhances the overall efficiency and effectiveness of traffic crash management. Continuous evaluation and adjustment of the system's parameters are essential to maintain its accuracy and reliability under changing traffic conditions. This comprehensive approach to crash prediction represents a significant advancement in proactive traffic management and road safety enhancement.

Authors Zhaoxiang He, University of Wisconsin, Madison
Xiao Qin, University of Wisconsin, Milwaukee

Sponsoring Committee Standing Committee on Safety Performance and Analysis (ACS20)

Session Number 2206

Session Title **Safety Performance and Analysis with Crash Predictions**

Paper Number TRBAM-25-04901

Paper Title **Applying Extreme Value Theory to Road Safety Evaluation using Safety Pilot Model Deployment (SPMD) Data**

Abstract The study's significance lies in its development of a proactive safety assessment framework that utilizes connected vehicle data and extreme value theory, overcoming persistent limitations in data availability and quality. The findings provide transportation agencies with a practical, data-driven tool that can estimate crash probabilities based on both infrastructure conditions and driver behavior, enabling more targeted safety interventions. As connected vehicle technology becomes more widespread, this methodology shows promising applications for real-time, personalized safety assessment and routing, aligning with the transportation industry's movement toward intelligent and connected infrastructure systems.

Authors	Jin Liu, Southeast University Hao Yu, Southeast University Pan Liu, Southeast University Xudong Ren, Southeast University Shuo Kong, Southeast University
Sponsoring Committee	Standing Committee on Safety Performance and Analysis (ACS20)
Session Number	2206
Session Title	**Safety Performance and Analysis with Crash Predictions**
Paper Number	TRBAM-25-04982
Paper Title	**Adopting Individual Vehicle Motion Patterns for Real-time Crash Risk Prediction Based on Empirical Vehicle Trajectories Prior to Crashes**
Abstract	In this study, we developed a real-world crash data collection framework, capturing precise vehicle trajectories prior to 68 rear-end crashes. On this basis, we used vehicle motion patterns and Bayesian logistic regression (BLR) model to conduct real-time crash risk prediction for individual vehicles. Six significant crash precursors have been noticed and analyzed. The early warning performance of the approach was also thoroughly investigated. The results indicate that the approach can reliably forecast crashes on average 2.0 seconds in advance. Additionally, a notable finding is that the 22 early warning models effectively reproduced the crash formation process by exhibiting distinct primary crash precursors at different early warning times.

Authors	Ritvik Chauhan, Indian Institute of Technology, Roorkee Ninad Gore, Ryerson University: Toronto Metropolitan University Said Easa, Ryerson University Shriniwas Arkatkar, Sardar Vallabhbhai National Institute of Technology, Surat Md. Mazharul Haque, Queensland University of Technology
Sponsoring Committee	Standing Committee on Safety Performance and Analysis (ACS20)
Session Number	2206
Session Title	**Safety Performance and Analysis with Crash Predictions**
Paper Number	TRBAM-25-05553
Paper Title	**Real-Time Conflict Risk Level Prediction Using Macroscopic Traffic Variables**
Abstract	This study addresses gaps in traffic safety assessment by introducing a scalable framework for real-time conflict prediction using macroscopic traffic variables. It is particularly suited for complex, non-lane-disciplined traffic in developing economies. Leveraging machine learning, the framework enables proactive safety evaluations and early risk detection, supporting improved traffic management and road design. Its practicality and adaptability make it a valuable contribution to safer road systems globally while advancing theoretical understanding of traffic conflicts.

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Sponsoring Committee	Standing Committee on Safety Performance and Analysis (ACS20)
Session Number	2206
Session Title	**Safety Performance and Analysis with Crash Predictions**
Paper Number	TRBAM-25-01393
Paper Title	**A Hybrid Model for Real-time Secondary Crash Likelihood Prediction Excluding Post Primary Crash Features**
Abstract	Secondary crash likelihood prediction is an important component of proactive traffic management to help mitigate congestion and adverse effects caused by secondary crashes. However, existing studies primarily relied on several post primary crash features (e.g., crash type and severity), which are not available in real-time. This limitation makes them impractical for real-world applications. To address such issue, we proposed a hybrid secondary crash prediction model excluding any post-crash features. First, a dynamic spatial-temporal window was designed to extract real-time traffic flow and environmental features. Among the hybrid models, a primary crash prediction model was trained to predict the likelihood of crash leading to secondary crash. Two models (1 and 2) were proposed to predict the secondary crash likelihood at the primary crash and its upstream segments. Model 1 assesses traffic status before secondary crashes against those at normal crashes without secondary crashes, while Model 2 compares the traffic status before secondary crashes with crash-free conditions. For the three models, an ensemble method of six machine learning models was developed to improve prediction accuracy. Finally, a voting- based strategy was utilized to combine three models' results to predict the final secondary crash likelihood. Experiments with Florida freeways show that the proposed hybrid model correctly identified 91% of secondary crashes with low FAR (0.19) without any post-crash features. The model AUC was improved from 0.65/0.74/0.90 of separate models to 0.95, even surpassing previous studies. The hybrid model has been implemented within a FDOT real-time traffic management system and works well across various freeways.

Authors	Abhijnan Maji, Indian Institute of Technology, Roorkee Apeksha Shah, Pandit Deendayal Energy University Indrajit Ghosh, Indian Institute of Technology, Roorkee
Sponsoring Committee	Standing Committee on Transportation Safety Management Systems (ACS10)
Session Number	2171
Session Title	**Decision Making with Safety Surrogates**
Paper Number	TRBAM-25-01152
Paper Title	**Development of a Driver Safety Reward System Incorporating YOLO-based Traffic Violation Detection at Roundabouts under Highly Heterogeneous Traffic**
Abstract	This research presents a novel Driver Safety Reward System (DSRS) integrating UAV-based traffic monitoring, vehicle detection and tracking using YOLOv8m and ByteTrack, and a MERN stack-based web platform to address traffic violations at roundabouts under heterogeneous conditions. By combining AI-driven detection, predictive analytics, and driving behavioral incentives, it offers innovative solutions for improving road safety. Its scalability and applicability to diverse traffic scenarios make it highly relevant for advancing Intelligent Transportation Systems (ITS) and proactive safety interventions.

Authors	Minsoo Oh, NRC Research Associate at FHWA Jing Dong-O'Brien, Iowa State University
Sponsoring Committee	Standing Committee on Transportation Safety Management Systems (ACS10)
Session Number	2171
Session Title	**Decision Making with Safety Surrogates**
Paper Number	TRBAM-25-03870
Paper Title	**Estimating Incident-Induced Delays Using Connected Vehicle Data with Machine Learning Algorithms**
Abstract	This study tackles the challenge of incomplete data in quantifying incident-induced delays (IID) by developing machine learning models using connected vehicle data from nearly 7,600 interstate crashes in Iowa. Achieving high accuracy with Random Forest and XGBoost models, the paper identifies key factors influencing IID, such as crash characteristics and roadway environment. This systematic approach enhances IID estimation and has significant potential for improving traffic management strategies and supporting real-time decision-making.

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Sponsoring Committee	Standing Committee on Safety Performance and Analysis (ACS20)
Session Number	2240
Session Title	**Safety Performance and Analysis for Safe Roads**
Paper Number	TRBAM-25-02415
Paper Title	**A Transformer-GAN framework for Advanced Crash Likelihood Prediction at Intersections**
Abstract	Intersections in major cities are often hotspots for road crashes, resulting in significant human casualties. We propose real-time crash likelihood prediction to proactively prevent these crashes and save lives. Existing algorithms are ineffective for predicting real-time crash likelihood at intersections, struggling with data imbalance and failing to address different crash types or provide granular cycle-level prediction. To address these gaps, we develop an anomaly detection framework integrating Generative Adversarial Networks (GANs) and Transformers to predict cycle-level crashes at intersections. Our framework achieves 76% sensitivity in predicting crash events using highly imbalanced real-world Signal Phasing and Timing (SPaT) and traffic data, highlighting its deployment potential in smart intersections. Key factors in predicting crash likelihood include yellow time, red clearance time for left-turning vehicles, and occupancy of through-moving vehicles during green. Overall, the results of this study offer a roadmap for city- wide application at smart intersections, enabling real-time solutions such as signal timing adjustments, driver warnings, and efficient emergency response, thus enhancing urban safety and livability.

Authors	Kirolos Haleem, Western Kentucky University Bharat Pathivada, Western Kentucky University Arunabha Banerjee, Western Kentucky University
Sponsoring Committee	Standing Committee on Safety Performance and Analysis (ACS20)
Session Number	2240
Session Title	**Safety Performance and Analysis for Safe Roads**
Paper Number	TRBAM-25-00049
Paper Title	**Crash Injury Severity Investigation along Interstate-64 in Kentucky**
Abstract	This study identified the factors affecting crash injury severity along Kentucky’s primary interstate, Interstate-64. The analysis used a myriad of microscopic real-time weather (air temperature, relative humidity, solar radiation, precipitation, and wind speed) and detailed traffic, roadway, environmental, driver-specific, and vehicle-related variables, as well as microscopic hourly traffic volume (extracted from automatic traffic recorder (ATR) loops) and hourly travel speed were used rather than applying the macroscopic annual average daily traffic. The study also used a rarely-explored real-time weather variable, solar radiation (in Watts/m2).

Authors	Sushmita Bhandari, University of Arizona Adrian Cottam, Auburn University Xi Zhang, University of Arizona Alyssa Ryan, University of Arizona Yao-Jan Wu, University of Arizona
Sponsoring Committee	Standing Committee on Transportation Safety Management Systems (ACS10)
Session Number	3039
Session Title	**Transportation Safety Management Systems from Start to Finish**
Paper Number	TRBAM-25-03318
Paper Title	**Integrating Crowdsourced Speed Data and Crash data for statewide Traffic Management and Road Safety Enhancement**
Abstract	The integration of crash data with speed segment data represents a pivotal advancement in the domains of traffic management and road safety. Current approaches often lack the real-time insight necessary to proactively address traffic issues and prevent crashes. Integrating these datasets addresses a significant knowledge gap, allowing for a more nuanced understanding of traffic patterns and crash causation. Crowdsourced real-time traffic flow and speed information offer the capability to identify congestion-prone areas and forecast potential crashes, presenting a transformative tool for traffic authorities. When integrated with crash data, this amalgamation provides unique insights into possible causes of crashes, facilitating the creation of effective preventative strategies. This research presents a comprehensive methodology for integrating crash data with Crowdsourced speed data from INRIX and utilizing crash data sourced from the Arizona Crash Information System (ACIS) database, which records crashes throughout the state of Arizona. The methodology outlined in this research encompasses the intricate process of integration and its practical application in the identification of crash hotspots. Additionally, it aids in pinpointing high-risk periods and regions necessitating countermeasures. The methodology presented serves as a valuable resource for traffic management and safety endeavors using real-time data. This research offers a critical roadmap for achieving efficient data integration and provides insights into how regions can record and harness real-time data for improved traffic management and road safety.

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Sponsoring Committee	Standing Committee on Transportation Safety Management Systems (ACS10)
Session Number	3039
Session Title	**Transportation Safety Management Systems from Start to Finish**
Paper Number	TRBAM-25-03364
Paper Title	**Development of Composite Risk Index (CORSI) to evaluate risky situations while MTWs decide whether to follow or filter**
Abstract	Since Motorized Two Wheelers (MTWs) are compact and highly maneuverable, they often show filtering behavior in mixed traffic conditions. However, owing to their low visibility and lack of physical protection, this behavior poses substantial risks. This study proposes the development of an index to quantify and evaluate the risks that the MTWs face when choosing whether to follow or filter through mixed traffic. Composite Risk Index (CORSI) is a normalized index ranging from 0 (safest interactions) to 1 (riskiest interactions) and is calculated using key parameters: Clear Lateral Gap (CLG), Relative Speed, Speed of MTW, and Acceleration of MTW. Each parameter is normalized between 0 and 1, and the weights assigned to them represent how much of an impact they have on risk. Based on CORSI values, the study uses the K-means clustering technique to classify 803 interactions into "Safe," "Moderately Risky," and "Risky" clusters. According to the data, younger riders, men, and non-helmet wearers are more likely to engage in dangerous exchanges, which also tend to involve filtering behavior and higher accelerations and speeds. Safer encounters are correlated with larger leader vehicles. This research contributes to better safety tactics by improving understanding of MTW behavior in urban mixed traffic and offering a strong tool for real-time risk assessment.

Authors	Xiao Zou, University of Alabama Jiayi Kong, University of Alabama Zihe Zhang, University of Alabama Jun Liu, University of Alabama Alex Hainen, University of Alabama Steven Jones, University of Alabama Asad Khattak, University of Tennessee, Knoxville
Sponsoring Committee	Standing Committee on Transportation Safety Management Systems (ACS10)
Session Number	3039
Session Title	**Transportation Safety Management Systems from Start to Finish**
Paper Number	TRBAM-25-02797
Paper Title	**Segment-Level and Intersection-Level Driving Volatility Analysis Using Large-Scale Crowdsourced Vehicle Movement Data**
Abstract	This study addresses the pressing need for real-time traffic safety measures by examining driving volatility as a predictive indicator of crash risk at both segment and intersection levels. With the increasing availability of connected vehicle data, driving volatility analysis can provide insights into safety performance and enable proactive interventions to improve road safety. These findings are especially relevant to TRB Meeting attendees interested in advanced traffic safety analysis and data-driven infrastructure planning.

Authors	Jeonghoon Jee, Hanyang University, Ansan Cheol Oh, Hanyang University
Sponsoring Committee	Standing Committee on Safety Performance and Analysis (ACS20)
Session Number	3147
Session Title	**Safety Performance and Analysis Using Machine Learning or Artificial Intelligence**
Paper Number	TRBAM-25-00443
Paper Title	**Ensemble-based Machine Learning Approach to Prioritize Driving Safety Indicators Using Connected Vehicle System Data for Proactive Safety Analytics**
Abstract	Driving safety indicators can quantitatively estimate crash potential, which enables proactive evaluations of traffic safety. Real-time traffic safety evaluation can contribute to crash prevention by identifying hazardous sections immediately. To implement an effective traffic safety evaluation model, selecting indicators that have a significant impact on identifying the presence of hazardous situations is necessary. The purpose of this study was to design a methodology for prioritizing driving safety indicators for effective safety evaluation. The outcome of this study is expected to be utilized as a valuable foundation for selecting indicators in safety evaluations for proactive traffic safety management.

Authors	Md Tufajjal Hossain, New Jersey Institute of Technology Joyoung Lee, New Jersey Institute of Technology Dejan Besenski, New Jersey Institute of Technology Lazar Spasovic, New Jersey Institute of Technology
Sponsoring Committee	Standing Committee on Regional Transportation Systems Management and Operations (ACP10) Standing Committee on Transportation Safety Management Systems (ACS10) Standing Committee on Traffic Law Enforcement (ACS30) Standing Committee on Disaster Response, Emergency Evacuations, and Business Continuity (AMR20)
Session Number	4081
Session Title	**Advancements in Emergency Response, Incident Management, and Post-Crash Care: Innovative Approaches to Enhancing First Responder Safety and Efficiency**
Paper Number	TRBAM-25-02405
Paper Title	**Real-Time Incident Detection Through Predictive Modeling of Crowdsourced Waze Data**
Abstract	Effective incident detection is essential for emergency response and transportation management. Traditional methods relying on stationary technologies are often costly and provide limited coverage, prompting the exploration of crowdsourced data such as Waze. While Waze offers extensive coverage, its data can be unverified and unreliable. This study aims to identify factors affecting the reliability of Waze alerts and develop a predictive model to distinguish true incidents from false alerts using real-time Waze data, thereby improving emergency response times. Real crash data from the New Jersey Department of Transportation (NJDOT) and crowdsourced data from Waze were matched using the DBSCAN algorithm to differentiate true and false alerts. A binary logit model was constructed to reveal significant predictors such as time categories around peak hours, road type, report ratings, and crash type. Findings indicate that the likelihood of accurate Waze alerts increases during peak hours, on streets, and with higher report ratings and major crashes. Moreover, two predictive models based on the XGBoost algorithm were developed: one using significant factors and the other incorporating all attributes. The model based on significant factors achieved an accuracy of 86.23%, while the model with all factors had an accuracy of 86.10%. Despite minimal differences in performance metrics, the significant factors model is computationally more efficient and suitable for real-time applications. The findings underscore the importance of user engagement and contextual factors in improving the reliability of crowdsourced traffic alerts, offering valuable insights for real-time traffic management and emergency response systems.

9 Safety Effects of Connected and Automated Vehicles

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Connected and Automated Vehicles (CAVs) are considered the future of transportation, bringing several benefits to traffic operations. One of the most outstanding improvements addressed by the CAVs is related to safety. This statement is based on the possibility that vehicles can interact among them in real-time preventing dangerous situations, but also because they will not rely on unpredictable human behavior, but only on rule-based algorithms and sensors, that will react instantaneously and in a predetermined and precise way to external inputs.

The increasing importance of CAVs and their impact on safety is highlighted by dedicated workshops, not only papers, during the TRB Annual Meeting 2025. An example is the "**Integrating Highly Automated Vehicles into Traffic in Cities and on Highways: A Safety-Centric Conversation"** sponsored by ACP30, ACP15, ACP20, ACP50, ACP80, dealing with the safety concerns and perspectives of AVs in urban and rural areas, looking at regulation issues, vision zero, best practices and case studies, and benchmarking. Another important aspect is educating users on automated technologies to reach adequate safety levels ("**Vehicle User Education, Training, and Licensing Committee**" sponsored by ACH60). On the regulatory side, it is debated the path to pursue when dealing with CAVs. Therefore, new perspectives from all over the world are investigated: "**International Perspectives on the Regulatory Challenges of Remote Automated Vehicle Operations**" sponsored by ACP30, A0020C, and ACP15 deals with this topic, looking at French, German, Industry, California, European and US Motor Vehicle Administrators' perspectives (Lectern session 2169). The possible impacts on safety that CAVs can exhibit on freight and truck travels have been thoroughly investigated by the AED70 committee, which dedicated a Lectern session (3007) "**Autonomous and Connected Trucks: Opportunities, Challenges, and Implications for Freight Data Generation"** to the general topic of CAVs with trucks, remarkably tackling safety. The "**Vehicle-Highway Automation Committee" by ACP30,** dedicated its purpose to the analysis of the impacts of automation on roads, also from a safety perspective. The analysis of safety is also investigated focusing on human factors. This is the main aim of the "**Human Factors of Road Vehicle**

Automation, ACH30(1), Joint Subcommittee of ACH30, ACH40" sponsored by ACH30 and ACH40 committees.

During the "**Doctoral Student Research in Transportation Safety: A Lectern-Poster Session"** sponsored by ACS20 and AED60 committees the importance of safety with CAVs was investigated. Raghupathi Kandiboina from Iowa State University proposed a thesis **"Enhancing Transportation Safety with Connected Vehicle Data: Frameworks for Real-Time Crash Detection and Stop Sign Safety Monitoring".** The focus on crash severity and issues with CAVs was investigated by two other researchers in the context of this panel: "**Comprehensive Analytics of Automated Vehicles' Effectiveness, Benefits, and Crash Severity",** by Shengxuan Ding, University of Central Florida; **"Modeling Risk Perception, Developing Risk Perception-Integrated Car Following Models, and Analyzing Control Transition in Semi-Automated Vehicles Using Machine Learning and Deep Learning Techniques: A Driving Simulator Approach"** by Saumil Sakib Bin Masud, University of Kansas.

CAVs are seen as a crucial part of the future safety system by achieving the potential of Vehicle-to-everything technology that can enhance the number of saved lives. This topic will be discussed in the Lectern Session 2035 (Executive Committee E0000) "**Department of Transportation Leadership in Innovation: Saving Lives with Connectivity: Achieving the Potential of Vehicle-to-Everything Technology**" by P25-21195.

The subcommittee identified **77 papers** related to the Safety Effects of Connected and Automated Vehicles. These papers are sponsored by different committees, as follows:

- The AKD10 Committee sponsored 1 paper out of 77
- The ACP15 Committee sponsored 2 papers out of 77
- The ACP50 Committee sponsored 2 papers out of 77
- The ACH60 Committee sponsored 2 papers out of 77
- The ACS10 Committee sponsored 2 papers out of 77
- The AMR40 Committee sponsored 3 papers out of 77
- The ACP30 Committee sponsored 15 papers out of 77
- The ACS20 Committee sponsored 24 papers out of 77
- The ACH30 Committee sponsored 26 papers out of 77.

These papers can be clustered according to their main topics. By making this analysis 6 macro groups were identified, as follows:

1. **Human factors related to CAVs (17 papers).**
2. **Trust and acceptance of CAVs and their systems (9 papers).**
3. **Education and training for CAVs and their systems (3 papers).**
4. **CAVs and cybersecurity concerns (4 papers).**

5. **Trajectory analysis and model development for safety enhancement of CAV scenarios (23 papers).**
6. **Crash dataset analysis and vulnerable road section identifications with CAVs (21 papers).**

Human factors related to the safety of CAVs

Different studies that investigated human factors in the context of the safety of Connected and Automated Vehicles (CAVs) were conducted.

Several of them were related to the critical phase of the takeover request. Based on the simulation of takeovers coupled with measures of eye movements, different patterns were revealed, which may help in updating the understating of drivers' cognitive transition process, also through visual metrics **(25-01170)**. The same aspect of takeovers differentiated into mandatory (triggered by alerts) and discretionary (initiated by the drivers) takeovers, was explored in terms of cognitive workload and driving stability **(25-01081)**. Moreover, fog may alter the functioning of Level 3 automated vehicles, and particularly the brain activation of human drivers in case of critical takeovers, as found in a simulator-based study, in which foggy scenarios were recreated **(25-00695)**. Three different take-over control mechanisms were studied (steering wheel, pedals, and button) revealing differences depending on the maneuver (lane-change in this case) and gender **(25-01801)**. Driving characteristics, observed also through vehicle kinematic data, were linked to takeover behaviors, crash events, and self-reported traits, based on a driving simulator experiment (and self-reported data) in which different L2 automation scenarios with warning and critical events were recreated **(25-03522)**.

Another frequently investigated topic concerns the effect of in-vehicle warnings. Based on a driving simulator study in different hurricane evacuation scenarios, the behavior of drivers may be improved, in terms of reduced speed, deceleration, and time to collision in emergencies in case of warnings sent through CAV technology **(25-05365)**. A simulator-based study conducted in a scenario that recreated safety-critical events revealed that traffic conflicts (based on the post-encroachment time) could be reduced thanks to connected vehicle warnings, considering also other factors **(25-02695).** Different types of warnings in CAVs (auditory, visual, bimodal) may produce different reactions in drivers, such as revealed by a driving simulator study, which particularly found that visual and bimodal warnings may lead drivers to focus more on CAV warnings than on the road **(25-05571)**. Lane departure warning systems may have positive effects on driver behavior who are distracted (such as in conversations with passengers or phone calls), as revealed by a study conducted in a controlled road environment **(25-05848)**. Some other studies were focused on the study of real-world interactions between human-driven vehicles and automated vehicles, studying in particular the aggressiveness of interactions and reactions which may depend on both driving styles **(25-03658)**. Moreover, differences between the behavior of human drivers and AV behavior were highlighted based on a naturalistic mixed traffic study that used real-world data from Phoenix, Arizona (USA) **(25-05831)**. AV conflicts in intersections in mixed traffic conditions were studied utilizing different data analysis techniques, showing in particular that AVs have safer interactions with other road users (other human drivers, vulnerable road users) and safer unprotected left turns concerning traditional vehicles **(25-03357)**. A novel merging decision framework using reinforcement learning algorithms was proposed, which tried to

distribute equitably risks among the involved vehicles (i.e., overcoming the usual algorithms that focus on the safety of AVs, not considering risks posed to other vehicles) **(25-02092)**.
Other studies which are not grouped into particular classes are briefly described as follows. The effect of ADAS may not be constant in time, as based on the analysis of FCW (forward collision warning) data from the New York City connected vehicle dataset **(25-01252)**. The activation of L2 automation can be related to more distraction in drivers, as revealed by a study based on naturalistic driving data, in which L2 driving was associated with longer eyes-off-road time and off-road glances **(25-01383)**. The issue of pedestrian crossing safety in blind spot scenarios was analyzed by employing virtual reality and, in particular, using external human-machine interfaces (eHMIs) **(25-01566)**. Factors influencing the performance of humans in private cars with conditional automation and of remote operators who support AV fleets for passenger transport were studied, from the perspective of Performance Shaping Factors **(25-02326)**.

Trust and acceptance of CAVs and their systems
Several articles were focused on the trust and acceptance of CAVs and their specific systems. The effect of trust, driving mode (manual/automated), and non-driving related tasks on drivers' mental workload was studied in a naturalistic driving experiment, coupled with a questionnaire: low-trust drivers were found to have higher mental workload during automated driving, while automated driving was found to reduce mental workload for high-trust drivers **(25-03362)**. The possibility that AVs may apologize after a mistake made (e.g., misidentifying road elements) was found to negatively influence trust repair, fostering concerns about the capabilities of AVs, based on online videos with different scenarios submitted to a sample of drivers **(25-03472)**. Based on driving simulation scenarios, in which different types of errors and drivers' expectations were mixed to study their effects on trust, it was found that initial expectations do not influence trust while performances of the system do (in particular, "inconsistent" errors) **(25-01231)**. Another study was dedicated to the relationship between warning system uncertainty and trust, still based on a driving simulator study **(25-04121)**. The relationship between AV vehicle-related factors (reliability, dynamics/accuracy of AV self-assessed confidence information, number of AV-driver interactions) and trust was also studied **(25-01205)**. A study on the perceived safety and trust in the choice of fully automated taxis (ATs) versus normal taxis (NTs) confirmed that perceived vehicle and personal safety have positive effects on trust, which translates into positive effects on choosing ATs. However, the AT behavioral models may show differences between one region to another (i.e., in this case, different results between Newcastle and Toronto) **(25-06248).** Based on data collected from low-interference devices, the identification of over-trust was modeled in real-time, to avoid having negative impacts in case of prompt take-over requests **(25-06190).** After the simulation of different AV levels, drivers evaluated those scenarios preferring, in most cases, Level 4. However, after conducting a benefit-cost ratio analysis between safety and travel delay, Level 2 was found to lead to the highest ratio than Levels 3 and 4 **(25-05787)**. Finally, it was highlighted that the acceptance of ADAS depends on drivers' age, particularly differentiating between older drivers (60+) and young and middle-aged drivers **(25-00527)**.

Education and training for CAVs and their systems

In some articles, a particular focus was dedicated to education and training for CAVs and their systems. In fact, education and training are important also for understanding and using the ADAS systems, as inquired in a study based on surveys and interviews **(25-02383)**. However, ADAS may be difficult to interpret, and specific training, as well as user-friendly interfaces, may be important for senior drivers **(25-04314)**. Moreover, results from the application of the Driver Behavior Questionnaire (DBQ) may vary from one country to another, as revealed by a study in which the behavioral structure of Indian drivers was inquired, suggesting implications for training and monitoring systems **(25-06251)**.

CAVs and cybersecurity concerns

The safety of CAV travel is endangered by cyberattacks. In this optic, talking about cybersecurity and providing secure operations of CAVs becomes essential to have a safe deployment of CAVs on roads. Unprotected CAVS will face serious issues and crashes under cyberattacks. Therefore, security strategies need to be developed to improve the safety and efficiency of CAVs under cyberattacks **(25-05059)**. An adversarial training for safe operations in complex traffic environments was developed to proactively defend CAVs against malicious attacks. The Vulnerability-aware and Curiosity-driven Adversarial Training (VCAT) framework enhanced the robust control capabilities of the system providing a marked crash reduction **(25-01085)**. Another defense from cyberattacks was developed by a robust design for the online routing of CAVs. The proposed design resists cyberattacks accurately predicting traffic and trajectories and outperforms traditional designs in the absence of attacks. This behavior is ensured by the fact that the design is independent of the detailed knowledge of specific attack models, so it performs well in any conditions, increasing the system's safety **(25-00121)**. Not only fully automated CAVs will face cyberattack issues, but also human-driven Connected Vehicles, that are vulnerable too. A strategy for mitigating cyberattacks, with trajectory-based forecasting and warning systems, can protect against cyberattacks **(25-05011)**.

Trajectory analysis and model development for safety enhancement of CAV scenarios

In the era of CAVs, two different approaches have been pursued, one focusing on the improvement of trajectories and models for safety and efficient CAV operations and the other highlighting the chance of relying on remote operations to improve ambiguous operations. Starting from the latter, considering that from July 2021 to May 2022 the NHTSA reported 130 crashes involving CAVs and ADAS-equipped vehicles (braking, bike and pedestrian hits, wrong side of the road collisions), the remote operation was thought as a safer alternative to manage risky situations. However, the latency of remote operations for speed selection, gap acceptance, and lateral positioning is still a concern. It was found that 100-200 milliseconds of latency are acceptable for safe operations. More than 300 ms of latency induces critical situations **(25-04559)**.

Looking at the first aspect, CAVs are challenged in their interaction with non-motorized vehicles, too. Not only interacting with human-driven ones. Thus, a trajectory planning method for CAV travels has been developed for safer conflict scenarios including non-motorized vehicles **(25-05513)**. Also jaywalking, so the interaction with aggressive pedestrians only is possibly dangerous. A risk-aware deep reinforcement learning (DRL) approach was developed to make decisions for CAVs in jaywalking situations. Three escalating jaywalking scenarios were tested highlighting that the proposed model helped to perceive potential risks in advance, increasing safety **(25-00372)**. It is immediate that the mixed traffic conditions in the presence of CAVs are extremely dangerous from a road safety perspective. CAV control strategies should incorporate the presence of Human-driven Vehicles (HVs) to enhance safety levels **(25-01396)**. Dilemma Zones, such as the signalized intersections, can be perfectly managed by CAVs reducing the potential conflicts **(25-05696)**. In urban traffic scenarios, in Korea, the impact of CAVs was investigated by using a real dataset and calculating a parameter to assess CAV safety: automated driving risk score (ADRS). Frequent interactions of CAVs with regular vehicles were associated with high ADRS, degrading the safety performance of roads **(25-00446)**. Also, a simulation-based study in Dublin was run to understand what the most suitable road layout for mixed traffic conditions is. Dedicated AV lanes did not improve the safety conditions, but the roundabouts and narrow lanes drastically improved safety, as a great CAV penetration rate **(25-00447)**. The existing safety assessment methods are not considered adequate for mixed and complex traffic scenarios. Therefore, a new Safety Surrogate Measure (SSM) for investigating mixed traffic situations was developed: the Weighted combination of Spacing and Speed Difference Rate (WS2DR). This SSM was found to outperform the traditional SSMs. Moreover, mixed traffic scenarios can be safer by increasing the CAV penetration rates **(25-01579)**. Other new SSMs have been proposed. For instance, the Time To Collision, TTC, was not considered accurate for CAVs as it has been for Human-driven vehicles. For this reason, a Trajectory-based TTC supported by CAV info was tested, considering actual vehicle movements and vehicle profile. In several scenarios, including overtaking, car-following, and non-conflict interactions, the Trajectory-based TTC performed better than the TTC, confirming the initial assumptions **(25-03024)**. An investigation of the TTC under different vehicle scenarios highlighted that the car-following TTC of CAVs was 0.95 for freeways and 1.05 for arterials **(25-04100)**. Also investigating the traditional models provided by the Highway Safety Manual for crash predictions, it is evident that CAVs are neglected. Therefore, alternative models have been developed and proposed for mixed traffic conditions. They perform better than the classical ones in mixed traffic conditions, according to the investigated facilities **(25-03192)**.

However, in truck platooning, the traditional TTC was used for investigating lane-changing scenarios on two-lane rural roads. The analysis accounted for other variables, such as the gender, age, and education level of the drivers. The proposed model relying on TTC outperformed existing ones and highlighted that older drivers are safer in the lane-changing approach in platoons **(25-00302)**. Platoons with HVs and CAVs can be made safe by using specific operational frameworks. In this optic, a Physics Enhanced Residual Policy Learning (REPRL) framework was developed. Its performance was found extremely positive in creating safety platooning operations **(25-03972)**.

Apart from specific frameworks and algorithms, it was found that by increasing the presence of CAVs on roads, safety is positively affected. From simulation-based studies in the Netherlands, the improvement of safety conditions increasing the dominance of CAVs was assessed **(25-06028).** This statement can also be assessed also looking at just Level 2 (L2) vehicles. The L2 vehicles are more reactive than predictive but intervening on the anticipation of sensors can drastically improve safety. Thus, anticipation and predictive sensors and algorithms in L2 vehicles will be key factors, also for the fully automated vehicle deployment **(25-04120)**. Despite this premise, the current presence of ADAS on vehicles in different combinations can already enhance safety. For example, the Automated Emergency Braking (AEB) was found to reduce crash occurrence. Its positive effects are more than double if compared to simple warning systems installed on vehicles **(25-02120)**.

Looking in detail at the safety concerns of CAVs, of course, the car-following and lane-changing trajectories represent a big deal for the safety and efficiency of traffic flows. For instance, tailgating impacts on rear-end crashes. Hence, a Tailgating Behavior Management (TBM) system was proposed for Connected Vehicles (CVs) to mitigate rear-end crash occurrence (reduced by more than 50%). Increasing the number of CVs traveling, the TBM system can perform better **(25-04150)**. Another model has been proposed for the car following. The model is a novel behaviorally dynamic car-following, called DynFollower, that leverages Deep Reinforcement Learning (DRL) to address the challenges of car-following in complex traffic scenarios with CAVs. Relying on large-scale-real-world datasets, the DynFollower outperforms all traditional models for safety and efficiency **(25-01039).** Looking at the car-following, the Modular Autonomous Vehicles (MAVs) were found to be safer thanks to a proposed distributed method for managing the car-following. This method was consistent in uncertain environments and for all the operations, as simulations and real-world tests highlighted **(25-05605)**. The efficiency and safety of CAVs can be achieved by trajectory predictions and motion planning combining car-following and lane-changing. In complex environments, this twofold approach was pursued by using long-term trajectory prediction of HVs as a base for the planning strategy. The proposed approach showed accurate and precise performance **(25-04622)**. Another trajectory planning strategy was proposed using crash-trajectories and a risk-trajectory algorithm. The results, also in this case, were promising **(25-04890)**.

Analyzing the lane-changing, always a risk-responsive reinforcement learning framework was proposed. This model outperformed existing algorithms in different traffic density levels **(25-00139).** More complex becomes the situation when CAVs are mixed with HVs. Lane-changing can perform well with a proactive CAV control strategy. In this case, as emerged from 72 driving simulations, the mixed traffic lane-changing was better than HVs-only maneuvers **(25-02598)**.

Crash dataset analysis and vulnerable road section identifications with CAVs
Relying on existing available crash datasets for CAVs, it is possible to make predictions, plan, and think about countermeasures for a safe massive deployment of CAVS on roads. One first attempt was done investigating the crash data from NHTSA (2021-2024) to understand the factors influencing crashes. ADAS-equipped vehicles were found to be associated with the severity outcome **(25-02183).** By analyzing CAV crash records from the California Department of Motor Vehicles (20218-2024) emerged that light conditions braking maneuvers, proceeding movements of HVs, involvement of bikes/scooters, and residential land use are crash contributing factors for CAVs **(25-01258)**. The same dataset over the same period (2018-2024) identified 641 collisions of CAVs in California. Several machine-learning technologies were used to investigate these crashes. Logistic regression and Support Vector Machines were found to be the best to recreate crashes and predict them **(25-03219)**. From CAV crashes that occurred in open road testing, 24 pre-crash scenario types correlated to rear-end, and intersection scenarios were identified with a 98.1% accuracy. Light conditions and driver violations are the main factors recurrent for pre-crash. These results can be useful to guide stakeholders towards CAV operations and regulations **(25-06320)**.

Using hardware equipped in navigation systems of vehicles can be a solution for getting vehicle fleet size and different motion data from multiple countries. This data can be used for the development of an accident detection system that becomes robust for traffic impairment immediately after an accident, to prevent secondary crashes and dangerous situations **(25-00827)**. In case of limited crash data available, safety-critical scenarios for CAV testing were deployed, enhancing the performance of the systems **(25-00906)**. Limited sample sizes of driving states can be detrimental to making accurate predictions of dangerous driving areas. However, using the Markov chain theory the CAV dangerous states were predicted accurately just using 0.03% of the sample size of all the driving states. This result helped identify the benefits of such models in case of reduced availability of data **(25-05379)**.

From available crash datasets, an insight into the effects of ADS and ADAS was obtained by looking at different aspects. L2 and L1 vehicles are more prone to be involved in rear-end crashes. Therefore, a rear-end crash dataset from 2017 to 2022 was investigated to get the impact of AEB in reducing this typology of crashes. It emerged that 86% of crashes were prevented by AEB even if the AEB performance should still be optimized for vehicle speed and dimensions, as well as the deceleration rate and the late activation, should be fixed. These results can help in improving the AEB performance for safety purposes **(25-01653).** Rear-end crashes can be managed by an AV sensor conflict detection framework at the network level, improving the performance and safety of the entire system **(25-05082)**. On the other hand, comparing L4 (Automated Driving Systems, ADS) vehicles with L2 vehicles from 1500 crashes, the impact of mileage, weather, and manufacturing of vehicles emerged to be crucial factors for severity outcomes **(25-02341)**. Therefore, a focus on ADS was due. In this optic, two different conditions were investigated: remote operations and no driver in critical situations to manage. The critical situations were intersections, adverse weather, and pre-crash speeds. Remote driving was associated with an 18.3% increase in injury risks and the absence of a driver with a 23.3% increase in risks. These results can represent the background for improving the ADS systems under critical situations **(25-03517).** Comparing general driving data with L4 data can provide a proxy for future L4 operations and help to plan training and requirements for adequate and safe L4 deployment **(25-04163)**. Other solutions for improving ADS deployment are to make them more equitable and think about evermore effective ADAS. In trying to maximize the benefits of CAVs with equity of their distribution, a tool for policymakers for equitable CAV strategies for safety was developed **(25-04566)**. Looking at the ADAS, they influence crash severity, as highlighted not only from previous studies but also from an investigation of the Queensland crash dataset (2015-2022). Improving vehicle design will benefit the ADAS responses and the sensor performance **(25-05004)**. The same dataset, from 2022 over was used to assess the importance of AEB in reducing crash likelihood and severity **(25-06397)**. An analysis of the crash dataset 2017-2022 in Ohio highlighted that ADAS-equipped vehicles reduce rural road fatalities due to sideswiping **(25-05769)**.

Integrating crash reports with real-world CAV trajectory data can help identify vulnerable road sections and provide valuable countermeasures for mixed traffic scenarios **(25-06120)**. A similar approach was used in **(25-06076)**: on Shanghai expressways, driving and trajectory data were collected from CAVs. These inputs were used to develop real-time high-risk location identification. Another approach to obtain the same output was to rely on Hard braking events. These events were used as a surrogate measure for networking screening including all crashes, rear-end crashes, no-injury crashes, and severe crashes. The proposed approach by **(25-05230)** was extremely suitable for rear-end crash detections (96.83% accuracy) and for all crashes (86.25% accuracy). Also investigating intersections, it is possible to make crash occurrence predictions within the next 15 minutes by relying on CAV data by an intersection-transformer framework **(25-02400)**.

Below, for each of the **77 papers** involving safety effects of connected and automated vehicles, the following information is provided: authors, sponsoring committee, session number, session title, paper number, paper title, and abstract.

Authors	Noah Rothermel, University of Connecticut Oluwaseun Olufowobi, University of Connecticut Paul (Young Joun) Ha, University of Connecticut Niloufar Shirani, University of Connecticut Eric Jackson, Connecticut Transportation Institute
Sponsoring Committee	ACH60
Session Number	Lectern Session 2060
Session Title	**Impact of Individuals, Family, Community, and Technology on Driving Safety and Training: A Lectern-Poster Session**
Paper Number	25-04314
Paper Title	**Enhancing Safety and Mobility with Advanced Driver Assistance Systems (ADAS) for Senior Drivers: A Review**
Abstract	As the global population ages, ensuring the safety of senior drivers is increasingly important. This paper reviews the impact of Advanced Driver Assistance Systems (ADAS) on enhancing driving safety for older adults, who face greater crash risks due to cognitive, sensory, and motor declines. Technologies like Forward Collision Warning (FCW) and Automatic Emergency Braking (AEB) have shown potential in reducing crash rates—FCW by up to 27% for front-to-rear collisions and AEB notably decreasing rear-end crashes. However, their effectiveness for older drivers remains underexplored. Challenges such as unfamiliarity with ADAS and inadequate system design for older users hinder their adoption. To improve ADAS benefits for seniors, this paper emphasizes the need for user-friendly interfaces, comprehensive training, and further research to tailor these systems to the specific needs of older drivers.

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Sponsoring Committee	ACH60
Session Number	Lectern Session 2060
Session Title	**Impact of Individuals, Family, Community, and Technology on Driving Safety and Training: A Lectern-Poster Session**
Paper Number	25-02383
Paper Title	**Future of Road Safety for Teen Drivers: A Qualitative Interview and Survey Study on Driver Education and ADAS Training**
Introduction	Teen drivers' elevated risk has been attributed to the absence of proper training and the inherent lack of experience on the road [3]. Additionally, Advanced Driving Assistance Systems (ADAS) are increasingly common in vehicles: 92 percent of new cars have adaptive cruise control [1]. As the interactions between teen drivers and ADAS technologies are emerging, understanding the efficacy of education and training on teen drivers is increasingly valuable. The objective of this research is to better understand: (1) the effectiveness of driver education; and (2) how education and training can improve the understanding and use of ADAS. Through interviews and surveys, the research will examine the role of the driver education framework, including ADAS centric training, and will identify opportunities to improve driver education programs.

Authors	Minghui Wu, University of Michigan Yafeng Yin, University of Michigan Jerome Lynch, Duke University
Sponsoring Committee	AMR40
Session Number	Poster Session 2222
Session Title	**Connected and Automated Vehicles: Cybersecurity and Threat Detection**
Paper Number	25-00121
Paper Title	**Online Routing for a Connected Vehicle Against Stealthy Cyberattacks**
Abstract	This paper introduces a novel online learning algorithm that enables a connected vehicle to recursively leverage real-time traffic predictions from a service provider to make informed routing decisions. Designed to be robust against received prediction, the algorithm withstands both natural noises and malicious errors. The proposed algorithm decomposes decision-making among different nodes, where each node executes an individual sub-algorithm that considers both immediate and long-term effects on the routing process. We theoretically establish a sub-linear regret bound for the algorithm, providing a guarantee on the worst-case performance. Numerical validation using real-world data demonstrates that our algorithm not only consistently resists cyberattacks but also outperforms traditional benchmarks in the absence of attacks. Unlike traditional defense strategies that require detailed knowledge of specific attack models, our approach operates independently of these elements, contributing to a reliable and safe transportation system.

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Sponsoring Committee	AMR40
Session Number	Poster Session 2222
Session Title	**Connected and Automated Vehicles: Cybersecurity and Threat Detection**
Paper Number	25-01085
Paper Title	**VCAT: Vulnerability-Aware and Curiosity-Driving Adversarial Training for Autonomous Vehicle**
Abstract	Autonomous vehicles (AVs) face significant threats to their safe operation in complex traffic environments. Adversarial training has emerged as an effective method for AVs to proactively learn to defend against malicious attacks. The dual processes of attack and defense training are crucial steps in enhancing the robustness of AVs. However, attackers in existing methodologies often get stuck in a loop of over exploiting known vulnerabilities. To overcome the limitations of current research, we propose a **V**ulnerability-aware and **C**uriosity-driven **A**dversarial **T**raining (VCAT) framework. Specifically, during the traffic vehicle attacker training phase, a surrogate network is employed to fit the value function of the AV victim, providing dense information about the victim's inherent vulnerabilities. Subsequently, random network distillation is used to characterize the novelty of the environment, constructing an intrinsic reward to guide the attacker in exploring uncharted territories. In the victim defense training phase, the attacker is positioned around the victim in various scenarios to generate safety-critical attack behaviors. Experimental results reveal that the training methodology provided by VCAT significantly enhances the robust control capabilities of learning-based AVs compared to universal training and other reinforcement learning approaches, with a marked reduction in crash rates.

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Sponsoring Committee	AMR40
Session Number	Poster Session 2222
Session Title	**Connected and Automated Vehicles: Cybersecurity and Threat Detection**
Paper Number	25-05011
Paper Title	**Safety Warning System for Connected Vehicles Under Spoofing Cyberattacks at a Connected Signalized Intersection: A Deep Learning-based Approach**
Abstract	As vehicles increasingly integrate with infrastructure and other vehicles, the risk of cyberattacks is escalating significantly. Existing research mainly focuses on the threats within the environments of connected autonomous vehicles (CAVs). However, connected vehicles (CVs) that are driven by humans are also vulnerable to the spoofing attacks. The trajectory of CVs under cyberattacks has not been comprehensively explored due to the challenges associated with collection. Besides, existing research primarily focuses on the countermeasures for detecting cyberattacks but lacks the strategies to be taken after a cyberattack has occurred. In this study, we propose a Cyberattack Trajectory-based Forecasting and Warning System (Cyber-TFWS) that demonstrates effective perception, prediction, judgement and warning capabilities under cyberattacks to enhance the safety against spoofing attacks. We introduce a research framework for effectively collecting the trajectories of human-driven CVs under cyberattacks and the trajectories were processed by an unsupervised k -Medoids algorithm. Then, we propose a novel generative-based algorithm named CAGAN integrating into the prediction module of Cyber-TFWS. The results indicate the proposed system successfully issued the warning actions to the specific drivers and prevented 100% of red-light running behaviors and also significantly enhanced the safety when attacks happen. The proposed system has the potential to be incorporated with CV applications and can benefit governs or police markers in developing the cyberattack protection system.

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Sponsoring Committee	ACH30
Session Number	Poster Session 2231
Session Title	**Human Factors of Vehicles: Road User Behavior**
Paper Number	25-03658
Paper Title	**Mitigating Aggressive Driving in Mixed Traffic: The Role of Driving Styles of Automated Vehicles and Human-Driven Vehicles**
Introduction	The simultaneous presence of AVs and HVs forms a mixed-autonomy traffic environment, leading to new challenges for road safety (1,2). Specifically, AVs must adapt to the presence of HVs, whereas human drivers need to understand how to interact with AVs. However, AVs are currently configured with defensive driving styles that prioritize road safety (3,4), which renders them vulnerable to exploitation by human drivers in mixed traffic (5). Moreover, the defensive driving style of AVs prevents them from adjusting to the diverse driving styles of HV drivers in real traffic (8,9). These issues emphasize the immediate necessity to develop strategies to mitigate HV drivers' aggressive behaviors toward AVs and enhance overall traffic safety. Empirical studies on HV-AV interaction have primarily evaluated HV drivers' decision-making in mixed traffic, compared to interactions with HVs in conventional traffic (6,7, 16-18). Most research suggests that human drivers are likely to exploit the defensive driving behavior of Avs more than they do with HVs (13,14), and this tendency may even lead to HV drivers' aggression toward AVs (15,6). However, HV drivers with different driving styles may exhibit varied driving behaviors when interacting with defensive AVs on the road, given the effect of their driving style on decision-making in driver-AV interaction (6,7,13,20). It is still unclear how the interaction effects of AVs' driving styles and HV drivers' driving styles influence HV drivers' decision making in mixed traffic (11, 12). This study aims to investigate how the AVs' driving styles and HV drivers' driving styles influence HV drivers' decision-making in mixed traffic. The findings of this study aim to enhance the understanding of driver interaction with AVs in mixed traffic and offer insights for developing automated driving styles that mitigate potential aggressive driving behaviors.

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Session Number Poster Session 2231

Session Title **Human Factors of Vehicles: Road User Behavior**

Paper Number 25-05365

Paper Title **Exploring the Effectiveness of Connected Vehicle Technology in Enhancing Driver Behavior and Safety During Hurricane Evacuation**

Abstract Connected vehicle (CV) technology can help drivers make more informed decisions through vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I), and vehicle-to-everything (V2X) communications. Previous studies on the impact of CV technology during evacuations have mainly relied on numerical simulations, frequently neglecting human factors.

This study seeks to fill this gap by evaluating the effectiveness of CV technology in enhancing driver behavior and safety during evacuations. The goal is to examine driver compliance with CV warning messages during hurricane evacuations and to evaluate their effectiveness in improving safety. A driving simulator experiment was developed featuring four events—rain, congestion, shoulder-blocked, and potential crash—that simulate hurricane evacuation scenarios under two conditions (with and without warning). In the "with warning" scenario, both text and audio alerts were provided, whereas in the 'without warning' scenario, no warnings were relayed.

Over 87% of the drivers complied with the warnings by slowing down in each event. Additionally, drivers who had no previous crash history and were more familiar with CV technology showed higher compliance with the warnings. The findings from the generalized linear mixed models showed significant enhancements in traffic safety. Providing advanced warning messages during rain, congestion, blocked shoulder, and potential crash resulted in approximately 20% lower maximum speed, 16% lower maximum deceleration, 22% higher time-to-collision, and 14% lower standard deviation of acceleration/deceleration. The results highlight the effectiveness of CV technology in improving driving behavior and safety during evacuations, as well as offer guidelines for automotive manufacturers to design safety features in connected and autonomous vehicles.

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Session Number Poster Session 2232

Session Title **Human Factors of Vehicles: Connected and Automated Vehicles and Intelligent Systems**

Paper Number 25-00527

Paper Title **Effects of Drivers' Age on Acceptance of ADAS**

Abstract Advanced Driver Assistance Systems (ADAS) are crucial in preventing traffic accidents, and drivers' acceptance of new technologies changes as they age. Studying the effect of driver age on the acceptance of advanced driver assistance systems is essential for improving the safety of older drivers on the road. This paper investigates the factors influencing the acceptance of ADAS based on the Technology Acceptance Model theory. Partial Least Squares Structural Equation Modeling was used to test hypotheses on the results of 358 driver questionnaires of different ages. The results show that social influence and perceived usefulness positively and significantly affect drivers' willingness to use ADAS. On this basis, all drivers were categorized into two groups, with 60 as the boundary. One group was for older drivers, and the other was for young and middle-aged drivers. A total of 13 antecedent constructs influencing drivers' behavioral intention to use ADAS were obtained through fuzzy set qualitative comparative analysis. The comparisons revealed that perceived ease of use, technology trust, and facilitation conditions were the core conditions affecting the acceptance of older drivers' behavioral intention to use ADAS.

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Sponsoring Committee	ACH30
Session Number	Poster Session 2232
Session Title	**Human Factors of Vehicles: Connected and Automated Vehicles and Intelligent Systems**
Paper Number	25-00695
Paper Title	**Influence of Foggy Weather on Drivers' Situation Awareness in The Takeover Process of Level 3 Automated Vehicles: An fMRI Study**
Abstract	Foggy weather stands as a prominent contributing factor to the malfunction of Level 3 automated driving systems, potentially impeding drivers' perception and reaction during the takeover process. While previous studies have investigated fog's impact on takeover safety by assessing drivers' visual attention, the influence of fog on drivers' recovery of situational awareness (SA) during takeover, especially concerning neural activities, remains disregarded. This research aims to use functional Magnetic Resonance Imaging (fMRI) to examine how fog affects drivers' brain activities during takeovers of Level 3 automated driving. Thirty volunteers participated in the experiment. Initially, they engaged in a non driving-related task (NDRT). Upon receiving a takeover request (TOR), participants pressed a button, which was followed by the presentation of a driving scenario video. The results showed that fog did not affect brain activation in non-critical takeovers, while significantly influencing brain activation in critical takeovers. Compared with the clear×critical scenario, the percentage change in signal intensity of the middle occipital gyrus (MOG) and the fusiform gyrus (FG) in the foggy×critical scenario was significantly lower. Moreover, the thalamus, prefrontal cortex (PFC), and precuneus were activated only in the clear×critical scenario, suggesting that high-level cognitive functions were impeded in foggy weather. Findings indicate that foggy weather impedes drivers' information perception (Level 1 SA) during takeovers, consequently suppressing comprehension (Level 2 SA) and projection (Level 3 SA). This highlights the potential of fMRI as an effective tool for comprehending drivers' cognitive states throughout takeover processes.

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Sponsoring Committee	ACH30
Session Number	Poster Session 2232
Session Title	**Human Factors of Vehicles: Connected and Automated Vehicles and Intelligent Systems**
Paper Number	25-01081
Paper Title	**Driver Takeover Behaviour in Conditional Automation: Insights from Immersive Virtual Reality Experiments**
Introduction	In conditional automation (L3, *1*), the automated driving system manages the vehicle control within predefined operational design domains (ODD). However, when the system reaches its functional limits or exits the ODD, it alerts drivers via visual-auditory signals to take back control, typically providing sufficient time for the transition. For example, if a broken-down car is detected ahead, a request-to-intervene (R2I) is issued, prompting drivers to shift from passive monitoring to active manual control to safely change lanes. Beyond such mandatory takeovers driven by system limitations, drivers may also choose to regain control voluntarily for personal reasons, such as comfort or a preference for active engagement. This highlights two main types of takeover conditions: mandatory takeover (MTOR), triggered by system alerts, and discretionary takeover (DTOR), initiated at the driver's discretion. The perceived cognitive demand (*2*) and driving stability of drivers differ significantly between these two takeover types. In MTOR scenarios, drivers must quickly stabilize vehicle control and perform evasive maneuvers, making transition performance critical. Although much research has focused on MTOR scenarios, the dynamics of DTOR events remain underexplored. This study addresses this gap by examining the perceived cognitive workload and driving stability associated with DTORs and MTORs, aiming to improve understanding of driver behaviour and enhance automated vehicle safety.

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Sponsoring Committee	ACH30
Session Number	Poster Session 2232
Session Title	**Human Factors of Vehicles: Connected and Automated Vehicles and Intelligent Systems**
Paper Number	25-01170
Paper Title	**Rethinking the Measure of Takeover Time: Insights from Drivers' Eye Movements**
Abstract	One major concern in conditionally automated driving is ensuring the safety and effectiveness of transitions between automated and manual modes. Particularly, when encountering scenarios beyond automation's operational design domain, drivers must promptly shift from non-driving tasks to manual driving within limited time, making takeover time (i.e., the time drivers spend to resume manual vehicle control) critical for evaluating control transition performance. Typically, takeover time is measured by operational metrics (e.g., steering and braking thresholds), which may overlook critical cognitive transition processes and lead to biases in pinpointing when drivers regain meaningful vehicle control. This study aims to offer insights into potential complementary metrics for operational-based measures of takeover time by investigating eye movements. With a driving simulator experiment, we illustrate the takeover process using time-related operational and visual metrics. Results reveal that drivers frequently initiate operational responses before conducting necessary visual checks, highlighting the limitations of measures relying solely on operational metrics. We investigate diverse visual fixation metrics and find that during takeovers, (i) drivers' tend to check the side mirror later and fixate on the human-machine interface more frequently as their perceived spare capacity decreases; (ii) the average duration of side mirror fixations significantly increases with decreased spare capacity when drivers perceive their spare capacity is insufficient, while it stabilizes around 0.26 seconds when drivers perceive their spare capacity is sufficient. Our findings are valuable for supplementing takeover time measures with promising visual metrics, thus advancing understanding of drivers' cognitive transition processes and improving human-vehicle interactions in conditionally automated driving.

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Sponsoring Committee	ACH30
Session Number	Poster Session 2232
Session Title	**Human Factors of Vehicles: Connected and Automated Vehicles and Intelligent Systems**
Paper Number	25-01252
Paper Title	**Time-Dependent Effect of Advanced Driver Assistance Systems on Driver Behavior Based on Connected Vehicle Data**
Abstract	This paper proposes a novel functional data analysis (FDA) approach to investigate the time-dependent effect of advanced driver assistance systems (ADAS) on driver behavior. Existing aggregate measures compress temporal information within driver behavior profiles and fail to explicitly reveal the temporal dependency of such effect. With the proposed FDA approach, the functional representation method is adopted to capture the underlying driver behavior in response to warning messages and address issues of irregularly spaced observations and measurement errors; the results of the functional principal component analysis (FPCA) with the bootstrap-enhanced Kaiser-Guttman method reveal important patterns in driver response behaviors; and a nonparametric functional varying coefficient regression model, considering vehicle initial motions and drivers' acceleration styles, is established. This regression model utilizes coefficient functions to estimate the time-dependent effect of ADAS. The FDA approach is evaluated based on the New York City connected vehicle dataset using forward collision warning (FCW) event records. The results suggest that the treatment effect of FCW are time-dependent, initially increasing before progressively decreasing over time. Driver responses can be decomposed into several phases at the 95% confidence level, including reaction time (1.3s), brake adjustment time (1.3s), progressive braking duration (2.7s), and effective treatment duration (4.0s). The time-dependent bootstrap confidence interval confirms driver heterogeneity in these distinct phases. The proposed FDA approach can serve as a paradigm for quantifying the treatment effect of other ADAS applications. The findings can support the improvements of ADAS design and the development and calibration of driver behavior models accounting for ADAS.

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Sponsoring Committee	ACH30
Session Number	Poster Session 2232
Session Title	**Human Factors of Vehicles: Connected and Automated Vehicles and Intelligent Systems**
Paper Number	25-01383
Paper Title	**Impact of Level 2 Automation on Driver Behavior: A Study Using Association Rules Mining**
Abstract	Driver distraction and reduced situational awareness pose significant risks in vehicles with Level 2 (L2) automation systems, such as adaptive cruise control and lane-keeping assistance. This study analyzed naturalistic driving data using Association Rules Mining (ARM) to investigate the impact of L2 automation on driver behavior. The dataset included 771 driving events categorized by L2 system activation status (active or inactive), intersection types, and hand positions on the steering wheel. Key variables were analyzed, such as eyes-off-road (EOR) time, off-road glance frequency and duration, and the influence of different driving conditions. The findings revealed that driver distraction, indicated by longer EOR times and more frequent off-road glances, is significantly higher when L2 systems are active. Additionally, drivers exhibit the highest levels of inattention with no hands on the wheel during L2 activation. These insights highlighted the need for improved driver-system interfaces. They targeted driver education to enhance the safety and effectiveness of L2 automation, ultimately contributing to safer roadways and better-informed policy decisions.

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Sponsoring Committee	ACH30
Session Number	Poster Session 2232
Session Title	**Human Factors of Vehicles: Connected and Automated Vehicles and Intelligent Systems**
Paper Number	25-01566
Paper Title	**Effect of eHMI-equipped Automated Vehicles on Pedestrian Crossing Behaviors and Safety: A Focus on Blind Spot Scenarios**
Introduction	Blind spot collisions pose a serious risk to vulnerable road users (VRUs), causing numerous injuries and fatalities annually in both the US and EU (1) (2). Heavy vehicles and buses are particularly involved due to their large blind spots. While advanced driver assistance systems (ADAS) like blind spot monitoring (BSM) and automatic emergency braking for pedestrians (AEB-P) aim to reduce these risks, sensor limitations and visibility obstructions remain significant challenges (3). High vehicle bodies and traffic congestion further exacerbate blind spot dangers, often leading to unsafe pedestrian decisions (4). With automated vehicles (AVs) becoming more prevalent, external human-machine interfaces (eHMIs) offer a way to communicate critical messages such as 'Walk,' 'Don't Walk,' and 'Blind Spot!' to pedestrians (5–8). However, existing research largely overlooks blind spot warnings and complex traffic scenarios. This study investigates the role of multi-modal eHMIs in improving pedestrian crossing safety in blind spot scenarios, hypothesizing that risk-based eHMIs are more effective than those reflecting only AV states. A VR experiment was designed to explore these effects and inform safer pedestrian-AV interactions.

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Sponsoring Committee	ACH30
Session Number	Poster Session 2232
Session Title	**Human Factors of Vehicles: Connected and Automated Vehicles and Intelligent Systems**
Paper Number	25-01801
Paper Title	**Examining the Impact of Take-Over Control Mechanisms on Merging Behavior and Performance in Conditionally Automated Driving Systems**
Abstract	The development of Conditionally Automated Driving (CAD) systems marks a significant milestone in automotive technology, combining high-level automation with critical human intervention. This study investigates the impact of different Take-Over Control (TOC) mechanisms on driver behavior and performance during merging maneuvers after resuming control from the automated system. Using a driving simulator, the study evaluates three TOC mechanisms: steering wheel, pedals, and button. Thirty participants were recruited to drive on a designed test track three times, with a different TOC mechanism activated each time. Weibull Accelerated Failure Time with Shared Frailty and linear mixed effects models were used to analyze these repeated measures simulation results. The results indicate that the steering wheel mechanism results in significantly longer lane-change durations during merging maneuvers compared to pedals, likely due to increased cognitive load. Gender differences were also observed, with female drivers showing longer lane-change durations than males. These findings highlight the need for personalized and optimized TOC system designs to improve safety and user experience in CAD systems. The study provides valuable insights for the development of more effective and user-friendly TOC mechanisms, ultimately improving the safety and efficiency of CAD systems. Future research should explore a broader demographic and real-world validation to further refine these mechanisms.

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Sponsoring Committee	ACH30
Session Number	Poster Session 2232
Session Title	**Human Factors of Vehicles: Connected and Automated Vehicles and Intelligent Systems**
Paper Number	25-02326
Paper Title	**Human-Autonomy Teams in Automated Driving System Operations: The Case of Drivers and Remote Operators**
Abstract	Automated Driving Systems (ADS) are expected to play a significant role in the mobility environment across multiple use cases, including passenger or goods transportation services, or as features in privately-owned passenger vehicles. As more use applications are being tested and deployed in public roads, there is an increasing interest in assessing real-world safety impacts and addressing new operational safety challenges. In this context, humans will continue interacting with these systems as drivers, operators, and/or fellow road users. Therefore, as crucial elements impacting the overall road safety, it is of interest to define, model and assess the interactions, collaborations, and teaming that can occur between human and autonomous agents in ADS operations. This work establishes the concept of Human-Autonomy Teams (HATs) in ADS operations, focusing on the relationship, tasks, and challenges on-board drivers and remote operators may face when interacting with highly automated vehicles. This work draws from Performance Shaping Factors (PSF) used in Human Reliability Analysis (HRA) to assess human operator's performance in high-risk industries, such as nuclear, aviation, and maritime operations. The analysis focuses on two different teams: drivers interacting with conditional automation in privately-owned passenger vehicles and remote operators supporting highly automated vehicle fleets deployed for passenger transport. This work identifies potential factors influencing the performance of both human and automated agents in ADS operations to apply team performance models such as the Information, Decision and Action in Crew (IDAC) context, highlighting the role that organizational, individual, system, team, and scenario-related factors play in the overall system's safety.

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Session Number	Poster Session 2232
Session Title	**Human Factors of Vehicles: Connected and Automated Vehicles and Intelligent Systems**
Paper Number	25-02695
Paper Title	**Safety Performance of Drivers in Connected and Automated Vehicles During Safety-Critical Events: A Networked Driving Simulation Study**
Abstract	Connected and automated vehicles (CAVs) hold tremendous potential for advancing driving safety. This study aims to delve into factors influencing driver safety performance within CAVs during safety-critical events that request drivers to take over. An experiment utilizing networked driving simulators was conducted, where two drivers were involved in one synchronized virtual driving environment. The experimenter operated one of the networked simulators to intentionally create safety-critical events involving running red lights/stop signs at intersections and highway merging. Drivers' safety performance during these safety-critical events were assessed using post encroachment time (PET), a widely accepted surrogate safety measure. Logit models with participant-specific random effects were developed to understand the relationship between the presence traffic conflict (categorized based on PET values) and various factors including connected vehicle (CV) warning, the presence of obstructions, automation level (Level 2 vs Level 3), traffic control, and time of day (daytime vs nighttime). In assessing model performance, the random effects logit models demonstrated superiority over the standard logit model based on measures like AIC and BIC. The findings revealed a noteworthy reduction in the likelihood of traffic conflicts in scenarios with CV warnings, with statistical significance levels of 0.064 for intersection scenarios and 0.073 for highway merging scenarios. This study provides insights into the development of human-machine interactions within CAV systems to enhance safety during critical events.

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Sponsoring Committee	ACH30
Session Number	Poster Session 2232
Session Title	**Human Factors of Vehicles: Connected and Automated Vehicles and Intelligent Systems**
Paper Number	25-03522
Paper Title	**Analyzing Driver Characteristics and Takeover Behaviors in L2 Automated Vehicles Using Vehicle Kinematic Data and Clustering Algorithms**
Introduction	Vehicle automation technologies have demonstrated significant potential to enhance driving safety by reducing human errors associated with crashes. According to SAE International (1), Level 2 (L2) automation—combining Adaptive Cruise Control with Lane-centering technology — supports both lateral and longitudinal vehicle control. However, L2 automation requires driver engagement, as these systems have limitations and may fail under uncertain conditions, necessitating driver takeovers (2). The growing adoption of automation technologies highlights the need to understand driver behavior, particularly how takeover quality varies among drivers with different characteristics. Reaction time to takeover requests is a key metric in evaluating takeover quality, with research indicating faster responses to multimodal alerts compared to single-modal alerts (3), as well as an impact of alert timing on response speed (4). Studies have also shown that multimodal alerts can reduce distraction within L2 automated vehicles (5). Understanding driver response patterns requires examining both individual characteristics and how these influence takeover behavior. To capture drivers' individual characteristics, self-reported surveys such as the Driving Behavior Questionnaire (DBQ) (6, 7) correlate with driving and sudden accelerations as well as steering corrections (8). Sensation-seeking traits also correlate with risky driving, such as speeding and seat belt noncompliance (9, 10). Relatedly, higher anger drivers are more aggressive, engage in risky driving behaviors, and are more crash prone than drivers with less anger (11). While surveys provide insights into driving traits, their reliability can be limited by self-report biases and variable data quality (12, 13). Given the limitations of self-reported data, vehicle kinematic data offers an objective measure of driving behavior, capturing metrics such as speed, acceleration, steering angle, and brake pressure. Recent research has leveraged this data to study driver responses in Automated Vehicles (AVs) during takeover requests. Findings show that drivers respond more quickly at higher speeds (14), abrupt changes in acceleration prompt quicker takeovers (15), and that drivers with high trust in AVs have slower reaction times, especially if they are not properly trained (16). Kinematic data has further revealed traits associated with risky drivers, such as frequent lane changes and abrupt braking (17), while conscientious individuals tend to engage in safer driving behaviors (18). The widespread availability of kinematic data from vehicle sensors enables real-time analysis for predicting driving behaviors, identifying risks, and enhancing driver assistance systems (19–22). This study explores the relationship between vehicle kinematic data and drivers' takeover behaviors, crash events, and self-reported traits in L2 automated environments. Specifically, we aim to answer the following questions: • Can drivers' driving characteristics be identified by the vehicle's kinematic data? • How do the identified driving characteristics relate to the types of warnings, types of critical events (e.g., pedestrian crossing), and crash events? • How do the identified driving characteristics relate to the survey responses (i.e., DBQ, sensation seeking, trust, and anger)? A driving simulator experiment was conducted, featuring six scenarios with L2 automation and varied warning modalities and critical event causes. Vehicle kinematic data was collected throughout, focusing on takeover behavior. We hypothesize that kinematic data reveals drivers' characteristics, with reaction times associated with alert types and critical event causes. We also expect that kinematic-derived characteristics relate to crash events and drivers' DBQ, sensation seeking, anger, and trust scores.

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Session Number	Poster Session 2232
Session Title	**Human Factors of Vehicles: Connected and Automated Vehicles and Intelligent Systems**
Paper Number	25-06251
Paper Title	**What Factors Contribute to Aberrant Driving Behavior: A Case Study in Maharashtra Region**
Abstract	Driver Behavior Questionnaire (DBQ) has been extensively used to analyze driving behavior due to its cost-effectiveness, large-scale applicability, and ease of interpretation. Several countries have utilized DBQ to analyze driving behavior. However, the literature indicates that its applicability from one nation to another raises concern due to variations in driving culture and environment. Further, behavioral structure identification of Indian drivers still requires a thorough investigation, as existing Indian DBQ studies do not address the negative behavioral attributes individually. Hence, the present study aimed to identify the behavioral structure of drivers from Maharashtra and investigate the influence of sociodemographic factors and accident history on the identified structure. A total of 338 responses were collected through in-person interviews in crowded public places in Maharashtra. Principal component analysis revealed that behavioral structure can be classified into two factors: errors and violations. Further, the mean of the ratings revealed that Indian drivers had distraction tendencies contrary to the speeding tendencies of European drivers. Multiple linear regression revealed that violations and errors decreased with an increase in the age and the annual mileage, respectively. Interestingly, errors increased while violations decreased for drivers with a crash or near-crash experience (as car drivers). The present study suggests that driver training programs, driver monitoring systems, and strengthening policy enforcement might help in correcting the error and violation tendencies of drivers. The proposed DBQ can also help in the self-assessment of drivers during the licensing process and in deciding insurance schemes based on driving behavior.

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Sponsoring Committee	ACH30
Session Number	Poster Session 2232
Session Title	**Human Factors of Vehicles: Connected and Automated Vehicles and Intelligent Systems**
Paper Number	25-06248
Paper Title	**The Roles of Perceived Safety and Trust in the Choice of Fully Automated Taxis**
Abstract	Safety is considered one of the most important factors for autonomous vehicles (AVs), but has received less attention than expected. In this paper we aim to investigate the role of perceived safety in the choice of automated taxis (ATs) versus normal taxis (NTs), focusing on both possible vehicle failures and personal harmful/property loss events, and investigating the causal relation between perceived safety and trust in their impacts to the choice of ATs. For this purpose, using data collected in Newcastle and Toronto, hybrid choice models were estimated to capture the effects of these three latent psychological factors in the choices of ATs. Results confirm that both perceived vehicle safety (PVS) and perceived personal safety (PPS) have significantly positive effects on trust, which in turn has a significant positive effect on the choice of ATs. This result confirms the foundation role of perceived safety for building trust on ATs as expected, but PVS is a stronger antecedent of trust than PPS, and this effect is consistent in both datasets, Newcastle and Toronto. Differently, we found that most significant individual characteristics (in latent variable component) in the Newcastle case are no longer significant in the Toronto case, indicating that AT behavioural models should be applied with caution in different regions. A sensitivity analysis further confirms this point, as the policy regarding enhancement of generic knowledge about AVs might work efficiently only in Newcastle, not in Toronto.

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Sponsoring Committee	ACH30
Session Number	Poster Session 2232
Session Title	**Human Factors of Vehicles: Connected and Automated Vehicles and Intelligent Systems**
Paper Number	25-06190
Paper Title	**Over-trust Identification in Conditionally Autonomous Vehicle Using Transformer-LSTM Based on Low-interference Indicators**
Abstract	Drivers' over-trust in autonomous driving systems (ADS) has led to frequent safety incidents in recent years. These drivers often neglect to monitor driving tasks, resulting in a failure to take over promptly when the 3 ADS encounters issues. Therefore, it is necessary to identify the driver's over-trust in real time. Traditional studies primarily use subjective questionnaires or physiological indicators such as EEG and skin conductance to identify driver trust levels. However, questionnaires are highly subjective and not real-time, while the devices for collecting physiological indicators may interfere with drivers and lack feasibility in real car applications. To address these issues, this study aims to use indicators collected from low-interference devices and proposes a Transformer-LSTM model to identify over-trust levels in real-time. A driving simulation platform was developed based on a real car and various low-interference indicators were collected through depth cameras, telemetric eye-tracking, seat pressure sensors, and steering wheel sensors. Results show that the model excels at capturing global dependencies and data relationships while processing various data types in parallel. It models the long-term formation of trust and the impact of unexpected events on trust fluctuations, capturing driver information from multi-source data to identify over-trust in real time. The model achieves a Root Mean Square Error (RMSE) of 0.205, representing an average 15.63% improvement in accuracy compared to baseline models. This study offers a novel method for identifying the over-trust level and has promising applications for autonomous driving safety.

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Sponsoring Committee	ACH30
Session Number	Poster Session 2232
Session Title	**Human Factors of Vehicles: Connected and Automated Vehicles and Intelligent Systems**
Paper Number	25-04878
Paper Title	**The Impact of Connected and Automated Vehicle Platoons on the Cut-in Decision of Human-Driven Vehicles: A VR-Enabled Approach and Empirical Insights**
Abstract	

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Sponsoring Committee	ACH30
Session Number	Poster Session 2232
Session Title	**Human Factors of Vehicles: Connected and Automated Vehicles and Intelligent Systems**
Paper Number	25-05571
Paper Title	**Assessing Driver Reactions to Various CAV Warnings Using an Advanced Driving Simulator**
Abstract	As the number of connected and autonomous vehicles (CAV) technologies increases, so does the number of auditory-visual notifications and warnings. Therefore, it is becoming increasingly important to investigate the potentially adverse effects of these warnings on drivers. This study used a driving simulator to examine the impacts of different CAV notification and warning modality types (auditory, visual, and bimodal) on drivers' behavior and gaze behavior. In this study, 35 participants wore eye trackers while driving in a simulated network across four scenarios. Participants also completed pre- and post-survey questionnaires. Based on the results of the ANOVA with a post-hoc test, there was a significant difference in throttle and steering velocity change between scenarios. It suggests that when drivers were presented with a visual warning, their focus was diverted from the road. As a result, they failed to adapt to the changing driving environment, resulting in rapid changes in the vehicle's direction. The results of the eye tracker and heatmaps demonstrated that during the visual and bimodal warnings, participants' gaze fixations were primarily focused on the CAV warnings rather than the road. The extended gaze fixation for visual warnings suggests that additional auditory cues in the bimodal scenario may have influenced participants to shift their attention more quickly between the warning and the road environment. Participants preferred bimodal alerts and acknowledged the positive influence of CAV warnings on their safety. The results emphasize the significance of combining several modalities to improve the effectiveness of CAV warnings.

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Session Number	Poster Session 2232
Session Title	**Human Factors of Vehicles: Connected and Automated Vehicles and Intelligent Systems**
Paper Number	25-05787
Paper Title	**Integrating Human Factors in Evaluating Safety and Operational Efficiency of Automated Vehicles: Insights for Global Robotaxi Services**
Abstract	The general public anticipates improved driving safety and efficiency with the implementation of Automated Vehicles (AV). However, there lacks an investigation into how human factors affect AV safety with considering all potential driving behaviors under the automated driving environment. With efficiency added to the discussion, existing research mainly optimizes safety and operational efficiency through simulation platforms. There lacks a consideration from the participation of human drivers since they are necessity in the automated driving environment until the full automation achieves. This research aims to evaluate safety performance based on human driving behaviors, understand conflict types of distribution, reveal reasons behind safety preferences for automation levels, and explore the tradeoff between AV safety and operational efficiency. Sixty participants completed driving tasks at Levels 0, 4, 3, and 2 on a driving simulator. Safety and efficiency performance were collected and computed. As a result, appropriate driving behavior has a significantly better safety performance than inappropriate driving behaviors. Level 4 was considered the most preferred level of automation by most participants. The reason can be attributed to the reduced traffic conflicts caused by human errors under Level 4. After converting them into cost, a benefit-cost ratio is introduced, measuring the ratio between safety and travel delay. The results show that Level 2 has a significantly higher benefit-cost ratio than Levels 3 and 4. This research benefits AV specialists by providing them with a further understanding of AV safety and efficiency by integrating human factors.

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Sponsoring Committee ACH30

Session Number Poster Session 2232

Session Title **Human Factors of Vehicles: Connected and Automated Vehicles and Intelligent Systems**

Paper Number 25-05831

Paper Title **Coexistence in Motion: Unveiling the Behavioral Dynamics of Humans and Highly Automated Vehicles in Naturalistic Mixed Traffic**

Abstract While automated vehicles (AVs) are expected to fundamentally change various aspects of the transportation system, our understanding of their impacts on roadway users' behavior is extremely limited. This is particularly critical for accurate planning for the future of our cities. Focusing on driver behavior and utilizing real-world data collected from commercial AV operations in Phoenix, Arizona (USA), this study aims to provide a comprehensive analysis of the impacts of AVs on human behavior in their vicinity and to evaluate the hypothesis that driver behavior changes in response to an AV. Our findings indicate that there are some differences between human-driver behavior and AV behavior. Although AV behaviors result in changes in human behavior, in many cases, human drivers treat AVs similarly to other human drivers, and in some cases, the AV presence contributes to smoother traffic flow.

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Sponsoring Committee ACH30

Session Number Poster Session 2232

Session Title **Human Factors of Vehicles: Connected and Automated Vehicles and Intelligent Systems**

Paper Number 25-05848

Paper Title **Effectiveness of Lane Departure Warning Systems Under Varying Driving Scenarios Among Young Drivers – Insights from Field Operation Tests.**

Abstract Driver distraction is among the leading contributors to road crashes. Distraction while driving may arise from several in-vehicle and external factors. Advanced driver assistance systems (ADAS) have been developed to assist drivers in mitigating distraction in various driving scenarios. Warning systems, such as lane departure warning, forward collision warning, and pedestrian collision warning, have been designed to enhance the safety of drivers and other road users. However, the efficiency of these systems in critical distracted driving conditions is a matter of concern. This study assessed the effectiveness of integrated lane departure warning systems under various driving conditions, such as warning-only, pedestrian presence, driver-passenger conversations, and phone call conditions. The study was conducted in a controlled road environment to assess driving behavior by examining lane departure events, driving speed, visual gaze, and signal violations. Additionally, moderation factors such as gender, age, driving experience, driver education, and prior crash experience were considered for comprehensive analysis. The results revealed that lane departure warning systems were more effective under distracted driving conditions, with a significant reduction in the average duration of lane departure by 26.46% in the driver-passenger conversation conditions and by 23.65 % during the phone call conditions. The findings from the study highlight the positive influence of lane departure warning systems on driver behavior under distracted driving conditions, supporting the idea of installing LDW systems in all new vehicles to enhance road safety.

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Sponsoring Committee	ACP50
Session Number	Poster Session 2236
Session Title	**Connected and Automated Vehicles**
Paper Number	25-04559
Paper Title	**Remote Driving: Latency Effects on Speed Selection, Gap Acceptance, and Lane Positioning**
Introduction	As advancements in artificial intelligence reshape various sectors, from healthcare and transportation to finance, autonomous vehicles (AVs) emerge as a particularly promising innovation. However, significant challenges continue to hinder the deployment of AVs on public roads, particularly under unpredictable and complex driving conditions. Between July 2021 and May 2022, the National Highway Traffic Safety Administration (NHTSA) reported 130 crashes involving AVs equipped with Advanced Driver Assistance Systems (ADAS). These incidents included blocking traffic, collisions with pedestrians and bicyclists, and even navigating on the wrong side of the road. Given the challenges inherent in fully autonomous vehicle (AV) deployment, remote driving (RD) is emerging as an interim solution to address these limitations. RD integrates human oversight into vehicle operation by allowing human operators to remotely control vehicles, enhancing adaptability in scenarios where AVs struggle. However, RD has its own challenges, such as network latency. Latency, which is the delay between the control station and vehicle response, significantly impacts driver performance. High latency levels can impair decision-making, disrupt trajectory control, and increase the risk of errors in critical driving scenarios. The scope of this research focuses on understanding how latency affects RD performance in three important areas: speed selection, gap acceptance, and lateral positioning. One study highlights the importance of low latency in remote applications such as gaming and teleoperation, with thresholds of 100–200 ms deemed critical for maintaining user performance (13). This study aims to understand how different latency conditions impact driving behavior using a virtual reality (VR) driving simulator to assess driver performance across four latency levels: 0 ms, 100 ms, 200 ms, and 300 ms. The research involves a rural road setting with driving tasks such as navigating horizontal curves and intersections, accepting gaps, and making right and left turns at priority intersections. The findings reveal that higher latency significantly impacts driver performance, with implications for RD system design and communication infrastructure. This study contributes to establishing a theoretical framework for understanding how latency affects human performance in RD. It confirms that performance degradation becomes critical at 300 ms.

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Session Number	Poster Session 2236
Session Title	**Connected and Automated Vehicles**
Paper Number	25-05513
Paper Title	**A Trajectory Planning Method for Autonomous Vehicles in Conflict Scenarios with Non-motorized Vehicles**
Introduction	Traffic crashes remain one of the leading causes of human fatalities. According to the 2017 report of the ethics commission on autonomous driving, the goal of automated and connected driving is to reduce harm to the point of complete prevention. Interacting with vulnerable road users, such as cyclists and pedestrians, continues to be a major challenge for autonomous vehicles (AVs). Non-motorized vehicles (NMVs), including bicycles and e-bikes, with their diverse appearances and dynamic trajectories, present significant challenges to AVs in terms of environment perception, intent recognition, and decision planning. In the study of planning decisions in conflict interaction scenarios between AVs and NMVs, current research primarily focuses on collision avoidance through AV braking. While such an approach prioritizes safety in near-crash situations, AVs have the potential to prevent near-crashes altogether by selecting better trajectories in conflict scenarios, thus enhancing interaction and travel experience. This study focuses on developing a safe, efficient, and comfortable (*9*) trajectory planning method for AVs in conflict scenarios with NMVs.

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Sponsoring Committee	ACS10
Session Number	Poster Session 3039
Session Title	**Transportation Safety Management Systems from Start to Finish**
Paper Number	25-01579
Paper Title	**Ensuring Accurate Mixed Traffic Safety Assessments: The Vital Role of Safety Metrics and Behavioral Modeling**
Abstract	In future traffic systems, where automated vehicles (AVs) coexist with human-driven vehicles (HVs), ensuring road safety is of utmost importance. Existing safety assessment methods, however, are inadequate for the complex scenarios presented by mixed traffic conditions. These methods often fail to distinguish sufficiently between AVs and HVs, leading to inaccuracies in safety evaluations. To address these issues, this paper highlights the shortcomings of current surrogate safety measures (SSMs) in mixed traffic contexts and introduces a novel SSM, the Weighted Combination of Spacing and Speed Difference Rates (WS2DR). We propose a comparative analysis method to validate the effectiveness of WS2DR and to establish its safety threshold. Experiment results reveal that WS2DR outperforms traditional metrics such as time-to collision and deceleration rate to avoid crashes, in terms of adaptability and detection of a wider range of unsafe conditions in both homogeneous and heterogeneous traffic environments. Additionally, the paper presents a sophisticated mixed traffic modeling approach that accounts for different characteristics of AVs and HVs, incorporating factors such as errors of estimating the motion of other vehicles and the extended reaction time of HVs, as well as the perceptual and cooperative-active control capabilities of AVs. The results of the comparison analysis underscore the critical importance of considering the differences between AVs and HVs in modeling for accurate safety evaluations of mixed traffic. Simulation experiments confirm the positive impact on safety with increased AV penetration rates, emphasizing the necessity of employing refined modeling and safety assessment metrics to capture the full benefits of AV integration.

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Sponsoring Committee	ACS10
Session Number	Poster Session 3039
Session Title	**Transportation Safety Management Systems from Start to Finish**
Paper Number	25-02120
Paper Title	**Estimating the Cost and Benefits of and Number of Lives Saved by Crash Avoidance Technologies**
Abstract	Crash prevention systems play an important role in enhancing vehicle safety by alerting drivers about potential risks and, in some instances, taking corrective action to mitigate these risks. This research uses vehicle insurance claims reports and national crash datasets to evaluate the societal and private economic impacts of deploying crash avoidance technologies throughout the US light duty vehicle fleet across two scenarios. The first scenario focuses on warning systems, including blind spot monitoring (BSM), lane departure warning (LDW), and forward collision warning (FCW). The second scenario looks at the benefits of equipping vehicles with AEB in addition to the aforementioned warning systems. Based on the cost to deploy these technologies and the economic benefits that arise from crash prevention and crash severity changes, the fleet wide deployment of AEB in addition to warning systems could provide $79.2 and $65.2 billion in annual net-societal and net-private benefits, respectively. Because AEB has significantly higher reductions in crash frequency than the warning systems, adding AEB to vehicles would more than double the societal and private benefits than that from warning systems alone. Additionally, considering the different combinations of crash avoidance technologies available in vehicles today, there were around 110 lives saved in 2019 due to the ability for crash avoidance technologies to help drivers avoid crashes. Because the current penetration rate of crash avoidance systems are still low and effectiveness of the systems are likely to improve over time, the number of lives saved and economic benefits should increase over time.

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Sponsoring Committee	AKD10
Session Number	Lectern Session 3067
Session Title	**Connected and Automated Vehicles Impacting Road Design**
Paper Number	25-00447
Paper Title	**Road Design Optimisation for Autonomous Vehicles**
Abstract	The rapid progress of Autonomous Vehicle (AV) technology has generated considerable interest in the potential impact on road design. The paper presents the results of research about how the integration of AVs will influence the design and efficiency of road networks. The evaluation utilized a combination of PTV VISSIM software and the Surrogate Safety Assessment Model (SSAM) to construct a network model consisting of a primary arterial road and connecting roads within Dublin City, Ireland. Several scenarios were considered, each exploring various design elements and AV market penetration levels. The study analysed key performance indicators such as throughput volumes, average speed, travel time, vehicle and junction delays, queue length, level of service (LOS), and traffic conflicts to compare the different scenarios. The results revealed that a fully autonomous vehicle fleet led to enhanced throughput volumes and improved junction performance. Surprisingly, a dedicated AV lane did not significantly enhance overall network performance. Instead, a roundabout design emerged as a promising solution, showcasing remarkable improvements in various indicators while also mitigating conflicts compared with other scenarios. Narrower lanes improved travel time and vehicle delay but raised safety concerns due to higher conflict levels. Similarly, as expected, a higher design speed demonstrated better travel speeds. The study underscores the complexity of AV integration and the importance of a balanced approach to optimize safety and efficiency.

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Sponsoring Committee	ACP30
Session Number	Lectern Session 3111
Session Title	**Moving Automated Vehicle Research into Practice**
Paper Number	25-02092
Paper Title	**Ethical Decision-Making in Autonomous Vehicles: A Reinforcement Learning Approach for Fair Risk Management**
Abstract	With the rise of connected and autonomous vehicles driving technology, moral decisions previously made by humans are now governed by AI algorithms. However, current decision-making algorithms primarily focus on ensuring the safety of autonomous vehicles themselves, neglecting the potential safety risks these decisions impose on other vehicles. The on-ramp area, a critical part of highways, is significantly impacted by vehicle merging behavior, which is a key factor in the safety of this area. Therefore, we propose an ethically-aligned vehicle merging decision framework that utilizes reinforcement learning algorithms, aiming to distribute risks equitably among all vehicles involved in the merging progress. To our knowledge, this is the first framework to integrate reinforcement learning algorithms with ethical driving standards, and it holds potential for application to other traffic scenarios. This approach could provide valuable insights into the ethical considerations for future autonomous connected and autonomous vehicle decision-making algorithms.

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Sponsoring Committee	ACP30
Session Number	Lectern Session 3111
Session Title	**Moving Automated Vehicle Research into Practice**
Paper Number	25-03357
Paper Title	**Conflict Resolution Behavior of Autonomous Vehicles at Intersections in Mixed Traffic Environment**
Abstract	Navigating intersections in mixed traffic poses a major challenge for autonomous vehicles (AVs). This study investigated AV's conflict resolution behavior in mixed traffic by analyzing the Arogoverse-2 motion forecasting dataset to understand the driving behavior of AVs at intersections. The conflict scenarios were categorized into AV-involved and no AV conflict scenarios. Depending on whether AVs passed the conflict region first or second, AV-involved scenarios were further classified into AV-first and AV-second scenarios. An agglomerative hierarchical clustering with t-SNE dimension reduction technique was applied to categorize the driving styles, and a three-layer Bayesian hierarchical model was applied to analyze the effect of driving volatility measures and traffic characteristics on relative crash risks. The clustering result showed that about 26% of the AV-first scenario conflict events exhibited high-risk conflicts. In contrast, all conflict events in the AV-second category were low-risk or medium-risk. Parameter estimates showed that AVs had safer interactions with the other roadway users (i.e., Human Drivers (HDVs), pedestrians/cyclists) while maintaining higher speeds and uniform driving profiles. AV's interaction with vulnerable road users (i.e., pedestrians and cyclists) showed lower crash risk than HDVs, indicating AV's safer driving behavior. AVs also demonstrated safer conflict resolution behavior in performing unprotected left turns compared to HDVs. This study discovered some unique insights into the challenges of introducing AVs in diverse intersection types (i.e., signalized, unsignalized, stop-controlled), which can be used to identify AV technology's improvement need to better adapt to the mixed traffic driving environment.

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Sponsoring Committee	ACP15
Session Number	Poster Session 3211
Session Title	**Intelligent Transportation Systems in the Era of Connected Vehicles and Vehicle to Everything Communication**
Paper Number	25-03024
Paper Title	**<u>A New Framework for Traffic Conflict Identification by Incorporating Predicted High-resolution Trajectory and Vehicle Profiles in a CAV Context</u>**
Abstract	Time to Collision (TTC) measure which is one of the Surrogate Safety Measures to identify traffic conflicts has been widely studied in the past decades in conventional road environments. Towards the future Connected and Autonomous Vehicles (CAV) environments, more accurate and timely identification on traffic conflicts are pursued to guarantee a higher-level safety. However, traditional TTC measures only consider vehicle length in one-dimensional scenarios and assume vehicles maintain current motion states to predict collisions, neglecting the impacts of vehicle profiles and changes in vehicle movements on traffic conflicts. Therefore, this paper proposes a new framework of extending the traditional TTC measure into the Trajectory-based TTC (TTTC) measure by incorporating predicted high-resolution trajectory and vehicle profiles into TTC in a CAV context. The predicted high-resolution trajectory with high accuracy and detailed vehicle profiles of surrounding vehicles could be fully supported by the CAV system. In the framework, actual movements instead of an assumption of unchanged acceleration or velocity in the following frames are considered. Additionally, the impacts of vehicle profiles are modeled using the Planar Collision Index (PCI), which is proposed to identify and model collisions between the edges and angles of vehicles at various collision angles. At last, the proposed method is tested in different scenarios, including car-following, non-conflict interaction, and risky overtaking. Numerical results show that the TTTC performs better than TTC. Meanwhile, the impacts of trajectory prediction accuracy are discussed, indicating that higher accuracy of the trajectory prediction, higher accuracy of the traffic conflict identification.

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Sponsoring Committee	ACP15
Session Number	Poster Session 3211
Session Title	**Intelligent Transportation Systems in the Era of Connected Vehicles and Vehicle to Everything Communication**
Paper Number	25-04150
Paper Title	**<u>Real-Time Tailgating Behavior Management under Connected Environment</u>**
Abstract	Tailgating driving behaviors introduce high risk of rear-end collisions, especially in instances of traffic oscillations on roads. Urgent measures are required to implement traffic management strategies aimed at mitigating the collision risk associated with tailgating vehicles. This paper presents a method to model tailgating behaviors and manage connected vehicles (CVs) to reduce the risk of collision caused by tailgating vehicles. The system leverages CVs to actively monitor their surrounding vehicles and identify tailgating vehicles with predefined probabilities. Through the tailgating behavior management (TBM) system, the CVs affected by their surrounding tailgating vehicles receive optimal lane-changing and acceleration instructions to mitigate potential rear-end collisions with tailgating vehicles. The simulation results demonstrate the advantages of the TBM system, showcasing a reduction in the risk of rear-end collisions by over 50%. Furthermore, the system’s reliability is validated through sensitivity analysis of the market penetration rates (MPRs) of CVs. Overall, higher MPRs correlate with more significant reductions in the frequencies of various collision levels. This study highlights the safety benefits of the TBM system, particularly in mitigating extreme high-risk tailgating behaviors.

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Sponsoring Committee ACP30

Session Number Poster Session 3212

Session Title **Vehicle-Highway Automation**

Paper Number 25-00139

Paper Title **Enhancing Lane Change Safety: A Hierarchical Risk-Resposive Reinforcement Learning Model for Autonomous Vehicle Merging on On-Ramps**

Abstract
Lane-changing behavior is a frequent yet complex task for Autonomous Vehicles (AVs). To enhance the safety of AVs, it is essential to accurately assess driving risks and provide safe lane-changing strategies. This paper presents a novel risk-responsive reinforcement learning framework aimed at facilitating safer lane changes for AVs. We first introduce a comprehensive lane change risk index (LCRI) to evaluate the driving risk during interactions with other vehicles. The lane-changing task is then modeled as a Markov Decision Process (MDP), and a Soft-Actor-Critic (SAC) algorithm-based driving strategy is developed to address it. Furthermore, we construct a dual-layer motion planning controller to translate driving decisions into vehicle movements, embedding an online risk perception module based on the LCRI into the driving strategy to correct unsafe behaviors and guide the training process. Experimental results indicate that our proposed framework outperforms existing algorithms in terms of efficiency and success rate across three traffic density levels. Compared to human drivers, the trained agent demonstrates a reduced risk level in interactions with surrounding vehicles and optimizes the timing and positioning of lane changes.

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Session Number Poster Session 3212

Session Title **Vehicle-Highway Automation**

Paper Number 25-00302

Paper Title **Exploring the Impact of Various Lateral Movement Strategies of Autonomous Truck Platooning on Traffic Safety and Efficiency**

Abstract
Truck platooning, an advanced vehicular technology, leverages connectivity and autonomous driving that may enhance roadway efficiency and safety through proximity convoys. However, their impacts on traffic operation and safety in a mixed-traffic environment (including both human driven and autonomous vehicles) have not been explicitly explored. This study investigates the impacts of two lane-change strategies of Truck platooning —First Vehicle Changes Lane First (FVCLF) and Last Vehicle Changes Lane First (LVCLF)—on traffic safety and operational efficiency under varied weather conditions and platoon configurations.

Utilizing a high-fidelity driving simulator experiment, 74 licensed U.S. drivers navigated through eight distinct scenarios. Several surrogate measures including Time-to-Collision (TTC) and travel time delay were recorded. Randomized Block Design (RBD) and Generalized Linear Mixed Model (GLMM) were employed to explore the differential impacts of FVCLF and LVCLF strategies.

The findings reveal that FVCLF maneuvers significantly enhance traffic flow and safety, evidenced by superior TTC and reduced delays in travel time, particularly under clear weather conditions. For instance, within a three-truck platoon scenario, the FVCLF strategy yielded a mean TTC of 3.1 seconds and a mean delay in travel time of 2.3 seconds, significantly outperforming the LVCLF strategy. Furthermore, the study explored the interaction between driver's characteristics and the effectiveness of platooning maneuvers, revealing nuanced insights into how age, gender, and education level influence their interactions with lateral movement strategies. For instance, mature drivers exhibited higher TTC, indicating safer driving behaviors, while the impact of education level on driving safety presented a mixed pattern.

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Sponsoring Committee ACP30

Session Number Poster Session 3212

Session Title **Vehicle-Highway Automation**

Paper Number 25-00372

Paper Title **Decision-making of Autonomous Vehicles in Interactions with Jaywalkers: A Riskaware Deep Reinforcement Learning Approach**

Abstract Jaywalking, as a hazardous crossing behavior, leaves little time for drivers to anticipate and respond promptly, resulting in high crossing risks. The prevalence of Autonomous Vehicle (AV) technologies has offered new solutions for mitigating jaywalking risks. In this study, we propose a risk aware deep reinforcement learning (DRL) approach for AVs to make decisions safely and efficiently in jaywalker-vehicle interactions. Notably, a risk prediction module is incorporated into the DRL framework, making the AV agent risk-aware. Considering the complexity of jaywalker-vehicle conflicts, an encoder-decoder model is adopted as the risk prediction module, which comprehensively integrates multi-source data and predicts probabilities of the final conflict severity levels. The risk aware DRL approach is applied in a simulated environment established in Anylogic. The trained driving policies are evaluated from perspectives of safety and efficiency across three scenarios with escalading levels of jaywalker volume. Regarding safety performance, our *Proposed risk-aware* method outperforms the other methods in "medium jaywalker volume" scenario and "high jaywalker volume" scenario, with the "low TTC ratio" metric stabilizing near 0.09. Moreover, as the scenario gets more complex, the superiority of our *Proposed risk-aware* policy gets more evident. In terms of efficiency performance, our *Proposed risk-aware* policy ranks the second best, achieving an "AV delay" metric around 9.0 seconds in the "medium jaywalker volume" scenario and 9.8 seconds in the "high jaywalker volume" scenario. In practice, the proposed risk-aware DRL approach can help AV agents perceive potential risks in advance and navigate through potential jaywalking areas safely and efficiently.

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Session Number Poster Session 3212

Session Title **Vehicle-Highway Automation**

Paper Number 25-00446

Paper Title **Level of Automated Driving Safety in Urban Mixed Traffic Environment based on Real-world Autonomous Vehicle Data**

Introduction Identifying where, when, and how often hazardous driving situations occur on a road is essential for effectively preventing traffic crashes. There is considerable interest in analyzing mixed traffic consisting of autonomous vehicles (AVs) and manually driven vehicles (MVs) in terms of traffic safety because AVs and MVs have different driving behaviors. The level of autonomy and market penetration of AVs are important factors in determining the performance of mixed traffic streams. Guériau & Dusparic suggested that the introduction of low-level AVs will increase the number of traffic conflicts (*1*). Yao et al. reported that AV penetration below 50% in a connected AV environment increased the risk of rear-end collisions and resulted in a low time to collision (TTC) (*2*). The safety-prioritizing conservative behavior of AVs operated by Google's Waymo is threatened by adjacent MVs (*3*). Consequently, identifying the hazardous driving scenarios for AVs resulting from the interaction between AVs and MVs is fundamental for developing useful countermeasures to prevent traffic crashes in mixed traffic in the era of automated driving systems. Thus, we propose a methodology for determining the level of automated driving safety.

In the proposed method, the level of automated driving safety in mixed traffic is determined using the automated driving risk score (ADRS), which is obtained by integrating evaluation indicators for driving behavior. An open-source AV dataset obtained from a real-world autonomous mobility testbed in Korea is used to extract the evaluation indicators to identify road sections where driving safety is degraded. The ADRS is further processed to categorize the level of automated driving safety. This study is performed on an urban interrupted road network with mixed traffic, where frequent interaction between AVs and MVs deteriorates safety performance.

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Sponsoring Committee	ACP30
Session Number	Poster Session 3212
Session Title	**Vehicle-Highway Automation**
Paper Number	25-01039
Paper Title	**DynFollower: A Deep Reinforcement Learning based Car-Following Model for Smooth and Safe Cut-in Handling**
Abstract	The successful integration of autonomous vehicles (AVs) into the complex traffic environment hinges on the development of advanced car-following models capable of handling unexpected situations. Traditional car-following models often exhibit suboptimal performance during cut-in maneuvers, resulting in abrupt braking, reduced passenger comfort, and increased risk of accidents. This paper introduces DynFollower, a novel behaviorally dynamic car-following model that leverages Deep Reinforcement Learning (DRL) to address these challenges. By dynamically adjusting the desired gap time based on real-time traffic conditions, DynFollower prioritizes safety and comfort without compromising traffic efficiency. To evaluate DynFollower’s effectiveness, we conduct a comprehensive evaluation using a large-scale real-world dataset and extensive simulations of various cut-in scenarios. Our results demonstrate that DynFollower significantly outperforms traditional car-following models across multiple performance metrics, including safety, comfort, and overall driving experience. By enhancing the ability of AVs to navigate complex traffic situations, DynFollower contributes to the advancement of safe and efficient autonomous transportation.

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Sponsoring Committee	ACP30
Session Number	Poster Session 3212
Session Title	**Vehicle-Highway Automation**
Paper Number	25-01396
Paper Title	**An Optimization Framework for Safety-Critical Longitudinal Control of Connected Autonomous Electric Vehicles in Mixed Traffic**

Introduction

Roadway safety has been a widely discussed topic for a long time. Over the past decade, more than 370,000 people have died in transportation incidents, with over 350,000 of these fatalities occurring on our roads [1]. This threat to our safety is worsening. Consequently, reducing traffic incidents and improving the safety of the traffic system have become critical and urgent issues. Emerging automotive technologies are expected to bring significant changes to traffic and transportation. Recently, connected and autonomous vehicle (CAV) technology has garnered global attention. It is anticipated that the implementation of this technology will significantly alleviate issues like traffic congestion and accidents. CAVs have the potential to improve traffic safety by controlling their driving styles using real-time traffic information obtained from other connected vehicles (CVs) and RSU-installed infrastructure via V2X communication [2].

Several simulation-based studies have investigated the safety impact of CAVs on mixed traffic environments [3, 4, 5]. Most studies utilize stability analysis and simulation methods to evaluate the optimization potential of mixed traffic flow [6, 7]. Furthermore, an optimal control mechanism with safety guarantees for coordinating autonomous vehicle (AV) movements at a signal-free intersection has been developed without requiring vehicle-to-vehicle communications [8]. Although accurate traffic prediction and the safety impact of CAVs have been studied separately, to the best of our knowledge, their effective integration has not yet been fully explored. In addition, while HVs can benefit from a certain level of safety when following a CAV with optimal driving controls, previous studies have not explicitly considered the dynamics of HVs behind the CAV when devising optimal driving strategies. Consequently, this may limit the safety benefits for vehicles behind a controlled CAV. To fill these research gaps, this article examines the safety impact of a safety-critical control strategy that optimizes only the target CAV, incorporating traffic prediction under different TTC thresholds. We apply this to CAEV controls, optimizing both their speed and powertrain. Furthermore, the study focuses on designing a modified safety-critical control strategy for the target CAEV that accounts for its impact on the following HV. The proposed approach has the potential to enhance the safety of the HV following the optimally controlled target CAEV.

The present study contributes to the literature in the following aspects:

- We conduct systematic analyses on the safety improvements of the target CAEV using a baseline safety-critical longitudinal control strategy that focuses solely on the CAEV itself, in conjunction with the traffic prediction framework established in our recent study [9]. Based on the accurately predicted trajectory obtained from this framework and the safety-critical control strategy, the safety of the target CAEV is ensured across different TTC thresholds.

- Based on the aforementioned control strategy, we develop an enhanced real-time safety-critical longitudinal control algorithm that considers both the target CAEV and the HV following it. This control strategy is designed using a model predictive control (MPC) approach, which facilitates efficient computation and enhances safety for both the target CAEV and its following HV across various TTC thresholds.

- To assess the effectiveness and robustness of the proposed control strategy, we conduct extensive numerical simulations to evaluate its safety impact on a platoon of following HVs with various driving behaviors under different TTC thresholds. The promising results indicate that the proposed control strategy is effective across different driving scenarios.

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Sponsoring Committee	ACP30
Session Number	Poster Session 3212
Session Title	**Vehicle-Highway Automation**
Paper Number	25-02598
Paper Title	**Lane-Change Behavior of Human Drivers in Mixed-Traffic Conditions: A Safety Perspective**
Abstract	In mixed traffic, the lane-change behavior of human-driven vehicles (HDVs) depends on their interactions with connected and autonomous vehicles (CAVs). Since lane-change maneuvers are associated with a significant proportion of road accidents, it is important to investigate human drivers' lane-change behavior in the presence of CAVs with different control strategies to promote safe CAV operations. The study examines the safety performance of HDV lane changes in both HDV-only traffic and mixed-traffic conditions. Specifically, we evaluate three proactive CAV control strategies, involving assistance, preclusion, or management of HDV lane changes before execution, and one passive control strategy addressing induced traffic oscillation after lane changes. We analyze multiple surrogate safety metrics to evaluate three aspects of lane-change performance: available reaction time to potential collision (minimum time headway), risk of imminent collision (minimum time-to-collision), and driver's response intensity (maximum deceleration rate). In addition, we adopt a comprehensive safety performance index that integrates these metrics and provides an overall safety assessment. Driving data of 72 participants were collected in driving simulator experiments. The results show a significant improvement in participants' lane-change safety performance (e.g., larger minimum time headways) under mixed traffic with the proactive assistance CAV control strategy compared to HDV-only traffic. However, their safety performance was significantly worse under mixed traffic with proactive preclusion, proactive management, and passive control strategies compared to HDV-only traffic. The study findings deliver valuable insights into the dynamics of CAV-HDV interactions in mixed traffic, providing practical implications for the development of CAV control systems.

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Sponsoring Committee	ACP30
Session Number	Poster Session 3212
Session Title	**Vehicle-Highway Automation**
Paper Number	25-05605
Paper Title	**Safety Assurance Adaptive Control in Automated Vehicles: A Case Study on Modular Vehicles**
Abstract	Recent studies and industry developments indicate that Modular Autonomous Vehicles (MAVs) have the potential to enhance transportation systems by offering vehicles with adjustable capacities en route. This advantage largely relies on the precise control of docking operations, which involve safety concerns due to the proximity of MAVs. This paper proposes a distributed method to achieve docking and splitting operations for MAVs in uncertain environments. Specifically, the proposed method integrates a time-varying objective Model Predictive Control module, an adaptive module to dynamically adjust control parameters, and an adaptive safety assurance module utilizing Control Barrier Functions to ensure safe operation during risky maneuvers. We validated the effectiveness of the proposed method through simulations in Simulink and field tests using a reduced-scale MAV platform. Experimental results demonstrate that our approach effectively ensures smooth and safe vehicle following, as well as the execution of docking and splitting operations in uncertain environments.

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Sponsoring Committee	ACP30
Session Number	Poster Session 3212
Session Title	**Vehicle-Highway Automation**
Paper Number	25-05059
Paper Title	**Security Strategy against Generalized Inter-Vehicle Cyberattacks in Car-following Scenarios for Connected and Autonomous Vehicles**
Abstract	Connected automated vehicles (CAVs) can enhance both safety and efficiency by transmitting future driving intentions to surrounding traffic participants, enabling them to make intelligent decisions. However, if inter-vehicle communication is compromised by cyberattacks, fully trusting inter-vehicle information can lead to serious safety risks. This paper proposes a control strategy that cautiously utilizes inter-vehicle information in car-following scenarios to ensure absolute safety. We first generalize various inter-vehicle cyberattacks without relying on any assumptions about the nature of attacks from the perspective of decision-making. We then develop a control mechanism to transition between four modes: the connected mode, which fully relies on intervehicle information, the non-connected mode, which does not rely on this information at all, and two intermediate transition modes. Two trajectory optimization models are proposed for CAVs in connected and non-connected modes. The design of the intermediate transition modes and the misbehavior identification module allow for the identification of potential and dangerous cyberattacks and preemptive responses to ensure safety during close following. To validate the effectiveness of the proposed security strategy, we also develop a safety-critical cyberattack generation method to optimize the most risky and dangerous temporal cyberattack strategy. Through numerical experiments, we show that unprotected CAVs will crash under cyberattacks, while the proposed security strategy can improve the safety and efficiency of CAVs under cyberattacks. Our code and data will be opened upon the acceptance of this paper.

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Sponsoring Committee	ACP30
Session Number	Poster Session 3212
Session Title	**Vehicle-Highway Automation**
Paper Number	25-04890
Paper Title	**Risk-Informed Diffusion Transformer for Long-Tail Trajectory Prediction in the Crash Scenario**
Introduction	Autonomous driving is a revolutionary technological advancement set to transform transportation. Trajectory prediction is essential as it enables autonomous vehicles to plan routes and avoid collisions by forecasting the future paths of road agents based on their historical movements. Current research has numerous trajectory prediction methodologies, but achieving high accuracy is hindered by two main challenges.Diffusion probabilistic models have shown promise in trajectory generation (1). They introduce noise and then denoise to reconstruct the trajectory distribution (2, 3). Recent studies replaced the traditional convolutional U-Net with Transformers in diffusion models for better multi-dimensional perception (4). We thus adopted the diffusion with transformers (DiT) as a trajectory generator.In this paper, we used crash scenario trajectory data to improve long-tail dataset prediction. We introduced risk information like ITTC, velocity, and traffic flow features. We proposed RI-DiT, which uses the DiT module to generate multi-modal trajectories for enhanced realism. By extracting crash scenario trajectories and integrating risk-info and traffic flow in DiT, we improved long-tail data prediction. Experiments with real-world crash scenario vehicle trajectories showed our algorithm’s excellent performance, with minADE and minFDE values of 0.009/1.519 m respectively.

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Sponsoring Committee ACP30

Session Number Poster Session 3212

Session Title **Vehicle-Highway Automation**

Paper Number 25-04622

Paper Title **Safe, Efficient, and Comfortable Motion Planning for Autonomous Vehicles: An Embedded Surrounding Multiple Vehicles Trajectory Prediction Approach**

Abstract

This study introduces a trajectory prediction and motion planning model for autonomous vehicles, aiming to enhance safety, efficiency, and comfort within complex and dynamic driving environments. In the existing research landscape, two predominant methods are static trajectory generation and dynamically optimized trajectory generation. However, these approaches often overlook real-time traffic conditions during decision-making and struggle with time-consuming optimization algorithms. This study employs transformer-based long-term trajectory prediction of surrounding human-driven vehicles (HDVs) to formulate a comprehensive motion planning strategy for autonomous vehicles (AVs). Three distinct AV motion planning strategies are proposed: prediction-based car-following, prediction-based lane-changing, and an experimental strategy.

The approach's validation uses a scenario with one ego AV and three HDVs. A total of 210 car following events are extracted from a camera-based trajectory dataset for training and testing the model. Performance evaluation utilizes indicators like time to collision, headway, and jerk to assess safety, efficiency, and comfort. The results exhibit significant enhancements compared to an experimental strategy representing the AV's real-world trajectory. Specifically, the prediction-based lane-changing strategy and prediction-based car-following strategy yield 13.4% and 12.4% combined performance improvements, respectively. Notably, the prediction-based lane-changing strategy excels in safety and efficiency, while the experimental strategy falls short in all aspects. These findings underscore the value of integrating predicted HDV trajectories into AV motion planning, boosting adaptability and robustness in complex environments. This study advances AV motion planning, particularly in intricate traffic scenarios, highlighting the pivotal role of trajectory prediction in optimizing AV behavior.

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Sponsoring Committee ACP30
Session Number Poster Session 3212
Session Title **Vehicle-Highway Automation**
Paper Number 25-04120

Paper Title **From Active Safety Systems to Pro-Active Assistance Systems: Proving Ground Evidence of Anticipatory Driving Behavior On Current Level 2 Systems**

Abstract
Partially automated driving systems are increasingly available in the market. However, their behavior often remains reactive (e.g. adaptive cruise control, ACC) rather than predictive, potentially limiting their safety benefits. As driver assistance systems continue to improve and gain more capabilities, incorporating anticipatory behavior could be essential for enhancing safety. This paper compares two Level 2 systems based on results from an experimental campaign conducted on a proving ground. The vehicles are tested in car-to-car lead vehicle decelerating/braking tests (CCRb) and in cut-in maneuver tests. A novel approach to analyzing such test results reveals that one of the vehicles anticipates upcoming critical events, while the other reacts once the scenario becomes critical. The results show that reactive systems (ACC with Automated Emergency Braking, AEBS) rely on hard decelerations triggered by the AEB system after an emergency is identified. In contrast, the predictive system applies harder-than-normal deceleration in anticipation of events, thereby avoiding AEB activation and the need for maximum braking force. Similarly, in the cut-in tests, the anticipatory system reacts before the target crosses the lane markings. The anticipatory system was better at avoiding critical situations, showing clear safety benefits, and suggesting that anticipation could be a key requirement for driving automation.

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Sponsoring Committee	ACP30
Session Number	Poster Session 3212
Session Title	**Vehicle-Highway Automation**
Paper Number	25-03972
Paper Title	**Physics Enhanced Residual Policy Learning (PERPL) for Safety Cruising in mixed traffic platooning under actuator and communication delay**
Abstract	Linear control models have gained extensive application in vehicle control due to their simplicity, ease of use, and support for stability analysis. However, these models lack adaptability to the changing environment and multi-objective settings. Reinforcement learning (RL) models, on the other hand, offer adaptability but suffer from a lack of interpretability and generalization capabilities. This paper aims to develop a family of RL-based controllers enhanced by physics-informed policies, leveraging the advantages of both physics-based models (data-efficient and interpretable) and RL methods. We propose the Physics-Enhanced Residual Policy Learning (PERPL) framework, where the physics component provides model interpretability and stability. The Residual Policy adjusts the physics-based policy to adapt to the changing environment, thereby refining the decisions of the physics model. We apply our proposed model to decentralized control to mixed traffic platoon of CAVs and HVs using a constant time gap (CTG) strategy for cruising and incorporating actuator and communication delays. Experimental results demonstrate that, in scenarios with artificially extreme conditions and real preceding vehicle trajectories, our method achieves smaller headway errors and better oscillation dampening than linear models and RL alone. At the macroscopic level, overall traffic oscillations are also reduced as the penetration rate of CAVs employing the PERPL scheme increases.

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Sponsoring Committee	ACH30
Session Number	Lectern Session 4001
Session Title	**Trust in Vehicle Automation**
Paper Number	25-03362
Paper Title	**Effects of Trust to Automated Vehicle on Drivers' Mental Workload: A Naturalistic Driving Study**
Abstract	The driver's trust to automated vehicles directly affects their willingness to use it and has an effect on driving safety. Research on human factors under automated driving suggests that there has a strong connection between driving safety, trust, and mental workload. To analyze the effect of driver trust in automated vehicle on mental workload, 20 drivers were recruited to participate in a naturalistic driving experiment that considered automated/manual driving mode and non-driving related tasks (NDRT). Data of subjective trust questionnaire, NASA-TLX scale, NDRT performance and pupil diameter were collected in the experiment. First, drivers were divided into high-trust group and low-trust group based on subjective trust scores. Then, analysis of variance (ANOVA) was used to explore the effect of trust, driving mode, and NDRT on mental workload indicators. Finally, a comprehensive evaluation model of driver's mental workload was constructed based on grey relation analysis and entropy weight TOPSIS method. The results of ANOVA show that, driving mode and NDRT difficulty have a significant effect on subjective workload scores. Trust and NDRT difficulty have a significant effect on NDRT performance. Trust, driving mode, NDRT difficulty, and their interactions all have a significant effect on pupil diameter. The TOPSIS reveals that low-trust drivers experience higher mental workload during automated driving (0-back task:0.513, 1-back task:0.947), with more fluctuations in workload during automation. In contrast, automated driving can reduce mental workload for high-trust drivers (0-back task:0.046, 1-back task:0.590) and help them maintain a stable level of workload.

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Sponsoring Committee	ACH30
Session Number	Lectern Session 4001
Session Title	**Trust in Vehicle Automation**
Paper Number	25-03472
Paper Title	**To Apologize or Not to Apologize? Trust Repair After Automated Vehicles' Mistake**
Abstract	As automated vehicles (AVs) become more prevalent on complex and dynamic roads, they may encounter unexpected challenges and fail to meet user expectations. For example, AVs may misidentify road elements due to technical limitations in perception and understanding. Such mistakes can damage the trust relationship between AVs and their users. To address this, AVs are expected to employ social strategies to repair these damaged relationships. This study focuses on the effectiveness of apologies—a common social strategy in human relationships—in repairing broken trust after an AV makes a false alarm mistake. In our pre-registered experiment, Chinese drivers (N = 291) watched two online videos: one demonstrating the AV's reliable operation and another showing the AV incorrectly identifying a non-existent pedestrian, leading to an unnecessary stop. They were randomly assigned to three groups: no repair (ignoring the mistake), an apology with a male Siri voice, and an apology with a female Siri voice. Surprisingly, the AV's apology, regardless of the voice's gender, negatively influenced trust repair. It damaged perceptions of the AV's ability but did not affect perceptions of the AV's integrity and benevolence. We explain that apologies may raise drivers' concerns about AVs' competence. Our findings highlight a potential side effect of using apologies in human-automation interaction.

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Sponsoring Committee ACH30

Session Number Lectern Session 4001

Session Title **Trust in Vehicle Automation**

Paper Number 25-01231

Paper Title **Trust Dynamics in Driving Automation: The Effects of Initial Expectations and Error Consistency**

Introduction

Recent advancements in Driving Automation Systems (DASs) have the potential to improve road safety, efficiency, and reduce human errors (1–2). However, the successful usage and acceptance of DASs depend heavily on drivers' trust in the system (3). This study investigated how drivers form trust based on their initial expectations and consistency in errors made by the DAS. Trust in automation refers to a driver's belief in a DAS's ability to perform its tasks accurately in uncertain and risky road conditions (4). Trust evolves through continuous interactions with the system or other meaningful experiences as drivers form a clearer understanding of the system, a process known as trust calibration (4, 5-6). Calibrated trust is essential to ensure drivers neither underutilize nor overtrust the system, both of which can lead to safety risks (7). Expectations refer to drivers' beliefs about how a DAS will behave (8), shaped by their mental models— a person's internal representation of that system, including its purpose, structure, and functioning (9–10). Mental models, and thus expectations, evolve with experience (11). Previous research shows mixed results on how expectations affect trust. Some studies found that the accuracy and completeness of expectations on system capabilities play a role in drivers' trust (12-13), while others did not reveal an effect of expectations (14). Due to the unsettled relationship, we grounded our study in Expectation-Confirmation Theory (ECT, 15) and proposed that trust in DASs would be influenced by the alignment between initial expectations and system performance, with trust increasing when expectations were met and decreasing when unmet.

As revealed by past studies, a system's failures to perform actions and Takeover Requests (TORs) that demand human intervention can reduce trust (16–17). However, little research has been conducted to understand how error consistency affects drivers' trust. Muir proposed that predictability–the system's ability to behave consistently and be reliably anticipated by operators–is crucial for trust development (18). Unpredictability can lead to unsafe driving behaviors, such as deviation from the ideal trajectory (19) and delayed responses in takeovers (20). Given its importance, it is vital to study how error consistency impacts trust and safety in automation systems. This study examined the effects of drivers' initial expectations and error consistency on trust in a Level-3 DAS. Participants' expectations were manipulated as either high or low through descriptions of the system's capabilities. Error patterns were varied across three simulated driving scenarios: no error, consistent errors, and inconsistent errors. Measures included trust (through subjective reports) and reaction time to TORs. We hypothesized that:

1.1: The low-expectation group would report higher trust than the high-expectation group;
1.2: Inconsistent errors were expected to result in the lowest trust, and no errors the highest;
2.1: The low-expectation group would have shorter TOR times;
2.1: Inconsistent errors would result in longer TOR times.

We found that while initial expectations did not significantly impact trust, the system's actual performance did. Inconsistent errors reduced trust by decreasing predictability. These results highlighted the importance of drivers' interactions with DASs and predictable system behavior in fostering calibrated trust and safer driving.

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Sponsoring Committee	ACH30
Session Number	Lectern Session 4001
Session Title	**Trust in Vehicle Automation**
Paper Number	25-04121
Paper Title	**Examining Driving Behaviors and Trust in An In-vehicle Warning System Under Uncertainty: A Driving Simulator Study**
Introduction	With advances in vehicular technologies, advanced driver assistance systems (ADAS) have been developed to provide real-time roadway information and improve drivers' situational awareness. As an important function of ADAS, collision assistance aims to alert drivers in situations where they may be distracted or at risk of a crash (Han, 2020; Jamson et al., 2008; Yue et al., 2021). Extensive research shows that ADAS can influence driving behaviors and enhance safety (Han, 2020). These studies explored the effects of the presence of warnings (McGehee et al., 2002; Yue et al., 2018, 2021), types of warning information (Liu & Jhuang, 2012; Y. Zhang et al., 2015), and warning timings (Lee et al., 2002; Winkler et al., 2016). Among different warning characteristics, warning timing is crucial for ADAS design, significantly influencing how drivers perceive and react to alerts (Winkler et al., 2016). However, warning time may not always be reliable due to variations in drivers' perceptions and/or sensor prediction errors (Ben-Yaacov et al., 2002; Navarro et al., 2017; Parasuraman & Riley, 1997; Sullivan et al., 2008; Wang et al., 2016), which significantly influences drivers' reactions and safety performance. On the one hand, early warnings offer greater potential for providing drivers with sufficient reaction time to prevent collisions. However, if warnings are issued too early, they may be perceived as false positives, where the system erroneously alerts the driver to a non-existent danger (Sullivan et al., 2008). Conversely, late warnings fail to provide adequate reaction time, which can be classified as false negatives—where the system does not alert the driver to an actual hazard. Regardless of whether warnings are provided early or late, if the warning system suffers from higher variations with higher uncertainty, drivers may lose trust (Bliss & Acton, 2003), which can directly influence the safety performance (Ayoub et al., 2023; Körber et al., 2018). Safety concerns related to uncertainties in prediction modules, particularly in machine learning-based models, have gained significant attention in recent years due to their susceptibility to noise and inference errors (Jain et al., 2021). These uncertainties can influence drivers' risk perception, which in turn affects their driving behavior, decision-making, and overall trust of the system. Therefore, it is necessary to 1) understand the relationship between warning system uncertainty and trust, and 2) predict drivers’ trust to ensure it aligns with the system's actual capabilities. Moreover, most existing studies use both hypothetical crash scenarios and warning time distributions, which may not accurately reflect real-world conditions.

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Sponsoring Committee	ACH30
Session Number	Lectern Session 4001
Session Title	**Trust in Vehicle Automation**
Paper Number	25-01205
Paper Title	**An Investigation into How Vehicle Reliability, Confidence Information, and Repeated Exposure Affect Trust in Automated Vehicles**
Introduction	There is growing optimism about the potential societal benefits of automated vehicles (AVs) (1–3). Despite widespread enthusiasm, one prevailing concern pertains to the trustworthiness of AVs (4, 5), as drivers' trust is suggested to be an important factor influencing one's usage of and interactions with automated systems. Particularly, low trust or distrust is often the result of one's belief that AVs do not always perform reliably (6). Numerous studies have identified ways to enhance drivers trust in AVs (7, 8). According to Lee & See (2004) (9), providing information about a system's status using a human-machine interface (HMI) is one way to elevate trust levels in AV systems. In anticipation of significant future advancements in the intelligence of AV, other studies have introduced the concept of an intelligent confidence (or certainty) display to show an AV's self-assurance in its own prediction of obstacle detection and future path planning. A second way to increase driver's trust is over time via repeated exposures to AVs (10, 11). Lee et al. (2021) (10) explored changes in driver trust when AV failures occurred and an increase in trust over repeated drives despite AV failures. Overall, previous studies have identified several factors that influence trust and/or examine how trust changes over time. However, this prior work has not comprehensively quantified the strength of how vehicle-related factors influence trust nor explored the degree of correlation among vehicle-related factors and trust. Also, AVs may occasionally commit errors in correctly predicting their behavior, thereby presenting inaccurate information to drivers. To address this research gap, in the present study, we seek to understand how certain vehicle-related factors, namely 1) an automated vehicle's reliability, 2) the dynamics and accuracy of an AV's self-assessed confidence information, and 3) the number of AV-driver interactions, impact drivers' trust (and takeover decisions) in conditionally automated vehicles. A second objective is to quantify the degree of interrelations among these factors. Hypotheses We identified several factors influencing trust in AVs (assessed via driver subjective trust, takeover decisions, and decision correctness), focusing on the impact of vehicle reliability, self-assessed confidence information dynamics and accuracy, and the repetition of AV exposure. To this end, we developed 12 hypotheses: H1-3: High vehicle reliability is associated with a positive effect on trust in AVs/a lower number of takeovers/a greater number of correct decisions. H4-6: High system confidence is associated with a positive effect on trust in AVs/a lower number of takeovers/a greater number of correct decisions. H7-9: Accurate information is associated with a positive effect on trust in AVs/ a lower number of takeovers/a greater number of correct decisions. H10-12: Repetitive experiences with AVs are associated with a positive effect on trust in AVs/ a lower number of takeovers/a greater number of correct decisions.

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Sponsoring Committee	ACS20
Session Number	Poster Session 4073
Session Title	**Safety Performance and Analysis for Safe Vehicles**
Paper Number	25-00827
Paper Title	**Spatio-Temporal Accident Detection through Traffic Impact Analysis Using Connected Vehicle Data**
Introduction	Traffic accidents represent a significant threat to public safety and a major disruption to the efficient flow of vehicles on road networks, posing a critical challenge for both emergency responders and traffic management authorities. According to the World Health Organization, road traffic accidents result in over 1.3 million deaths annually, with many more sustaining serious injuries, highlighting the urgent need for effective accident detection and response systems WHO (1). In addition to the human cost, accidents cause congestion, reduce mobility, and lead to significant economic losses. Efficient accident detection and prompt response can mitigate these negative impacts, but current systems face limitations in terms of accuracy and timeliness. While various methods have been developed for accident detection, many rely on static sensor infrastructure (e.g., roadside cameras Tian et al. (2) or loop detectors Liyanage et al. (3)) or post event reporting by individuals. These approaches often suffer from delayed detection and limited spatial coverage. Moreover, they struggle with accurately detecting accidents in real-time, particularly in cases involving rapid traffic flow changes. There remains a research gap in developing real-time, high-precision detection methods that leverage dynamic data from connected vehicles. The use of real-time vehicle data to differentiate between congestion caused by accidents and that caused by other factors, as well as to track the formation and resolution of these patterns, has not been thoroughly explored in current research. This study aims to address these limitations by evaluating an advanced accident detection method that leverages real-time data from vehicles continuously transmitting their GPS positions to a central server. This data is analyzed using Kerner's three-phase traffic theory (3PTT) Kerner (4), which models the complex behavior of traffic flow transitions. By integrating this theory with an innovative rule-based algorithm, our approach identifies accident-prone locations and times with high precision. The algorithm assesses traffic patterns based on data from a connected vehicle fleet, analyzing the formation and dissipation of congestion. The research uses a robust global dataset consisting of 2,500,000 vehicle probes from various regions, with different levels of vehicle fleet penetration. Ground truth data is incorporated from traffic services that aggregate information from police reports, public authorities, and individual users. This diverse and comprehensive dataset allows for a thorough evaluation of the proposed method, particularly its ability to detect both the onset of traffic jams due to accidents and their resolution. Studies using similar datasets can be found in Kessler and Bogenberger (5), Paczia et al. (6) and Rempe et al. (7).

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Sponsoring Committee	ACS20
Session Number	Poster Session 4073
Session Title	**Safety Performance and Analysis for Safe Vehicles**
Paper Number	25-00906
Paper Title	**Crash-based Safety Testing of Autonomous Vehicle: Insights from Generating Safety-Critical Scenario based on In-Depth Crash Data**
Abstract	Safety is a paramount concern in the development of Autonomous Vehicles (AVs) within the automotive industry. Ensuring AVs reliable performance requires the development of varied and realistic testing scenarios. Identifying unknown hazardous scenarios presents a notable challenge in testing process. To address a wider spectrum of unknown hazardous scenarios, this study introduces a novel methodology for generating safety-critical scenarios for AV safety testing based on in-depth crash data. First, we utilized the China In-depth Mobility Safety Study-Traffic Accident (CIMSS-TA) database to decompose crash scenarios into static and dynamic variable tuples. Subsequently, the time series Generative Adversarial Networks (TimeGAN) was utilized to capture temporal features and to generate safety-critical scenarios using the original dataset. The synthesized scenarios were then assessed in terms of similarity, usability, and risk. Finally, a well-known autonomous driving system, Baidu Apollo, was tested in both original and synthesized scenarios. The experimental results demonstrate that safety-critical scenarios derived from in-depth crashes preserve the essential risk characteristics. Furthermore, Baidu Apollo exhibits superior safety performance in hazardous situations compared to human drivers. The synthesized scenarios provide a comprehensive dataset for testing AVs in high-risk situation. This method addresses the challenge of limited crash data, broadening the scope of safety-critical scenarios and enhancing the assessment and advancement of AV technology

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Session Number	Poster Session 4073
Session Title	**Safety Performance and Analysis for Safe Vehicles**
Paper Number	25-02183
Paper Title	**Analysis of ADAS- and ADS-equipped Vehicle Crashes Using Mixed-effects Logistic Regression**
Abstract	With the advent of vehicle automation technologies, the question of the association between vehicles with automation capabilities and safety looms large among transportation professionals and researchers. So far, little is known about this topic, primarily due to the lack of empirical evidence and dearth of quality data. To this end, this study explores various factors influencing crash severity and other crash characteristics in vehicles with automated driving capabilities of different levels (ADAS and ADS) utilizing mixed effects logistic regression with crash data between 2021 and 2024 from NHTSA. The study reveals factors including vehicle mileage, lighting, roadway surface, and weather conditions, airbag deployment, safety belt use, crashes with pedestrians, and other vehicle movement significantly influenced ADAS-equipped vehicle crash severity. Also, predictors including speed limits, vehicle mileage, driver engagement type, weather conditions, crashes with pedestrians, and other vehicle maneuvers were significantly associated with ADS-equipped vehicle crash severity. Furthermore, while speed limits, vehicle age and mileage, and crashes with pedestrians impacted safety belt use and airbag deployment in ADAS-equipped vehicle crashes, factors including speed limits, crashes with pedestrians, vehicle age and mileage, driver engagement level, ADS-equipped vehicle and other vehicle movements, and crash location influenced safety belt use and airbag deployment in ADS-equipped vehicle crashes. The results of this study shed light on the limited knowledge pertaining to safety of automated vehicles and might help industry and researchers to delve more into the key areas of interest related to safety of vehicle automation technologies.

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Sponsoring Committee	ACS20
Session Number	Poster Session 4073
Session Title	**Safety Performance and Analysis for Safe Vehicles**
Paper Number	25-01653
Paper Title	**What Can We Learn from Field Tests of Commercially Available Automatic Emergency Braking Systems: A Focus on System Limitations**
Introduction	Rear-end crashes account for one-third of US traffic crashes (*1*). Automatic Emergency Braking (AEB) systems, commercially available in levels 1-2 Automated Vehicles (AVs), promise to mitigate rear-end crashes. It has been shown that AEB-equipped vehicles experience 34% to 50% fewer police-reported front-to-end crashes than similar vehicles without AEBs (*2-4*). While AEBs have proven to be effective in reducing the incidence of front-to-rear crashes, their performance varies due to various factors (*5-8*). This study evaluates the effectiveness and limitations of AEBs, analyzing 924 well-designed controlled tests conducted by the Insurance Institute for Highway Safety (IIHS) from 2017-2022, of which 128 resulted in crashes. A Bayesian random-effects regression model is applied to estimate the impact speed in crashes, providing insights into the correlates of AEB performance. Findings show AEBs prevent crashes in 86% of tests, but limitations like late activation (54.68% of crashes) and inadequate deceleration rate (27.34%) persist. Larger vehicles. e.g., SUVs and Electric Vehicles (EVs) are associated with higher impact speeds, necessitating tailored AEB designs. By shedding light on the potential benefits and limitations of AEBs, this study aims to make a valuable contribution to addressing the pressing issue of safety in commercially available AVs, reflecting the high priority of the US Department of Transportation (*9*).

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Sponsoring Committee	ACS20
Session Number	Poster Session 4073
Session Title	**Safety Performance and Analysis for Safe Vehicles**
Paper Number	25-02341
Paper Title	**Crash Injury Severity Analysis under Different Levels of Driving Automation**
Abstract	Vehicles equipped with automated driving capabilities have shown potential to improve safety and operation. Advanced driver assistance systems (ADAS) and automated driving systems (ADS) have been recently developed to support vehicular automation. Studies on the injury severity outcomes of automated vehicles are still limited, particularly investigating the difference between injury severity outcomes for the ADAS and ADS equipped vehicles. To ensure a comprehensive analysis, a multi-source dataset that includes 1,001 ADAS crashes (SAE Level 2 vehicles) and 548 ADS crashes (SAE Level 4 vehicles) is used. Two random parameters multinomial logit models with heterogeneity in the means of random parameters are estimated to gain a better understanding of the variables impacting the crash injury severity outcomes for the ADAS and ADS vehicles. The model estimation results reveal that the weather, driver indicator, differences in the system sophistication that are captured by both manufacture year and high/low mileage as well as rear and front contact indicators all play a role in the injury severity outcomes. The results offer an exploratory assessment of safety performance of the ADAS and ADS equipped vehicles using the real-world crash data and can be used by stakeholders to refine the direction of their deployment and usage.

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Sponsoring Committee	ACS20
Session Number	Poster Session 4073
Session Title	**Safety Performance and Analysis for Safe Vehicles**
Paper Number	25-03517
Paper Title	**Are We Ready for Automated Vehicles? Evaluating Automated Driving Systems' Safety and Reliability Using Propensity Score Matching**
Introduction	Traffic crashes remain a critical issue, with approximately 40,000 fatalities and millions of injuries annually in the United States (*1*). Automated Driving Systems (ADS) have emerged as a potential solution, promising significant improvements in road safety, traffic efficiency, and mobility (*2-5*). By employing advanced technologies such as sensors, cameras, and artificial intelligence, ADS vehicles aim to operate with minimal human intervention (*6-9*). However, their integration into existing traffic systems presents unique safety and reliability challenges (*10-12*). Prior studies have highlighted several concerns regarding ADS functionality, including rear-end collisions, higher crash rates in certain scenarios, and challenges in detecting vulnerable road users (*13-15*). Moreover, issues such as disengagements, limitations in handling adverse weather, and interactions with complex driving environments exacerbate injury risks, especially in remote or no-driver configurations (*16-22*). These challenges underscore the need for robust evaluation of ADS reliability and safety protocols. This research employs Inverse Probability Weighted Regression Adjustment (IPWRA) to examine ADS-related injury crashes using NHTSA data from July 2021 to July 2024 (*23; 24*). The analysis focuses on injury likelihood under varying operational scenarios, including remote and fully autonomous configurations, while controlling for critical factors such as intersections, adverse weather, and pre-crash speeds. The findings reveal that remote driver involvement increases injury risks by 18.3%, while no-driver scenarios elevate these risks by 23.3%. These results emphasize the need for refining ADS detection, response mechanisms, and operational protocols to ensure safer integration into traffic systems. This research provides actionable insights for policymakers and manufacturers, advancing the understanding of ADS safety and contributing to future transportation innovations.

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Sponsoring Committee	ACS20
Session Number	Poster Session 4073
Session Title	**Safety Performance and Analysis for Safe Vehicles**
Paper Number	25-04100
Paper Title	**Safety Evaluation of Automated Vehicles Using Surrogate Safety Measures**
Abstract	In recent years, automated vehicles (AVs) are increasingly penetrating road networks with the main purpose of reducing driver error. Since around 94% of traffic crashes are due to driver error, automated vehicles have the potential to enhance road safety by eliminating human drivers' tasks. To date, researchers have used surrogate safety measures, such as time-to-collision (TTC) to quantify the near-crash occurrence of vehicles, where 1.5 seconds is typically considered as the critical TTC for manually-driven vehicles. Although AVs can travel with shorter headway due to their enhanced safety features, studies continue to use the same threshold value in their analysis. The purpose of this study is to measure the reaction time of AVs currently available in the market while they are traveling in car-following mode on the network. These findings can be used to identify the critical TTC and assess potential conflicts. To this end, two different approaches, cross-correlation and visibility graph algorithm, were used to determine the reaction time of AVs both along freeway and arterial facilities. The results indicate that the mean reaction time of AVs is 0.95 seconds and 1.05 seconds on freeways and arterials, respectively. Considering these values as the critical TTC thresholds, this study found no incidents of potential conflicts for AVs in the provided dataset, which aligns with previous studies, proving the safety benefits of AVs.

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Session Number	Poster Session 4073
Session Title	**Safety Performance and Analysis for Safe Vehicles**
Paper Number	25-04566
Paper Title	**Examining Spatial Disparities in Safety Benefits from Automated Vehicle Adoption in Alabama and Kentucky**
Introduction	This study investigates the spatial disparities in safety benefits associated with adopting Automated Vehicle (AV) technologies in Alabama and Kentucky, focusing on the differences between urban and rural communities. Automated Vehicles offer significant potential to reduce traffic crashes caused by human error, which accounts for 90% of such incidents (*1*). Advanced safety systems, including vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) technologies, are expected to mitigate critical crash causes such as recognition, decision, and performance errors (*2*). However, despite the promise of these technologies, it remains unclear whether their safety benefits will be equitably distributed across different geographic and sociodemographic contexts. The research integrates AV adoption predictions at the Census Block Group (CBG) level with a spatial analysis of crash data to explore these disparities. By combining AV adoption models with crash reduction estimates, the study identifies areas with varying crash frequencies and AV adoption interest levels, including urban areas with high crash frequencies but low AV interest and rural areas with specific crash types like rollovers. These findings provide a valuable tool for policymakers to design equitable strategies for AV deployment that maximize safety benefits across different regions. This work contributes to both theory and practice by combining adoption modeling with geographically disaggregated safety analyses, ensuring the insights can inform both academic research and transportation policy planning.

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Sponsoring Committee	ACS20
Session Number	Poster Session 4073
Session Title	**Safety Performance and Analysis for Safe Vehicles**
Paper Number	25-05004
Paper Title	**Examining the Role of Vehicle Dimensions and Advanced Driving Assistance Systems on Pedestrian and Bicyclist Injury Severity Outcomes**
Abstract	In the event of a crash between active traveler and motor vehicle, vehicle characteristics (both internal and external vehicle features) are likely to play a significant role. With regards to external and internal vehicle features, it might be beneficial to examine the interplay of vehicle dimensions and Advanced Driving Assistant System (ADAS) on active traveler injury severity outcomes. 6 Towards that end, the major contribution of this study is grounded in examining the effect of vehicle type (represented by vehicle length and width) on active traveler injury severity outcomes while also controlling for ADAS and other exterior features of motor vehicles. Specifically, we propose a joint modeling framework to examine vehicle types and injury severity outcomes as two dimensions of the active traveler injury severity mechanisms. In the joint modeling process of this study, the vehicle type component is estimated by using random regret minimization based multinomial logit model, while the injury severity component is estimated by using generalized ordered logit formulation. Further, the time-varying effects of exogenous variables are accommodated by using piecewise linear function of crash year. The proposed model is demonstrated by using active traveler crash data from Queensland, Australia for the years 2015 through 2022. The outcomes of the study will inform future vehicle design in improving active traveler safety.

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Sponsoring Committee	ACS20
Session Number	Poster Session 4073
Session Title	**Safety Performance and Analysis for Safe Vehicles**
Paper Number	25-05082
Paper Title	**Network-wide Spatiotemporal Extreme Value Theory Model for Estimating Crash Risks From Traffic Conflicts Using Autonomous Vehicle Sensor Data**
Statement of significance	Autonomous vehicle (AV) trials on public roads have generated unprecedented, detailed datasets, which has the potential to aid the development of comprehensive conflict-based network-wide safety models. Existing conflict-based extreme value theory models, mostly based on roadside sensors, are restricted to a few concentrated locations and are not scalable to the network level because of the lack of capability to account for spatial heterogeneity. This study proposes a spatiotemporal generalised extreme value (GEV) modelling framework to estimate the rear-end crash risks at a network level utilising the traffic conflicts extracted from AV sensors. This study contributes to the literature in the following ways. First, this study contributes significantly to traffic safety analysis by validating extreme value theory models in conjunction with traffic conflict techniques for assessing rear-end crash risks network-wide, addressing a notable gap where large-scale, conflict-based crash risk assessments are relatively rare. Second, the study develops a network-wide safety analysis framework that uses AV sensor data to obtain trajectory information, providing rich behavioural information about road user interactions and their surroundings, which is often missing in extreme value theory studies, as noted in a recent review study [1].

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Sponsoring Committee	ACS20
Session Number	Poster Session 4073
Session Title	**Safety Performance and Analysis for Safe Vehicles**
Paper Number	25-05230
Paper Title	**Integrating Connected Vehicle Hard Braking Event Data for Proactive Road Network Safety Screening**
Abstract	Advancing road safety necessitates a systematic departure from reliance on historical crashes to alternative measures to facilitate proactive road safety improvement. This study examines the potential integration of hard braking events (HBE) from connected vehicles (CV) as crash surrogates for network screening. After an initial spatial autocorrelation and Spearman correlation, the suitability of HBE as a surrogate safety measure for network screening was examined for four crash types, including all crashes, rear-end crashes, no-injury crashes, and severe crashes. The common hotspots analysis showed that a significant proportion of the crash-based hotspots were also identified using HBE as follows: all crashes (86.25%), rear-end crashes (96.83%), no-injury crashes (85.37%), and severe injury crashes (78.22%). The comparison of the common hotspots ranking based on crash data and HBE revealed that the rear-end crashes had the least TRD for the top 20 and 30 hotspots. The average ranking difference shows a decreasing trend as the number of top hotspots increases for all the crash types except for severe crashes. These findings indicate that HBE could be more appropriate for identifying locations with elevated risks of rear-end crashes than other considered crash types. This study provides helpful insight into the potential of HBE as crash surrogates for network screening. The findings can assist safety management agencies in conducting timely road network performance evaluations and identifying locations that could benefit from advanced safety improvement to mitigate the possible manifestation of traffic conflicts into crashes.

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Sponsoring Committee	ACS20
Session Number	Poster Session 4073
Session Title	**Safety Performance and Analysis for Safe Vehicles**
Paper Number	25-05379
Paper Title	**Safety Validation of Automated Vehicles Using Aggregate Markov Chain Theory**
Abstract	AV safety testing requires the evaluation of the occurrence and evolution of safety-critical rare states. Existing scenario-based methods use designed episodes of limited lengths to estimate accident rates, which fails to address how vehicles transition into dangerous states over time. This paper proposes a new perspective that analyzes the occur probabilities of various states over an infinite driving process, providing a comprehensive analysis of the distribution and evolution of near-collision states. By employing Markov Chain steady-state probability theory, state probability distributions are derived from state transition matrices, which can be directly extracted from AV action models, thus avoiding the "curse of rarity." To address the high-dimensional state space issue, aggregate Markov Chain theory is introduced to cluster the state space for effective estimation. We aggregate microscopic states into macroscopic blocks, simplifying the high-dimensional microscopic state transition relationships into macroscopic block transition probability estimation to reduce the complexity. An iterative steady-state sampling method is designed to estimate transition patterns across states of varying danger levels. Simulation experiments compare the proposed method with the Monte Carlo benchmark, showing that the proposed method can estimate dangerous state probabilities using just 0.03% of the sample size and provide more valuable assessment insights than existing studies.

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Sponsoring Committee	ACS20
Session Number	Poster Session 4073
Session Title	**Safety Performance and Analysis for Safe Vehicles**
Paper Number	25-05696
Paper Title	**Leveraging Automated Vehicle Technology to Enhance Driving Safety in Dilemma Zones: A Validation Study**
Abstract	Existing research primarily employs signal-based approaches or Connected Vehicle-based technologies to alleviate the negative impacts of the yellow-light Dilemma Zone (DZ) on safety. However, these methods either reduce the mobility performance at the intersection level or challenge the driver to perform multiple tasks. Emerging Automated Vehicle (AV) technology has the potential to enhance DZ driving safety without involving human drivers if full automation is achieved. Until then, drivers are needed in the automated driving environment to handle AV disengagements. Therefore, how drivers will behave and respond when driving an AV to proceed through the intersection at the onset of yellow remains unknown. More importantly, whether AV is the ultimate answer to DZ driving safety remains unanswered. To address these issues, this research aims to validate whether AV technology is effective in improving DZ safety and identify the characteristics that make AV effective in enhancing safety performance at DZ. A driving simulator study was conducted by inviting 45 participants to drive through a signalized intersection at the onset of yellow under Levels 0, 3, and 4, respectively. Demographical information, driving behavior, and safety performance were collected. The research concludes that as the level of automated driving increases, the probability of traffic conflicts significantly decreases in the DZ scenario. Individuals with high income and education levels but do not believe AV's safety benefits are at a high level can benefit from Level 4 automation in enhancing driving safety through the signalized intersection. The conclusions will benefit AV deployment in urban scenarios.

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Sponsoring Committee ACS20

Session Number Poster Session 4073

Session Title **Safety Performance and Analysis for Safe Vehicles**

Paper Number 25-05769

Paper Title **Investigating the Role of Advanced Driver Assistance Systems (ADAS) in Reducing Sideswipe Collisions in Rural Ohio**

Abstract Rural areas experience a higher fatality rate per distance traveled compared to urban areas. A significant portion of rural crashes are sideswipe collisions attributed to driver error. Advanced Driver Assistance Systems (ADAS), including Blind Spot Warnings (BSW), Lane Departure Warnings (LDW), and Lane Keeping Assistance (LKA), can help mitigate these types of collisions. Despite the availability of these technologies, there is limited literature exploring their benefits. This study analyzes the impact of vehicles with and without ADAS technologies, considering various factors contributing to sideswipe collisions in rural Ohio. Using Bayesian Networks, the study examines crash data collected from 49 rural counties in Ohio between 2017 and 2022. The crash statistics indicate that adult drivers are frequently involved in sideswipe crashes. Additionally, the analysis identifies vehicles with level 0 automation as being more likely to be involved in these collisions. The findings from the Bayesian Network suggest that vehicles equipped with either BSW, LDW, LKA, or all three technologies have a reduced probability of fatal or severe injury crashes. Ultimately, this study aims to inform transportation engineering professionals and policymakers that ADAS is a potential solution for significantly reducing sideswipe collisions in rural Ohio. It also advocates for implementing policies such as in-cab cameras to prevent distracted driving.

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Sponsoring Committee ACS20

Session Number Poster Session 4073

Session Title **Safety Performance and Analysis for Safe Vehicles**

Paper Number 25-06028

Paper Title **Evaluating Safety Benefits of Various Automation Levels and Penetration Rates of Automated Vehicles: A Case Study from the Netherlands**

Abstract Road traffic crashes result in approximately 1.19 million deaths annually, with vulnerable road users (VRUs) accounting for over half of these fatalities. With human error responsible for over 90% of crashes, the potential of connected and automated vehicles (CAVs) to enhance road safety by minimizing such errors is significant. This study aims to comprehensively analyze the safety impacts of different levels of CAV market penetration using traffic microsimulation based surrogate safety assessment. A calibrated and validated microsimulation model (developed in AIMSUN Next) of Veenendaal city in the Netherlands was used to perform the simulation experiments. The driving characteristics of CAVs in the microsimulation model were defined based on various previous research studies and the safety impacts were examined under a range of mixed scenarios with different levels of automation and CAVs market penetration. Results indicate that with high dominance of CAVs, conflicts can be reduced significantly. These findings suggest that the integration of CAVs can substantially enhance road safety, provided there is a sufficient market penetration of higher-level automated vehicles.

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Sponsoring Committee	ACS20
Session Number	Poster Session 4073
Session Title	**Safety Performance and Analysis for Safe Vehicles**
Paper Number	25-06076
Paper Title	**Identifying High-Risk Locations on Expressways Using Connected Vehicle Data: An Empirical Analysis**
Statement of significance	This research leverages connected vehicle (CV) data to address limitations in traditional road safety analysis, such as long accumulation period, limited data volume, imprecise location description and underreporting. By utilizing empirical data from Shanghai expressways, the study demonstrates the potential of CV warnings, including headway monitoring and forward collision warnings, to identify high-risk locations in real time. By integrating spatial autocorrelation methods and advanced statistical modeling, including instrumental variable approaches, the research provides a robust framework for analyzing the relationship between warnings and collisions. This study offers TRB attendees valuable insights into a novel, data-driven approach to proactive road safety management, with actionable implications for policymakers, engineers, and researchers dedicated to improving urban traffic safety.

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Sponsoring Committee	ACS20
Session Number	Poster Session 4073
Session Title	**Safety Performance and Analysis for Safe Vehicles**
Paper Number	25-06120
Paper Title	**Evaluating Traffic Safety Information Strategies for Identified Hazardous Infrastructures Using Autonomous Vehicle Demonstration Data**
Statement of significance	This research addresses critical safety challenges in mixed traffic environments involving autonomous and manually driven vehicles. By integrating real-world AV trajectory data with accident reports, the study identifies vulnerable sections and evaluates the effectiveness of traffic management strategies, such as Variable Message Signs (VMS), through simulations and linear mixed models. The findings provide actionable insights for enhancing traffic safety and operational efficiency, making it highly relevant to policymakers, researchers, and practitioners. Attendees of the TRB Meeting will benefit from the study's innovative methodology and practical implications for managing the transition to autonomous mobility systems.

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Sponsoring Committee	ACS20
Session Number	Poster Session 4073
Session Title	**Safety Performance and Analysis for Safe Vehicles**
Paper Number	25-06397
Paper Title	**Effects of Advanced Driving Assistance Systems (ADAS) on Driver Injury Severity Outcomes: A Joint Multinomial Logit and Generalized Ordered Logit Model**
Abstract	The arrival of Connected and Autonomous Vehicles (CAVs), Autonomous Vehicles (AVs) and vehicles equipped with Advanced Driving Assistant Systems (ADAS) on our road networks marks a significant shift in transportation safety as these vehicles have the potential to reduce the frequency of road crashes, and also lessen the crash severity outcome. However, managing the mixed traffic environment (CAVS, AVS, traditional vehicle with ADAS, and traditional vehicle) requires thoughtful policies and adaptable traffic management strategies to maximize safety while minimizing risks. Towards that end, the major contribution of this study is grounded in examining the effects of ADAS features on driver injury severity outcomes while also controlling for other confounding factors. Specifically, we propose a joint model of ADAS features and driver injury severity component modeled as two dimensions of injury severity mechanism. In the joint modeling process of this study, the combinations of different ADAS features available in motor vehicles are modeled by employing multinomial logit model while driver injury severity outcomes component is modeled by employing generalized ordered logit model. The proposed model was estimated by using crash data from Queensland, Australia, for the year 2022. The results highlighted the superiority of ADAS features, especially AEB contributes towards reducing crash likelihood and driver injury severity outcomes.

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Sponsoring Committee	ACS20
Session Number	Poster Session 4073
Session Title	**Safety Performance and Analysis for Safe Vehicles**
Paper Number	25-01258
Paper Title	**Exploring Factors Influencing Crash Occurrence Involving Autonomous Vehicle: Random Parameters Model with Heterogeneity in Means and Variances Approach**
Abstract	Autonomous vehicle (AV) technologies are expected to play a crucial role in reducing traffic crashes occurred by human factors; however, foreseeable coexistence of AVs with human-driven vehicles (HDVs) for an extended transition period raises safety concerns. Understanding factors influencing AV-involved crashes is crucial, especially as human drivers may struggle to comprehend the behavior of AVs during interactions. This study addresses this gap by employing a random parameter probit model with heterogeneity in means and variances. Dataset comprises AV crash records obtained from the California Department of Motor Vehicles from 2018 to the first quarter of 2024. Crashes on roadway segments and intersection are modeled separately. Modeling results reveal that factors such as poor lighting conditions, braking maneuver of AVs, proceeding straight movement of HDVs, involvement of bikes/scooters, residential land-use significantly contribute to AV-involved crash occurrence on segments and at intersections. On segments, first quarter of the year, the retail/entertainment land use, sideswipe collision, dangerous maneuver of HDVs and proceeding straight moment of AVs affect the likelihood of AV-involved crashes. Meanwhile, at intersection, rear-end collision, raining/snowing, unusual road conditions, four-leg intersection, lack of pedestrian island/intersection control significantly increases the probability of AV-involved crashes while angle collision and large skew angle decreases it. The findings highlight the need for more targeted goals to improve AV's safety, such as enhancing AV sensor perception capabilities, incorporating scenario-based tests by categorization of crash location, and developing mass education initiatives to facilitate the broader acceptance and understanding of AV technologies.

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Sponsoring Committee ACS20
Session Number Poster Session 4073
Session Title **Safety Performance and Analysis for Safe Vehicles**
Paper Number 25-02400
Paper Title **Predicting Crash Likelihood at Intersections Using Connected Vehicle Data**

Abstract Crash likelihood prediction model is a crucial proactive traffic safety management strategy. While numerous studies have focused on crash prediction for freeways, the application of this strategy to intersections is relatively rare. In this study, we propose inTersection-Transformer (inTformer), a time-embedded attention-based Transformer model to predict crash likelihood at intersections. The inTformer model predicts whether crashes will occur at intersections within the next 15 minutes. We developed these prediction models using traffic data from connected vehicles, a previously unexplored data source for intersection crash prediction. Due to the complex traffic flow patterns at intersections, we used a zone-specific modeling approach by dividing the intersection region into within-intersection and approach zones. The inTformer models achieved a sensitivity of up to 73% in the 'within-intersection' zone and up to 74% in the 'approach' zone. Benchmarking the optimal zone-specific inTformer models against several established deep learning models confirmed the superiority of the proposed inTformer. Further, we identified low speeding increased crash likelihood in the 'within-intersection' zone, while high split failure rates increased crash likelihood in the 'approach' zone.

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Sponsoring Committee ACS20
Session Number Poster Session 4073
Session Title **Safety Performance and Analysis for Safe Vehicles**
Paper Number 25-03192
Paper Title **Incorporating the Influence of Vehicle Mix on Crash Frequency and Severity**

Abstract The current approaches for crash frequency and severity prediction in the Highway Safety Manual (HSM) do not employ vehicle mix information. In this research effort, we build advanced alternatives to HSM methods while incorporating vehicle mix information. Two model systems: (a) multivariate Poisson-lognormal model (MVPLN) and (b) negative binomial-ordered probit fractional split model (NB-OPFS) are estimated by incorporating vehicle mix variables. The developed model systems can also capture the influence of observed and unobserved heterogeneity of different independent variables including vehicle mix variables. We estimate the models for three facility types including Urban Arterial 4-Lane Divided segments, Rural 3-Leg STOP Controlled and Rural 4-Leg STOP Controlled intersections using data from four Highway Safety Information System (HSIS) states including California, Illinois, Minnesota, Washington, and three Non-HSIS states including Connecticut, Florida and Texas. For modeling crashes at each facility level, we adopt a pooled modeling technique that accounts for state specific observed and unobserved heterogeneity in the pooled datasets. A comprehensive set of independent variables including traffic volume, vehicle mix indicators, roadway characteristics and state-specific indicators are considered in the analysis. The model comparison exercise is conducted based on a comprehensive set of quantitative and qualitative metrics. The study highlights how different methodological approaches perform better for different facilities. The study findings also underscore how capturing the observed and unobserved impacts of vehicle mix variables improves model performance in crash frequency and severity dimensions across the facility types.

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Sponsoring Committee	ACS20
Session Number	Poster Session 4073
Session Title	**Safety Performance and Analysis for Safe Vehicles**
Paper Number	25-03219
Paper Title	**Investigating Factors Contributing to Autonomous Vehicle Crash Severity Using Machine Learning and Recursive Feature Elimination (RFE)**
Abstract	The safe deployment of autonomous vehicles (AVs) presents significant challenges, requiring a thorough understanding of factors contributing to collisions and injuries. This study examines 641 AV collisions reported to the California Department of Motor Vehicles (CA DMV) from 2018 to 2024, focusing on identifying key features that contribute to crash severity. Various machine learning techniques, including Decision Trees (DT), Logistic Regression (LR), Random Forests (RF), Support Vector Machines (SVM), Naive Bayes (NB), and K-Nearest Neighbors (KNN), were employed to identify significant predictors of crash severity. Recursive Feature Elimination (RFE) determined the most influential features, while Multi-Distance Augmentation (MDA) addressed minority class imbalances, enhancing model robustness. The findings reveal that SVM and LR models perform exceptionally well, achieving accuracy scores of 92% and 91% respectively, with minimal variability across both original and augmented datasets. This was validated by k-fold cross-validation which demonstrated consistent performance. These models demonstrate strong predictive capabilities, effectively classifying varying severity levels with high precision and recall. Conversely, NB significantly underperforms with high variability, indicating it is not well-suited for this dataset. The results underscore the efficacy of traditional machine learning approaches, particularly SVM and LR, in this domain. Top-ranking features that contributed to these models include vehicle movement and status, specific damage location and collision type, vehicle type, environmental conditions, geographical factors, and vehicle company. Understanding how these key features play a role in collision severity provides insights into the underlying factors that contribute to AV safety.

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Sponsoring Committee	ACS20
Session Number	Poster Session 4073
Session Title	**Safety Performance and Analysis for Safe Vehicles**
Paper Number	25-04163
Paper Title	**The Future Driver: Exploring the Safety Challenges of Level 4 Automated Vehicles During Manual Control**
Introduction	In the past decade, Automated Vehicles (AVs) have become widely recognized as a solution for numerous traffic-related issues, such as safety, efficiency, and energy consumption (1). In practice, many Advanced Driver Assistance Systems (ADAS) are available in new vehicles, with rear cameras, rear parking sensors, and front crash prevention expected to be present in more than half of the registered vehicles by 2027 (2). However, the development of AVs faces several challenges, which can be classified into four categories: technical (e.g., safety and reliability, security, and hacking), non-technical (e.g., consumer trust, cost, liability), social (e.g., human behavior, ethical and moral issues), and policy (e.g., regulations, legislation) (3). Given the above challenges, level 4 AVs, which are defined as “the sustained and ODD [Operational Design Domain]-specific performance by an ADS [Automated Driving System] of the entire DDT [dynamic driving task] and DDT fallback” (4), are likely a more realistic goal for the industry, with a regular expansion of the ODD as the technology evolves. The main difference between Level 3 and Level 4 AVs is that the former may require immediate takeover from drivers, and the latter functions independently for much longer intervals (5). Drivers in a Level 4 context will likely assume a role similar to that of current safety drivers, who are employed in AV testing by manufacturers such as Cruise and Waymo. However, although many previous studies explore the safety benefits and challenges of AVs, including the effects of disengagements and take-over requests of Level 3/4 AVs, no prior studies explored the safety challenges of manual operation of Level 4 AVs. In this context, the present study uses crash data from manually operated Level 4 AVs in California as a proxy for the future operation of Level 4 AVs, acknowledging the limitations such as differences in training and driving tasks faced by future drivers. This data was then compared with data from the general driving population, extracted from the Crash Reporting Sampling System (CRSS) dataset, to understand how the crash patterns would likely change considering this future driver. To perform the above comparison, the present study uses Crash Sequence Analysis (CSA), which uses event information from crash data to output clusters based on the sequence of events present in each crash. The CSA method can be effective in creating a holistic and comprehensive understanding of existing crashes involving safety drivers or the general driving population, providing insights for the future of Level 4 automation. The results can also support the development of policy regarding AV operation, including driver training and vehicle requirements.

104th ANNUAL MEETING
January 5–9, 2025 • Washington, DC

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Sponsoring Committee	ACS20
Session Number	Poster Session 4073
Session Title	**Safety Performance and Analysis for Safe Vehicles**
Paper Number	25-06320
Paper Title	**Characteristics Analysis of Automated Vehicle Pre-crash Scenarios**
Abstract	To date, hundreds of crashes have occurred in open road testing of automated vehicles (AVs), highlighting the need for improved AV reliability and safety. Pre-crash scenario typology classifies crashes based on vehicle dynamics and kinematics features. Characteristics analysis based on pre-crash scenarios can identify similar features under comparable crashes, offering a more effective reflection of general crash patterns and providing more targeted recommendations for enhancing AV safety. In this paper, we analyze the latest California autonomous vehicle collision reports and use the newly revised pre-crash scenario typology to identify pre-crash scenarios. We propose a set of mapping rules for automatically extracting these AV pre-crash scenarios, successfully identifying 24 types with a 98.1% accuracy rate, and obtaining two key scenarios of AV crashes (i.e., rear-end scenarios and intersection scenarios) through detailed analysis. Based on the abundance of crash data, we adopt different analysis methods to analyze the features of key scenarios. Association analysis results for rear-end scenarios show the significant environmental influencing factors are traffic control type, location type, light, etc. For intersection scenarios prone to severe crashes with detailed descriptions, we employ causal analysis to obtain the significant causal factors: habitual violations and expectations of certain behavior. Optimization recommendations are then formulated, addressing both governmental oversight and improvements by manufacturers. The findings of this paper can guide government authorities in developing related regulations, help manufacturers design AV test scenarios, and identify potential shortcomings in control algorithms specific to various real-world scenarios, thereby optimizing AV systems effectively.

10 Transportation Safety Management

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Seventy-two papers studying diverse perspectives of transportation safety management will be presented in three sessions sponsored by the Standing Committee on Transportation Safety Management Systems (ACS10). The three sessions include Lectern Session 2123 titled **Creating a Safer System: A Lectern-Poster Session,** Lectern Session 2171 titled **Decision Making with Safety Surrogates**; and Poster Session 3039 titled **Transportation Safety Management Systems from Start to Finish** at the 2025 TRB Annual Meeting. The following is a brief overview of the papers.

Four papers discussed the **Safe System Approach** and factors related to **Crash Severity**.

- TRBAM-25-04148, Supporting the Safe System Approach Decision-Making Through Crash Sequence Analysis
- TRBAM-25-04729, Safe System for Whom? Quantifying the Impacts of Transport Infrastructure Using a Systematic Analysis
- TRBAM-25-01202, Analyzing Crash Severity in Texas Piney Woods Rural Areas Using Machine Learning
- TRBAM-25-03718, Spatial Variations in the Relationship Between Built Environment and Severe Crashes: A Case Study in Florida

Eight papers investigated **effects of speed on traffic safety**.

- TRBAM-25-02906, Assessing the Level of Speed Stability with Reliability-based Empirical Indexes for Sustainable Urban Mobility Environment
- TRBAM-25-01631, Modelling The Drivers' Over speeding Choice Using Simultaneous Equations
- TRBAM-25-03897, A Context-sensitive Roadway Classification Framework for Speed Limit Setting in the US
- TRBAM-25-01229, Impact of Operating Speed, Roadway Curvature, and Precipitation on Crash Risks in Rural Two-Lane Roads
- TRBAM-25-03724, Impact of the 20mph Speed Limit in the UK: What Does the Evidence Show?
- TRBAM-25-02461, A Comprehensive Assessment of Pedestrian Fatalities on High-Speed Roads in Rural Areas

- TRBAM-25-05636, Using Probe Data to Model Speeding on Interstate Horizontal Curves and Ramps
- TRBAM-25-03318, Integrating Crowdsourced Speed Data and Crash data for statewide Traffic Management and Road Safety Enhancement

Four papers discussed **vehicle safety**, including **connected vehicles, electric vehicles, and technology**.

- TRBAM-25-00607, How Do EV Crashes Differ from ICEV Crashes: A Comparative Study of Pennsylvania
- TRBAM-25-03870, Estimating Incident-Induced Delays Using Connected Vehicle Data with Machine Learning Algorithms
- TRBAM-25-06361, Assessment of Vehicle Age as a Contributor to Temporal Shifts in Single-vehicle Driver Injury Severities
- TRBAM-25-06465, Characterizing Behavioral Differences and Adaptations of Automated Vehicles and Human Drivers at Unsignalized Intersections: Insights from Waymo and Lyft Open Datasets

Eight papers explored **safety analysis methods**, including network screening and systemic analysis methods to prioritize sites with potential for safety improvement.

- TRBAM-25-04703, Prioritizing Safety Treatment of Rural Corridors using Curve Context
- TRBAM-25-00754, Comparative Analysis of Three Proposed Network Screening Methods on Rural Highways
- TRBAM-25-03996, Comparison of Segment Ranking and Sliding Window Ranking Methods for Rural Two-lane Undivided Roadways in North Carolina
- TRBAM-25-02797, Segment-Level and Intersection-Level Driving Volatility Analysis Using Large-Scale Crowdsourced Vehicle Movement Data
- TRBAM-25-05595, ROADFIRST: A Comprehensive Enhancement of the Systemic Approach to Safety for Improved Risk Factor Identification and Evaluation
- TRBAM-25-02459, Advancing the Methodology for Implementing a Systemic Approach for Identifying Roadway Sites for Safety Improvements

Nine papers focused on **road user behavior, perceptions, and quality of life**.

- TRBAM-25-03178, How Does Subjective Perception of Streetscape Affect Traffic Crashes? A Spatial Analysis for Integrating Safety into Street Planning
- TRBAM-25-01577, Getting a “W” for Safety: Flipping the Script on the Safety “Es” in Search of a Winning Strategy
- TRBAM-25-01152, Development of a Driver Safety Reward System Incorporating YOLO-based Traffic Violation Detection at Roundabouts under Highly Heterogeneous Traffic
- TRBAM-25-04997, Investigating Trends in High-Risk Driving Behaviors Before and After the Onset of the COVID-19 Pandemic
- TRBAM-25-01579, Ensuring Accurate Mixed Traffic Safety Assessments: The Vital Role of Safety Metrics and Behavioral Modeling

- TRBAM-25-01709, Safety-Oriented Route Guidance System Considering the Impact of Driving Behaviors
- TRBAM-25-03881, A Spatial Analysis of Safety Perceptions across Different Transport Modes: Insights from Athens and Munich
- TRBAM-25-04805, Community Perceptions of Vision Zero: A case Study of Tacoma, Washington
- TRBAM-25-05732, Understanding the Association Between Transportation Safety and Quality of Life in Austin Using Bayesian Networks

Three papers focused on **conflict and surrogate data** to assess safety and identify crash contributing factors.

- TRBAM-25-05224, Traffic Conflict-Based Micro-level Hotspots Identification at Signalized Intersections
- TRBAM-25-04594, Assessing Traffic Conflicts Severity Through Simulated Collision Dynamics and Impact Analysis
- TRBAM-25-04801, A Surrogate Safety Measure at Non-signalized Intersections Based on Probability Trajectory Prediction

Six papers investigated **traffic safety of vulnerable road users and micromobility**.

- TRBAM-25-04271, Investigating Factors Affecting Pedestrian Fatalities in the US: A Comparative Study of Pre-Pandemic, Pandemic, and Late-Pandemic Periods
- TRBAM-25-03225, Effect of Traffic Characteristics on Pedestrian Crash Risk Around School - A Micro-level Pedestrian Casualty Model
- TRBAM-25-05599, Safety Contributing Factors Analysis of Elderly Vulnerable Road Users: Global and Local Perspectives
- TRBAM-25-05800, Understanding Pedestrian and Bicyclist Safety Trends in the Post-Pandemic Era
- TRBAM-25-00294, Assessing E-scooter Rider Safety Perceptions in Shared Spaces: Insights from Sweden
- TRBAM-25-01151, Spatial Analysis of E-Scooter Accidents, the Case Study of England and Wales

Three papers discussed **societal and economic impacts of crashes**.

- TRBAM-25-02491, Advanced Crash Weighting Techniques for Forecasting the Future Economic Impact of Collisions
- TRBAM-25-02725, Comparing Location-Based and Home-Addressed Based Approaches in Evaluating Societal Crash and Congestion Costs
- TRBAM-25-02120, Estimating the Cost and Benefits of and Number of Lives Saved by Crash Avoidance Technologies

Three papers discussed **crash and insurance data**.

- TRBAM-25-03857, A Comparison of Road Crash Reporting in High-, Middle-, and Low-Income Countries: Global Perspectives
- TRBAM-25-03526, Crash data availability and best practices across the United States
- TRBAM-25-02795, The Role of Insurance in Nighttime Hit-and-Run Crashes: A Geo-Spatial Analysis

Three papers discussed **evaluations**, including program and countermeasure level.

- TRBAM-25-04351, A Data-Driven Framework for Evaluating the Effectiveness of Traffic Safety Countermeasures
- TRBAM-25-05833, Evaluation of Traffic Safety Improvement Effect Based on “Shanghai Traffic Safety Improvement Program”
- TRBAM-25-00232, The Benefits of High-speed Rail on Reducing Traffic Accidents: Evidence from China

One paper discussed **equity**.

- TRBAM-25-02539, Spatial Inequality in Socio-Demographic and Commute Patterns and their Impacts on Traffic Crash Rates: A Comparison of Interpretable Machine Learning and Spatial Statistical Modelling

One paper discussed **safety funding**.

- TRBAM-25-04774, How Can We Ensure Traffic Safety Funds Improve Safety? A Conversation with Transportation Engineering Professionals.

Twelve papers explored a variety of **motorcycle-related** topics, including rider behavior, risk factors, the impact of COVID-19, injury severity modeling, and post-crash care.

- TRBAM-25-06096, Two-wheelers Trajectory Prediction in Complex Crowded Intersection Scenarios Considering Driving Style and Vehicle Interaction Forces
- TRBAM-25-05447, Analysis of Motorcycle Riders’ Gap Acceptance at Unsignalized Mid-Block Crosswalks
- TRBAM-25-03180, Do Riding Behavior, Speeding, and Law Adherence Differ between Professional and Non-professional Riders?
- TRBAM-25-01298, Characterizing the Riding Behavior of Food Delivery Motor Scooters Based on Sensor Data Mining
- TRBAM-25-00102, Impact of COVID-19 Pandemic on Distraction-Related Motorcycle Crashes
- TRBAM-25-03313, Transferability and Temporal Heterogeneity of Motorcyclist Injury Severity in Wet and Dry Season: A Case Study in Cambodia
- TRBAM-25-06437, Investigating the Association of Post-Crash Medical Conditions and Human Factors with Motorcyclists Injuries: Insights from Fine Injury Data From Hospital Records
- TRBAM-25-04039, Motorcycle Following Distance and its Relationship to the Risk of Rear-End Collisions

- TRBAM-25-03364, Development of Composite Risk Index (CORSI) to evaluate risky situations while MTWs decide whether to follow or filter
- TRBAM-25-04640, Recent Trends and Factors Associated with Risky Motorcyclist Behaviors
- TRBAM-25-00080, Developing Safety Performance Functions for Fatal and Severe Motorcycle Crashes at Intersections
- TRBAM-25-00065, Motorcycle Safety Performance Functions along Kentucky's Rural Multilane Segments

Nine papers assessed **school transportation safety**.

- TRBAM-25-02850, Analyzing Injury Severity of School Bus Crashes considering Temporal and Spatial Heterogeneity Using Random Parameters Ordered Probit Model
- TRBAM-25-06278, The Designation of School Zones Using a Mathematical Framework Based on a Simulated Annealing Algorithm
- TRBAM-25-04043, Multi-Faceted Walkability Analysis for School Zone Safety in Delhi
- TRBAM-25-02841, Comparative Analysis of School Bus Crash Severity on Urban versus Rural Roadways: a Random Parameter Logit Model with Mean Heterogeneity
- TRBAM-25-06141, Prioritization and Implementation of Safe Routes to School (SRTS) in Austin, Texas
- TRBAM-25-02346, Invited Student Paper Understanding the Importance of Safe Routes to School: Observing School Safety in Lower-Income and Underserved Communities
- TRBAM-25-04485, Examining School Bus Stop-Arm Violation Reporting and Enforcement: A Minnesota Case Study
- TRBAM-25-04862, Analyzing School Bus-Related Crashes in New Jersey Using Machine Learning Techniques
- TRBAM-25-03255, Safe Route to Landels Elementary School in the City of Mountain View California

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Sponsoring Committee	ACS10
Session Number	2123
Session Title	**Creating a Safer System: A Lectern-Poster Session**
Paper Number	TRBAM-25-04148
Paper Title	**Supporting the Safe System Approach Decision-Making Through Crash Sequence Analysis**
Abstract	The Safe System Approach (SSA) aims to eliminate fatal and serious injury roadway crashes through a holistic view of the road system, moving away from the traditional silo-based approaches. A core element of the SSA is using historical crash data to support the selection of countermeasures. Traditional crash analysis, however, classifies crashes based on broad crash categories (e.g., head-on, sideswipe) that do not capture crash progression and contributing factors. To address this issue, the present study applies Crash Sequence Analysis, which uses sequence of events information from crash data to output clusters of crashes with similar underlying characteristics. Data from fatal and serious injury crashes from urban intersections in the state of Ohio between 2018 to 2022 were used in the analysis. The results show twelve clusters with unique characteristics that consider the sequence of events of each crash. The clusters provide an in-depth understanding of the factors associated with each cluster and help identify cluster-specific countermeasures related to multiple SSA elements. State and local jurisdictions can use the presented methodology in transportation safety programs, by focusing on the clusters that represent local challenges or on countermeasures related to the issues of multiple clusters. Finally, the method can also be associated with site-specific analysis, providing a comprehensive toolkit for practitioners.

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Session Number	2123
Session Title	**Creating a Safer System: A Lectern-Poster Session**
Paper Number	TRBAM-25-05833
Paper Title	**Evaluation of Traffic Safety Improvement Effect Based on “Shanghai Traffic Safety Improvement Program”**
Abstract	The “Shanghai Traffic Safety Improvement Program” was implemented on March 25th, 2016, to address the longstanding issues of traffic crashes and violations in Shanghai. The program aimed to enhance the road traffic safety through strict enforcement and targeted all traffic participants across the city, focusing on ten major violations. Despite the importance of such program, there has been a lack of studies evaluating the effectiveness of these programs. Traditional methods, such as randomized controlled trials (RCTs), often face significant biases due to the non-random nature of policy interventions, making accurate evaluations challenging. To address these issues, this study employs the Interrupted Time Series method and introduces a Bayesian causal Interrupted Time Series model, based on traffic crash and violation data from 2014 to 2019 in Shanghai. The findings indicate that the program led to a 25.58% reduction in traffic crashes and a 178.55% increase in traffic violations. This study identified the latency in crash numbers, revealing how policy interventions on violations impact the number of crashes. This study also analyzed the effectiveness of rectifying intersection violations, aiding in determining whether such violations should be a focus of enforcement. Finally, a placebo test was conducted by delaying the intervention time. This study primarily explains the causal impact of interventions on the number of crashes and violations by incorporating Bayesian causal effects and a counterfactual framework. The causal effect analysis revealed the latency in crash numbers and explained the principles by which interventions impact road traffic safety levels.

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Sponsoring Committee ACS10

Session Number 2123

Session Title **Creating a Safer System: A Lectern-Poster Session**

Paper Number TRBAM-25-04801

Paper Title **A Surrogate Safety Measure at Non-signalized Intersections Based on Probability Trajectory Prediction**

Abstract Development of sensing and artificial intelligence technologies has provided the necessary conditions for proactive pedestrian safety at non-signalized intersections. Proactive pedestrian protection requires the prediction of pedestrian and vehicle information for future conflict evaluation. In reality, predicting future information involves inherent uncertainties due to the limited observable information available for each individual. Consequently, it is more practical to assign probabilities to these future predictions. However, current studies on future conflict evaluations have largely overlooked these uncertainties associated with future state predictions. To fill this research gap, we introduce probabilistic trajectory prediction into proactive pedestrian protection and propose a new surrogate safety measure, stochastic predicted time to collision (SP-TTC), for evaluating future conflicts at non-signalized intersections. The experiment is carried out using a real-field CCTV dataset. Performance of SP-TTC is evaluated by its ability to recognize conflicts, understand different conflict scenarios, and identify dynamic conflict patterns. Results verify the capability of SP-TTC to recognize conflicts, especially achieving the best performance with an F1 score of 0.8372 in short distance conflicts. The results also demonstrate that the SP-TTC distribution varies with different conflict scenarios, indicating its ability to identify specific conflict scenarios based on these values. Additionally, the dynamic utility of SP-TTC is showcased through case studies, demonstrating its potential to recognize whether a conflict eases or escalates into a more dangerous situation. SP-TTC can be used in proactive pedestrian protection systems, enhancing pedestrian safety through proactive measures such as alerting pedestrians or activating vehicular brakes at crucial moments.

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Sponsoring Committee ACS10

Session Number 2123

Session Title **Creating a Safer System: A Lectern-Poster Session**

Paper Number TRBAM-25-01709

Paper Title **Safety-Oriented Route Guidance System Considering the Impact of Driving Behaviors**

Abstract Modern navigation systems prioritize fuel efficiency and time savings, often overlooking the critical aspect of road safety. This study addresses this gap by developing an advanced safe route guidance approach for Electronic Route Guidance Systems that incorporates personalized safety metrics based on individual driving behaviors and road conditions. Using the Safety Performance Function to evaluate the overall risk of road segments, and the copula model to capture the correlation between driving behaviors and roadway risk, this research uses conditional probability theory to quantify the safety levels of road segments for drivers with different driving behaviors to tailor safer route recommendations. The proposed approach is validated using the crash data, roadway geometric data, and driving behavior data collected from Los Angeles, demonstrating its capability to customize navigation based on individual driving behavior and significantly enhance route safety. The findings suggest that the safest route may vary depending on driving behavior. This research not only incorporates individualized traffic safety in navigation but also offers a scalable framework for future navigation systems to incorporate safety as a fundamental component.

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Sponsoring Committee	ACS10
Session Number	2123
Session Title	**Creating a Safer System: A Lectern-Poster Session**
Paper Number	TRBAM-25-00232
Paper Title	**The Benefits of High-speed Rail on Reducing Traffic Accidents: Evidence from China**
Abstract	To assess the nexus between High-Speed Rail (HSR) and road traffic accidents in China, this study analyzes how HSR influences accidents and then conducts a battery of empirical checks using the Difference-in-Differences (DiD) estimator and city-level data from 2005-2017. We find that new HSR routes lead to a 0.417-point reduction in accidents and a 1.511-point reduction in total traffic fatalities, translating to a 20% and 17% decrease respectively after accounting for meteorological variables and fixed effects. Heterogeneity analyses reveal more pronounced effects in economically developed cities with larger urban populations, better public transit infrastructure, and those in western regions. Furthermore, utilizing Tencent migration big data, we demonstrate that these reductions stem from substituting road passenger transport with HSR, especially for medium-to-short journeys. This paper addresses an academic gap in understanding HSR's impact on road safety and provides an idea for future road traffic safety management, that is, should corresponding measures to build an HSR-friendly environment be considered.

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Sponsoring Committee	ACS10
Session Number	2123
Session Title	**Creating a Safer System: A Lectern-Poster Session**
Paper Number	TRBAM-25-03724
Paper Title	**Impact of the 20mph Speed Limit in the UK: What Does the Evidence Show?**
Abstract	Studies on the effectiveness of 20 mph speed limits in the UK vary due to differences in context, methods, data, environments, and schemes. Many do not account for confounding factors like regression-to-the-mean, long-term trends, or changes in traffic volume, making it difficult to generalize their overall impact. This paper addresses these issues by developing a methodology to assess and classify the quality and validity of existing studies on 20 mph speed limits. It reviews 24 studies and 224 effect estimates, applying fixed-effects, random-effects, and multi-level meta-analysis models to evaluate the impact on collisions, personal injuries, and speed changes. The analysis shows that 20 mph speed limits reduce traffic collisions by an average of 26.45%, with a 21.6% reduction for schemes with signs only. Casualties decrease by 22.9% for all schemes, compared to 10.9% for sign-only schemes. The introduction of 20 mph speed limits with physical measures results in greater reductions in collisions and casualties than sign-only schemes. Additionally, sign-only schemes reduce mean speed by 1.76 mph. These findings will help policymakers make informed decisions on implementing 20 mph speed limits.

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Sponsoring Committee	ACS10
Session Number	2123
Session Title	**Creating a Safer System: A Lectern-Poster Session**
Paper Number	TRBAM-25-03857
Paper Title	**A Comparison of Road Crash Reporting in High-, Middle-, and Low-Income Countries: Global Perspectives**
Abstract	The quality of road safety improvement is dependent on the quality of the respective data on which improvements are based. Due to the ability of police reported crash data to provide an overall outlook of crash factors, and the lack of an equally informative alternative, these data have become the standard for road safety research. Thus, enhancing police reported crash data is paramount to enhancing data driven road safety improvements. However, the type of data recorded often vary between regions, resulting in a lack of comparability. The United Nations recognizes the overall importance of improved quality, harmonization, and comparability of road safety data collection at the international, national, and regional levels as part of the Global Plan for the Second Decade of Action for Road Safety. In this regard, focus should be directed toward harmonizing and developing best practices for road safety data collection across high-income (HIC), and low- and middle-income countries (LMIC). This study synthesizes and compares road crash reports from various countries, internationally to improve crash reporting and subsequently the quality of crash data. Reportable variables are compared by assessing the level of data coverage and resolution between 12 HICs and 13 LMICs on a global scale. Further, attention is drawn to disparities in crash data collection among these countries, with the accompanying discussion having the potential to provide a basis on which current crash reporting systems may be enhanced. Results contribute to the improvement of road safety research, interventions, crash reporting methods, and promote collaboration among agencies.

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Sponsoring Committee	ACS10
Session Number	2171
Session Title	**Decision Making with Safety Surrogates**
Paper Number	TRBAM-25-01152
Paper Title	**Development of a Driver Safety Reward System Incorporating YOLO-based Traffic Violation Detection at Roundabouts under Highly Heterogeneous Traffic**
Abstract	This study introduced a novel Driver Safety Reward System (DSRS) leveraging YOLO-based traffic violation detection and an incentive mechanism to promote safer driving behaviors at roundabouts. Unmanned Aerial Vehicle (UAV)-captured aerial videos at unsignalized roundabouts were used for detecting vehicles and extracting trajectory data to analyze various traffic violations such as wrong-way driving, anti-clockwise driving, and improper U-turns. The YOLOv8m model, coupled with ByteTrack, facilitated robust vehicle tracking using high-quality aerial video data. Driver behavior was scored based on detected violations, overspeed events, and sharp acceleration and deceleration instances. Additionally, a MERN stack-based reward system was developed to assign and visualize reward points for drivers. The system provided a clear and accessible way for drivers to understand their driving performance. Furthermore, a Multinomial Logistic Regression (MLR) model was developed to predict violation types, demonstrating good prediction accuracy. This study highlighted the potential of cutting-edge image processing technologies to enhance road safety by identifying problematic traffic scenarios and developing a proactive driver reward disbursement system. The system provided valuable insights into violation patterns predominantly occurring at roundabouts under mixed traffic conditions for different vehicle types. The research, uniquely combining aerial surveillance, machine learning, and a user-friendly reward platform, aimed to reduce traffic violations and promote safer driving practices significantly. This innovative approach contributed to the broader goal of enhancing road safety through technological innovation.

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Sponsoring Committee ACS10
Session Number 2171
Session Title **Decision Making with Safety Surrogates**
Paper Number TRBAM-25-04594
Paper Title **Assessing Traffic Conflicts Severity Through Simulated Collision Dynamics and Impact Analysis**
Abstract Traffic conflict analysis is a crucial proactive approach for evaluating roadway safety, particularly at signalized intersections, which are inherently complex due to diverse road users, turning movements, and signal phases. This study introduces an integrated framework for assessing traffic conflict severity by integrating collision mechanisms into the analysis. Initially, the framework identifying conflict instances through time-to-collision (TTC) using accurately represented vehicle polygons. It then evaluates collision mechanisms assuming no evasive actions are taken, extracting forces, kinetic energies (K. E), angles of impact (AOI), and crash influence points (I. Ps) at the anticipated collision time. Eight crash simulation scenarios using an authorized C1500 pickup truck model are performed. The results reveal that for equivalent K. E values, head-on conflicts are significantly more severe compared to angle and rear-end conflicts, based on vehicle damage and sharp drops in K. E post-collision. Analysis also shows that in angle crashes, the amount of energy absorbed increases with the AOI but decreases with higher pre-collision speeds. The proposed framework outperforms traditional methods like Delta-V by offering a more detailed assessment of energy absorption and severity. This method enhances intersection safety evaluations and can optimize resource allocation for effective safety measures at hazardous locations.

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Sponsoring Committee ACS10
Session Number 2171
Session Title **Decision Making with Safety Surrogates**
Paper Number TRBAM-25-05224
Paper Title **Traffic Conflict-Based Micro-level Hotspots Identification at Signalized Intersections**
Abstract Traditional approaches to identifying traffic crash hotspots have mainly focused on determining dangerous intersections within road networks. These models, however, are limited in their capacity to recommend specific countermeasures due to varying risk levels within different sections of an intersection. Therefore, Identifying these micro-level crash hotspots can help determine risk factors and suggest specific preventive measures. This study aims to identify micro-level hotspots within three signalized intersections using traffic conflict measures derived from drone video. We employed an algorithm designed to calculate detailed conflicts for various conflict angles and vehicle sizes. Time-to-collision (TTC), modified TTC (MTTC), and post-encroachment time (PET) are used as traffic conflict measures. To determine the optimal conflict measure and its threshold for each intersection, we developed a crash frequency model based on a generalized linear model (GLM). The selected conflict measures and thresholds were then used to identify micro-level hotspot sections using kernel density. Our analysis revealed that MTTC and PET were more closely correlated with micro-level crash frequencies and showed different correlation patterns with crash locations. Specifically, MTTC-based conflicts were highly correlated with areas before the stop line, while PET-based conflicts were closely associated with crashes within the intersection, particularly with left-turning movements. As a result, using both MTTC and PET as covariates provided more accurate micro-level crash frequency estimation than using a single conflict measure. This study contributes to traffic safety by identifying effective traffic conflict measures for micro-level hotspot identification and offering more detailed safety management strategies.

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Sponsoring Committee	ACS10
Session Number	2171
Session Title	**Decision Making with Safety Surrogates**
Paper Number	TRBAM-25-03870
Paper Title	**Estimating Incident-Induced Delays Using Connected Vehicle Data with Machine Learning Algorithms**
Abstract	This paper addresses the challenge of incomplete data in quantifying incident-induced delay (IID) by developing classification and estimation models using connected vehicle data. We analyzed 9,795 crashes that occurred on interstates in Iowa between September 2021 and March 2023, with 23% cases lacking the necessary data for IID quantification. Various classification methods were explored to determine whether IID occurs or not for a specific crash, including artificial neural networks (ANN), support vector classifier (SVC), Naïve Bayes (NB), K-nearest neighbors (KNN), and random forest (RF). The RF model achieved the highest accuracy of 84% and the lowest false alarm rate. The key influential features included crash characteristics, traffic volume, roadway environment, and the time of the event. Furthermore, an extreme gradient boosting (XGBoost) model was developed to estimate IID for cases without connected vehicle data. The XGBoost model demonstrated superior performance with an R-squared score of 0.847. Feature importance analysis revealed that crash characteristics were the most influential, followed by crash locations and the roadway environment. The primary contribution of this paper lies in its systematic approach to IID estimation and in addressing the interpretability challenge of machine learning methods by presenting the importance of key factors. The IID estimation framework has potential for application in evaluating various traffic management strategies and supporting real-time traffic management.

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Sponsoring Committee	ACS10
Session Number	3039
Session Title	**Transportation Safety Management Systems from Start to Finish**
Paper Number	TRBAM-25-00065
Paper Title	**Motorcycle Safety Performance Functions along Kentucky's Rural Multilane Segments**
Abstract	Despite motorcycle crashes accounting for a large percentage of traffic fatalities in the U.S., studies investigating motorcycle crash frequency are relatively limited. This study took the initiative and developed motorcycle crash-specific safety performance functions (SPFs) along rural multilane road segments in Kentucky, separately for the pre-COVID-19 pandemic (2015-2019) and post-COVID-19 pandemic (2020-2022) periods. Eight years of motorcycle crash records (2015 through 2022) and site-specific characteristics (e.g., shoulder width and annual average daily traffic "AADT") were collected and used. Conway-Maxwell-Poisson (CMP) and heterogeneous Conway-Maxwell-Poisson (HTCMP) models were fitted and compared while accounting for motorcycle crash under-dispersion (i.e., crash variance being less than its mean). The results showed that, for both pre- and post-pandemic periods, the HTCMP models outperformed their CMP counterparts based on various goodness-of-fit measures (e.g., Akaike information criterion "AIC" and McFadden pseudo R-squared) and prediction performance measures (i.e., mean absolute deviance "MAD" and mean square prediction error "MSPE"). From the developed SPFs, for the pre-pandemic period, presence of horizontal curves and undivided roadways were significantly associated with increased motorcycle crash frequency along rural multilane segments, while in the post-pandemic period, wider right shoulders and higher AADT were significantly associated with increased motorcycle crash frequency. The predicted crash frequencies while applying the best-fit models (i.e., the HTCMP models) were then used to identify and rank high-crash rural multilane segments in Kentucky. Based on the study findings, several countermeasures were proposed to improve motorcyclists' safety along Kentucky's rural multilane segments, e.g., adding centerline grooved rumble strips along undivided rural multilane roadways.

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Sponsoring Committee	ACS10
Session Number	3039
Session Title	**Transportation Safety Management Systems from Start to Finish**
Paper Number	TRBAM-25-00080
Paper Title	**Developing Safety Performance Functions for Fatal and Severe Motorcycle Crashes at Intersections**
Abstract	Although intersections contribute significantly to traffic fatalities and severe injuries, there is a noticeable lack of research on motorcycle safety performance functions (SPFs) at intersections, especially in the U.S. This study develops SPFs for fatal and severe injury (FSI) motorcycle crashes at intersections in Kentucky. FSI motorcycle-involved crashes between 2015 and 2022 were retrieved from the Kentucky Transportation Cabinet (KYTC), and extensive intersection-specific information (e.g., traffic control type and presence of exclusive left- and right-turn lanes) at 1,372 intersections were manually collected. The crash data in this study were under-dispersed, with a high proportion of sites with zero FSI crashes. Therefore, the Conway-Maxwell-Poisson (CMP) model and its extensions, including zero-inflated CMP (ZICMP), heterogeneous CMP (HTCMP), and zero-inflated heterogeneous CMP (ZIHTCMP) models, were explored. Overall, the goodness-of-fit measures indicated that the ZIHTCMP model outperformed the other comparative models. The SPF model results revealed that higher AADT, presence of physical median (raised or depressed) on major approaches, traffic signal control, and four-legged configuration were significantly associated with reduced FSI motorcycle crashes. On the other hand, higher posted speed limits on major approaches (55 mph or greater) and narrower right shoulders on major approaches (less than 3 feet) significantly increased FSI motorcycle crashes at intersections. Furthermore, predictions from the ZIHTCMP model were used to identify intersections with higher-than-expected FSI motorcycle crashes using the empirical Bayes (EB) method. Several countermeasures were proposed based on the study results to improve motorcyclist safety and reduce FSI motorcycle crashes at intersections.

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Sponsoring Committee	ACS10
Session Number	3039
Session Title	**Transportation Safety Management Systems from Start to Finish**
Paper Number	TRBAM-25-00294
Paper Title	**Impact of COVID-19 Pandemic on Distraction-Related Motorcycle Crashes**
Abstract	Shared spaces prioritize the role of micromobility in urban environments by separating vulnerable road users from motorized vehicles, aiming to enhance actual objective and subjective safety perceptions. However, various modes of transport with differing navigation characteristics impact road users' perception of safety. Despite the rise of emerging transport modes such as e-scooters, there is a lack of theoretical and empirical evidence regarding their safety perception in shared spaces. In response, we conducted an online video experiment and polled 920 e-scooter users in Sweden to assess their safety perceptions. We collected data on socio-demographics, travel habits, crash history, and responses to hypothetical video scenarios depicting interactions where riders overtake or meet cyclists in shared spaces. We then employed a random effect latent class ordered logit model to quantify the determinants of e-scooter riders' safety perceptions. The findings indicate that women feel less safe in shared spaces compared to men. Additionally, the direction of encounters significantly affected young adults, who perceived meeting other users as more unsafe than overtaking them. These findings highlight the importance of accounting for unobserved heterogeneity in safety perceptions, emphasize the significant role of demographic variables in understanding users' safety perceptions, and reinforce the need for inclusive design of shared spaces for all road users.

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Sponsoring Committee	ACS10
Session Number	3039
Session Title	**Transportation Safety Management Systems from Start to Finish**
Paper Number	TRBAM-25-00607
Paper Title	**How Do EV Crashes Differ from ICEV Crashes: A Comparative Study of Pennsylvania**
Abstract	As electric vehicles (EVs) become more common due to adoption and policy incentives, understanding their safety facts compared to internal combustion engine vehicles (ICEVs) is crucial for safety and acceptance. This study leveraged crash data from Pennsylvania during 2020 and 2022 to investigate the patterns and characteristics of crashes involving EVs (including battery electric vehicles, plug-in hybrid electric vehicles, and hybrid electric vehicles) and compare them with ICEV crashes through spatiotemporal analysis, statistical tests, and regression models. The results indicated that EV-involved crashes predominantly occurred in urban areas and were more frequent during daylight hours, with a time-of-day distribution exhibiting more fluctuation. Moreover, EV crashes had a lower percentage of fatal and severe injury crashes compared to ICEV crashes. Aggressive driving and traffic sign/signal violations were more common among EV crashes, whereas driving under the influence (DUI) and speeding-related behaviors were more commonly related to ICEV crashes. For multi-vehicle crashes, DUI, speeding, running red lights, head-on collisions, and angle collisions were positively associated with crash severity for both ICEV- and EV-involved crashes. This study provides valuable insights into the distinctive patterns of EV crashes and crash severities, thus offering vital references for the development of road safety plans and strategies that accommodate the emergence of EVs.

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Sponsoring Committee	ACS10
Session Number	3039
Session Title	**Transportation Safety Management Systems from Start to Finish**
Paper Number	TRBAM-25-00754
Paper Title	**Comparative Analysis of Three Proposed Network Screening Methods on Rural Highways**
Abstract	This study presents a comprehensive analysis comparing the effectiveness of three proposed network screening methods for identifying safety improvement sites on rural roads. The proposed methods are: the Global Risk Scoring (GRS), the Crash Risk Index (CRI), and the Predicted Empirical Bayes (P-EB) methods. Using historical crash data, traffic and roadway information from the rural two-lane road network in Oregon, the study conducted a comparative analysis of these screening methods. The analysis revealed distinct strengths among the screening methods. The GRS method demonstrated a high level of consistency with historical crash data while the Predicted EB method exhibited superior consistency across different time periods, suggesting its value for long-term safety planning. The CRI method demonstrated reasonable consistency in performance, irrespective of the test carried out. While no single method outperforms the others in all scenarios, each has unique advantages and data requirements that can better suit the agency needs given available resources.

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Session Number 3039

Session Title **Transportation Safety Management Systems from Start to Finish**

Paper Number TRBAM-25-01151

Paper Title **Spatial Analysis of E-Scooter Accidents, the Case Study of England and Wales**

Abstract The recent surge in electric scooter (e-scooter) adoption for urban transportation has increased safety concerns. This study conducts a spatial analysis of e-scooter accidents in England and Wales using Geographic Information Systems (GIS) techniques to investigate crash patterns. Geographically Weighted Regression (GWR), Getis-Ord Gi*, and Moran's I were employed to understand spatial variations and identify significant hotspots.

The study analyzed e-scooter crash data from STAT19, spanning three years (January 2020 to December 2022), alongside 2021 Census data from the Office for National Statistics (ONS). It identified 303 statistically significant hotspots and 48 cold spots, providing insights into spatial clustering. Analysis revealed peak incidents during weekday mornings, afternoons, and weekend evenings, predominantly on single-carriageways with 30 mph or lower speed limits. It was further revealed that e-scooter accidents are more prevalent on residential roads, followed by primary roads.

Comparative analysis between Ordinary Least Squares (OLS) and GWR models demonstrated that GWR effectively captures spatial heterogeneity. Positive correlations were found with population density, single-carriageways, social housing areas, and minority Asian and Black populations, whereas increased green spaces showed a negative correlation. The study offers insights into e-scooter challenges in the UK's urban landscapes, informing safety interventions and urban planning.

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Sponsoring Committee ACS10

Session Number 3039

Session Title **Transportation Safety Management Systems from Start to Finish**

Paper Number TRBAM-25-01202

Paper Title **Analyzing Crash Severity in Texas Piney Woods Rural Areas Using Machine Learning**

Abstract Every year, crashes in rural towns take lives and alter the dynamics of entire communities. This research seeks to understand a broad scope of factors that determine the severity of crashes that produce either severe or fatal results, particularly in and around the region of Texas known as the “Piney Woods.” In the past ten years, the Piney Woods has accounted for over half of the rural population crashes in the state of Texas, giving specific interest in understanding the influencing factors of crashes that produce severe and fatal injuries in this region. Therefore, to better understand the factors that attribute to such crashes, we have extracted data from the Texas Department of Transportation (TxDOT) Crash Record Information System (CRIS) database, which was then further split into a training and a test data set. Then, five machine learning techniques, namely binary logistic regression, k-nearest neighbors, naïve Bayes, random forest, and an artificial neural network, were all applied to the unseen test data. The random forest model produced the most promising results by predicting non-severe crashes with 99.5% accuracy. The results of this research allow engineers a greater understanding of what influences crashes, specifically severe crashes, within the Piney Woods. In the future, this information could be used to understand roadway hazards and effect changes in design philosophy for our rural communities so that severity of crashes can be reduced, and lives saved, not only in the Piney Woods, but across the state and the U.S.

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Sponsoring Committee	ACS10
Session Number	3039
Session Title	**Transportation Safety Management Systems from Start to Finish**
Paper Number	TRBAM-25-01229
Paper Title	**Impact of Operating Speed, Roadway Curvature, and Precipitation on Crash Risks in Rural Two-Lane Roads**
Abstract	Roadway departure crashes account for many annual crashes on Texas roadways. Understanding the effects of various risk factors is essential for developing cost-effective safety countermeasures. This study focuses on rural two-lane segments, introducing a data collection method that includes operating speed, road geometry, precipitation, and land use characteristics. Addressing the gap in understanding the equivalent property damage only (EPDO) rate, this study analyzes its distributional characteristics and develops a machine learning model using Texas crash data from 2015 to 2019. The study compares risk factor modeling results for EPDO and total crash frequency using SHapley Additive exPlanations (SHAP). The results indicate that segment length, Average Annual Daily Traffic (AADT), AADT difference, curvature, land use characteristics, and precipitation positively correlate with crash risk, while wider lane and right-of-way widths reduce risk. Operating speed measures show complex interactions. The EPDO model demonstrates a higher impact of these factors compared to the total crash frequency model. This study offers valuable insights and a comprehensive framework for understanding crash risks on rural roadways, which can inform the development of targeted safety interventions.

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Sponsoring Committee	ACS10
Session Number	3039
Session Title	**Transportation Safety Management Systems from Start to Finish**
Paper Number	TRBAM-25-01298
Paper Title	**Characterizing the Riding Behavior of Food Delivery Motor Scooters Based on Sensor Data Mining**
Abstract	The rapid development of the online food delivery industry has increased motor scooter use, posing significant urban transportation safety. The delivery platform revenue models, which they receive a share of customers' orders and make deliveries, lead to risky riding. It has become necessary to collect actual riding data from delivery motor scooters and analyze their riding characteristics to construct an effective safety monitoring system. The purpose of this study is to classify riding patterns based on the riding characteristics of delivery scooter riders and analyze the riding characteristics by pattern. The Korean 100 naturalistic riding study was conducted from July 30 to November 16, 2021. The naturalistic riding data were collected using GPS and IMU sensors installed on the motor scooters of 100 riders. As a result of the clustering analysis, the average speed, average acceleration, average deceleration, average acceleration norm, and average angular velocity norm were statistically significant variables. The clusters were defined as risky riding pattern, normal riding pattern, and safe riding pattern. The riding characteristics of the riders and the number of aggressive riding behaviors were analyzed for each of the three riding patterns. Furthermore, the characteristics of each riding pattern were analyzed by age group and mileage group. The results of this study are expected to be used as fundamental data for developing a safety monitoring system that reflects the riding characteristics of riders who use motor scooters.

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Sponsoring Committee	ACS10
Session Number	3039
Session Title	**Transportation Safety Management Systems from Start to Finish**
Paper Number	TRBAM-25-01577
Paper Title	**Getting a "W" for Safety: Flipping the Script on the Safety "Es" in Search of a Winning Strategy**
Abstract	As we enter the second decade of Vision Zero in the US, this paper emphasizes the need to move beyond traditional safety silos and strategies. Historically, transportation safety has relied on the "Es" of safety: engineering, enforcement, education, and emergency services. The Safe System Approach represents a pivotal shift from those silos towards a system-based, proactive paradigm. While this approach has garnered substantial funding and support in the US, its implementation can still revert to the traditional Es mindset, missing the core principle of kinetic energy risk reduction. This paper argues that kinetic energy, the root cause of roadway injuries and deaths, must be central to safety strategies. By focusing on exposure, likelihood, and severity, the Safe System Approach can more effectively mitigate risks. Referencing the Safe Systems Pyramid, this paper explores safety through a public health lens, emphasizing systemic interventions over individual efforts. In alignment with the Pyramid, this paper proposes a "Ws of transportation safety" framework that examines who, what, when, where, why, and which policies influence travel behavior and the environment. This comprehensive view unlocks new safety tools and partnerships, highlighting the importance of upstream interventions such as land use planning, multimodal transportation options, and affordable housing. The paper concludes with practical applications of the Ws framework, illustrating its potential to transform roadway design and safety assessments. By institutionalizing these strategies, transportation practitioners can find a fresh set of tools, and hopefully refreshed motivation, funding, partners, and purpose, in support of Vision Zero 2.0.

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Sponsoring Committee	ACS10
Session Number	3039
Session Title	**Transportation Safety Management Systems from Start to Finish**
Paper Number	TRBAM-25-01579
Paper Title	**Ensuring Accurate Mixed Traffic Safety Assessments: The Vital Role of Safety Metrics and Behavioral Modeling**
Abstract	In future traffic systems, where automated vehicles (AVs) coexist with human-driven vehicles (HVs), ensuring road safety is of utmost importance. Existing safety assessment methods, however, are inadequate for the complex scenarios presented by mixed traffic conditions. These methods often fail to distinguish sufficiently between AVs and HVs, leading to inaccuracies in safety evaluations. To address these issues, this paper highlights the shortcomings of current surrogate safety measures (SSMs) in mixed traffic contexts and introduces a novel SSM, the Weighted Combination of Spacing and Speed Difference Rates (WS2DR). We propose a comparative analysis method to validate the effectiveness of WS2DR and to establish its safety threshold. Experiment results reveal that WS2DR outperforms traditional metrics such as time-to-collision and deceleration rate to avoid crashes, in terms of adaptability and detection of a wider range of unsafe conditions in both homogeneous and heterogeneous traffic environments. Additionally, the paper presents a sophisticated mixed traffic modeling approach that accounts for different characteristics of AVs and HVs, incorporating factors such as errors of estimating the motion of other vehicles and the extended reaction time of HVs, as well as the perceptual and cooperative-active control capabilities of AVs. The results of the comparison analysis underscore the critical importance of considering the differences between AVs and HVs in modeling for accurate safety evaluations of mixed traffic. Simulation experiments confirm the positive impact on safety with increased AV penetration rates, emphasizing the necessity of employing refined modeling and safety assessment metrics to capture the full benefits of AV integration.

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Sponsoring Committee	ACS10
Session Number	3039
Session Title	**Transportation Safety Management Systems from Start to Finish**
Paper Number	TRBAM-25-01631
Paper Title	**Modeling the Drivers' Over Speeding Choice Using Simultaneous Equations**
Abstract	One of the most significant factors in investigating of the likelihood, severity of car crashes, and safety research is drivers' speed choice. Understanding the impacts of the drivers' overspeeding choice could significantly improve the roads safety and severity of crashes. In this article, drivers' choice of speed in Tehran's urban and rural roads models simultaneously via data collection through a survey to reach a more efficient estimation. The Seemingly Unrelated Regression Estimation (SURE) model and the Three-Stages Least Square (3SLS) model are deployed and compared. The results indicate that socioeconomic factors, records of drivers' violations, besides behavioural and psychological parameters, affect the drivers' speed choice. Moreover, the results show that the SUR model provides a more powerful predicting power than the 3SLS models. Thus, although the drivers' speeding behaviours are correlated in error terms, these endogenous variables are not correlated.

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Sponsoring Committee	ACS10
Session Number	3039
Session Title	**Transportation Safety Management Systems from Start to Finish**
Paper Number	TRBAM-25-02120
Paper Title	**Estimating the Cost and Benefits of and Number of Lives Saved by Crash Avoidance Technologies**
Abstract	Crash prevention systems play an important role in enhancing vehicle safety by alerting drivers about potential risks and, in some instances, taking corrective action to mitigate these risks. This research uses vehicle insurance claims reports and national crash datasets to evaluate the societal and private economic impacts of deploying crash avoidance technologies throughout the US light duty vehicle fleet across two scenarios. The first scenario focuses on warning systems, including blind spot monitoring (BSM), lane departure warning (LDW), and forward collision warning (FCW). The second scenario looks at the benefits of equipping vehicles with AEB in addition to the aforementioned warning systems. Based on the cost to deploy these technologies and the economic benefits that arise from crash prevention and crash severity changes, the fleet wide deployment of AEB in addition to warning systems could provide $79.2 and $65.2 billion in annual net-societal and net-private benefits, respectively. Because AEB has significantly higher reductions in crash frequency than the warning systems, adding AEB to vehicles would more than double the societal and private benefits than that from warning systems alone. Additionally, considering the different combinations of crash avoidance technologies available in vehicles today, there were around 110 lives saved in 2019 due to the ability for crash avoidance technologies to help drivers avoid crashes. Because the current penetration rate of crash avoidance systems are still low and effectiveness of the systems are likely to improve over time, the number of lives saved and economic benefits should increase over time.

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Sponsoring Committee	ACS10
Session Number	3039
Session Title	**Transportation Safety Management Systems from Start to Finish**
Paper Number	TRBAM-25-02459
Paper Title	**Advancing the Methodology for Implementing a Systemic Approach for Identifying Roadway Sites for Safety Improvements**
Abstract	The traditional approach for network screening for identifying roadway sites for safety improvements has issues, such as the tendency for safety countermeasures to be targeted only at locations that have experienced a high frequency of crashes. The systemic safety approach, on the other hand, proactively identifies risk factors for focus crash types, then reviews the road network and prioritizes locations for implementation of appropriate countermeasures based on the prevalence of these risk factors. Using crash data of Ohio collector road segments as a case study, this research aims to advance the systemic approach methodology by first developing a severity index (SI) that considers the frequency and cost of crashes in each severity level. An advanced method that integrates XGBoost and SHAP algorithms was then proposed and applied to identify contributing factors to crashes by determining the factors affecting SI. The method produces importance scores that were then used to rank and compare contributing factors for focus crash types. Then, road segments were prioritized for safety improvement based on the prevalence of critical contributing factors and their importance scores.

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Sponsoring Committee	ACS10
Session Number	3039
Session Title	**Transportation Safety Management Systems from Start to Finish**
Paper Number	TRBAM-25-02461
Paper Title	**A Comprehensive Assessment of Pedestrian Fatalities on High-Speed Roads in Rural Areas**
Abstract	The high pedestrian fatality on rural roads is a less unexplored area in low-and middle-income countries. Pedestrian activities are increasing on these high-speed roads in rural areas because the built-up areas keep expanding along the growing road network of such roads. This study estimates pedestrian fatality rates based on crash data from 2017-2022, road length in rural areas, and highly exposed population living in a buffer of 500m across 83 different high-speed roads in Haryana, India. This population distribution is estimated from high-resolution population density maps. The highest pedestrian fatality rate per 100 km length is for NH44 (539.1), SH22 (124.4), and MDR131 (202.4), and per 10,000 population highly exposed is for NH48 (56), SH22 (15.6), and MDR132 (14.4) for different road categories. The crash prediction modelling is also performed to estimate the significant variables attributed to pedestrian fatalities on these high-speed roads using Generalised Poisson (GP) and Negative Binomial (NB) models owing to the over-dispersion in the dataset. The GP model better fits the estimates as it has lower AIC and higher ρ2 and log-likelihood values. The results show that variables like road length, population, multi-lane roads, minor access density, and village density are positively associated with pedestrian fatality occurrence. The pedestrian fatality on multi-lane roads is 1.5 times higher than the 2-lane road. The study results help identify the roads where pedestrians face high risk. Specific pedestrian safety-focused road designs should be adopted on these high-speed roads passing through settlements to reduce the risk faced by pedestrians.

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Sponsoring Committee	ACS10
Session Number	3039
Session Title	**Transportation Safety Management Systems from Start to Finish**
Paper Number	TRBAM-25-02491
Paper Title	**Advanced Crash Weighting Techniques for Forecasting the Future Economic Impact of Collisions**
Abstract	This study evaluates the effectiveness of current methodologies used by Departments of Transportation (DOTs) for forecasting the future economic impact of roadway crashes. Although the amount of previous estimated property damage only (ePDO) is commonly used by transportation agencies to prioritize safety improvement decisions, there is limited research validating the adequacy of this approach. The purpose of this paper is to evaluate existing methods and propose a new methodology with increased accuracy. Utilizing over 285,000 crash records in over 125,000 road segments between 2013 and 2022, the research compares traditional forecasting methods, based on historical ePDO and past crash numbers, with a novel approach that employs a custom weighting scheme derived from Lasso regression. This novel approach is based on correlation with future crashes, rather than solely on economic costs. Findings indicate that the Lasso regression model, which addresses multicollinearity and emphasizes severe crashes, outperforms both traditional methods in predicting future ePDO. The model effectively balances crash frequency and severity, providing a more accurate framework for identifying high-risk locations. The results show that although fatal crashes are significantly more costly, they are only slightly better risk indicators of future ePDO compared to injurious crashes, emphasizing the necessity for a more nuanced approach to crash forecasting. The proposed methodology allows for DOTs to improve safety prioritization programs without requiring additional data. Furthermore, it provides a novel framework for future research on how to weight crash data based on the risk of future crashes rather than the economic impact of previous crashes.

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Sponsoring Committee	ACS10
Session Number	3039
Session Title	**Transportation Safety Management Systems from Start to Finish**
Paper Number	TRBAM-25-02539
Paper Title	**Spatial Inequality in Socio-Demographic and Commute Patterns and their Impacts on Traffic Crash Rates: A Comparison of Interpretable Machine Learning and Spatial Statistical Modelling**
Abstract	Traffic crash rates are often closely related to the region's socio-demographic, commuting behavior, motivated by the risks associated with increased region density and excessive congestion. However, crash rates of different severities may vary considerably due to socio-spatial disparities and the mitigation behaviors adopted across regions. Thus, this study elucidates the intricate effects of socio-demographic dynamics and commuting behavior on overall and fatal traffic crash rates across Florida's counties, with particular emphasis on the underlying factors of spatial inequality. Employing an interpretable machine learning model, specifically eXtreme Gradient Boosting (XGBoost), we demonstrate its superiority in detecting spatial heterogeneity and the complex effects of various factors compared to traditional spatial statistical models, e.g. Spatial Lag Model (SLM) and Multiscale Geographically Weighted Regression model (MGWR). The findings reveal the spatial variations in both overall and fatal crash rates, correlating significantly with socio-demographic and commute pattern variables. Key variables include population demographics, commute duration, education levels, unemployment rates, and intersection density. Notably, the study dispels the conventional belief that higher overall crash rates directly correlate with higher fatal crash rates within the same counties, underscoring the importance of distinct analysis. Policy initiatives should prioritize enhancing accessibility to road infrastructure and healthcare services, differentiating between sparse and densely populated regions. These insights highlight the importance of addressing spatial inequalities in transportation infrastructure and policy interventions to mitigate traffic crash risks and enhance road safety for all regions.

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Session Number 3039

Session Title **Transportation Safety Management Systems from Start to Finish**

Paper Number TRBAM-25-02725

Paper Title **Comparing Location-Based and Home-Addressed Based Approaches in Evaluating Societal Crash and Congestion Costs**

Abstract Traffic congestion and safety pose two of the largest challenges for transportation planners and engineers worldwide, placing significant economic, environmental, and social burdens on the public. In the United States (US) crashes were estimated to have cost the American public $340 billion in 2019, with congestion costs estimated to be over $166 billion in 2017. With funding from the historic Infrastructure Investment and Jobs Act (IIJA) becoming available to transportation agencies around the US, it is vital that agencies identify the most impactful infrastructure projects to prioritize funding on to address these costs. At the same time, the US is seeking to address the lack of infrastructure spending in disadvantaged communities in previous decades. To guide this infrastructure spending, data is required to properly analyze the locations most in need of funding. This study assesses the trade-off between data accuracy and data availability in two methodologies to estimate societal crash and congestion costs, focusing on the comparison between county-level location-based aggregation and home-addressed based approaches. The study assessed crash data in the state of Massachusetts and utilized the results of the Boston Region MPO's TDM23 travel demand model to evaluate these trade-offs.

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Sponsoring Committee ACS10

Session Number 3039

Session Title **Transportation Safety Management Systems from Start to Finish**

Paper Number TRBAM-25-02795

Paper Title **The Role of Insurance in Nighttime Hit-and-Run Crashes: A Geo-Spatial Analysis**

Abstract Nighttime hit-and-run crashes significantly challenge public safety and law enforcement due to low visibility and reduced police, exacerbating the chances of drivers fleeing the scene. Various factors could contribute to a driver's decision to flee the scene. Among these factors, insurance may play a crucial yet underexplored role. The objective of this study is to explore the role of insurance in nighttime hit-and-run crashes. Considering that driver behaviors could be associated with diverse geographic contexts, the influence of insurance and other contributing factors (e.g., driver demographics) on hit-and-run decisions may vary spatially due to unobserved heterogeneity related to these contexts. To uncover this spatial unobserved heterogeneity, this study employs a geo-spatial analysis method, namely Geographically Weighted Logistic Regression (GWLR), to model hit-and-run behaviors in nighttime crashes. Using traffic crash data from Pennsylvania for the years 2021 to 2023, this analysis reveals relationships between hit-and-run decisions in individual traffic crashes and the auto insurance status of the vehicles involved, along with many other factors. The results show that the absence of auto insurance is associated with a significantly greater probability of a driver fleeing the scene, given a crash, compared to the presence of auto insurance. Further, the spatial analysis results show significant spatial variations in the influence of auto insurance. Drivers in western and eastern Pennsylvania are more likely to flee the scene if they lack insurance. The findings provide valuable insights for policymakers and insurance companies, helping them develop targeted interventions to reduce hit-and-run crashes and improve road safety.

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Sponsoring Committee ACS10
Session Number 3039
Session Title **Transportation Safety Management Systems from Start to Finish**
Paper Number TRBAM-25-02797

Paper Title **Segment-Level and Intersection-Level Driving Volatility Analysis Using Large-Scale Crowdsourced Vehicle Movement Data**

Abstract Traditional traffic safety analysis relies on crash data, which often requires multiple years of data to yield reliable outcomes. With the increasing availability of vehicle movement data from connected vehicles, researchers are presented the opportunity to understand the roadway safety performance in near real-time and identify locations exhibiting abnormal driving behaviors that may correlate with or precede traffic crashes. By using vehicle movement data, safety issues can be proactively identified. The objective of this study is to conduct a driving volatility analysis using large-scale crowdsourced vehicle movement data. Driving volatility measures the variability of vehicle movements, specifically capturing extreme driving instances such as rapid acceleration at specific locations or areas. This analysis is conducted at both the segment level and intersection level, aligning with traditional traffic safety analysis for infrastructure improvements. Rigorous models are developed to investigate the relationships between segment/intersection-level driving volatility and the annual crash frequencies. The results demonstrate a significant correlation between high driving volatility and increased crash frequencies. Specifically, a 1% increase in the driving volatility score is associated with an 28% increase in the annual crash frequency at the segment level and an 1.6% increase at the intersection level. This highlights the predictive value of driving volatility metrics in road safety analysis, with a stronger predictive value observed at the segment level. These findings suggest that integrating driving volatility analysis with traditional crash data can enhance the ability to proactively identify and mitigate safety issues, thus improving the overall safety performance of road networks.

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Session Number 3039

Session Title **Transportation Safety Management Systems from Start to Finish**

Paper Number TRBAM-25-02841

Paper Title **Comparative Analysis of School Bus Crash Severity on Urban versus Rural Roadways: A Random Parameter Logit Model with Mean Heterogeneity**

Abstract With growing concerns regarding the safety of school-aged children during their commutes, this study delves into an in-depth analysis of the severity of school bus crashes on urban versus rural local roadways. Leveraging a comprehensive dataset from the National Highway Traffic Safety Administration, which encompasses 492 rural and 531 urban crash incidents, the research employs Random Parameter Logit Models with a focus on unobserved heterogeneity in means. This sophisticated methodological approach allows for a nuanced examination of the myriad factors that contribute to crash severity in these divergent environments. The investigation is poised to uncover significant differences in the severity of crashes between urban and rural contexts, attributable to a variety of factors such as roadway infrastructure, traffic congestion, and environmental conditions. The incorporation of unobserved heterogeneity into the analysis underscores the complex nature of crash severity factors, indicating that some determinants may not be directly observable. In rural areas, early morning crashes decrease BC severity by 0.54% while evening crashes increase KA severity by 2.77%, and in urban areas, afternoon crashes decrease BC severity by 16.14% while arterial roads increase it by 25.88%, highlighting the significant influence of temporal and spatial characteristics on injury outcomes and the need for targeted interventions. This study not only delineates the distinct patterns of school bus crash severity between urban and rural settings but also offers concrete data to guide the crafting of specific safety measures aimed at reducing the incidence and impact of school bus crashes in these uniquely defined landscapes.

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Session Number 3039

Session Title **Transportation Safety Management Systems from Start to Finish**

Paper Number TRBAM-25-02850

Paper Title **Analyzing Injury Severity of School Bus Crashes considering Temporal and Spatial Heterogeneity Using Random Parameters Ordered Probit Model**

Abstract Ensuring the safety of students is a multifaceted task, extending beyond the mere design of vehicles. It involves analyzing crash data related to school buses, which plays a critical role in preventing injuries and fatalities of children both in and around these vehicles. The National Highway Traffic Safety Administration 1 gathers comprehensive data on a wide range of school bus-related crashes, from minor incidents to serious and fatal crashes. The school bus crash data not only educates parents and caregivers but also supports various prevention campaigns. The objective of this study is to investigate the different risk factors that influence the severity of injuries in school bus crashes, considering variations in time and location. To achieve this, a Random thresholds random parameters ordered probit (RPOP) model is used, which is particularly effective in identifying and accounting for unobserved variables that might affect the outcomes. Moreover, the model results suggest that springtime and highway locations significantly impact crash outcomes, considering crash details, vehicle information, and driver-passenger characteristics. These findings enhance our comprehension of the diverse factors that contribute to school bus crashes. This improved understanding aids in the development of effective strategies to reduce the severity of injuries resulting from such crashes.

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Sponsoring Committee	ACS10
Session Number	3039
Session Title	**Transportation Safety Management Systems from Start to Finish**
Paper Number	TRBAM-25-02906
Paper Title	**Assessing the Level of Speed Stability with Reliability-based Empirical Indexes for Sustainable Urban Mobility Environment**
Abstract	On urban roads, where conflicts between vehicles and pedestrians are frequent, special attention is required for pedestrian safety. Because of the strong relationship between vehicle speeds and urban vulnerable road users' safety, the importance of speed management as a primary traffic management strategy for promoting sustainable transportation has been highlighted in numerous studies. In Korea, speed management focuses on enforcing speed limits to encourage vehicle deceleration, overlooking consideration of vehicle speeds with geometric and traffic conditions for each road segment. This study developed a methodology to determine speed stability, under the assumption that the speed stability to reduce pedestrian injury severity may vary depending on the road environment and traffic conditions. Additionally, a method to evaluate the level of speed stability for each road segment and time period was proposed based on vehicle trajectory, traffic crash, and road geometry data. Then, thresholds of the level were calculated reflecting regional characteristics, and validated through correlation analysis with crash occurrence patterns. Finally, policy implications of preparing countermeasures for each level were presented. The approach presented in this study is expected to contribute to creating a safe and healthy pedestrian environment by encouraging voluntary competition to ensure pedestrian safety among local governments.

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Sponsoring Committee	ACS10
Session Number	3039
Session Title	**Transportation Safety Management Systems from Start to Finish**
Paper Number	TRBAM-25-03178
Paper Title	**How does subjective perception of streetscape affect traffic crashes? A spatial analysis for integrating safety into street planning**
Abstract	In previous research, objective factors of the built environment have been found to play a significant role in traffic crash frequency. While limited research has evaluated how people's all-around subjective perception indicators of streetscape affect crash risks. On the other hand, in urban planning field, people’s subjective perception of streetscape is a fine-grained evaluation approach for urban street quality, and the integration of traffic safety perspectives into street planning has received considerable attention. Our study aims to examine the association between people’s subjective perception of streetscape and the traffic crashes counts. Apart from this, this study intends to explore the spatial heterogeneity and distribution of this association to inform targeted safety prevention measures for key streets during the street planning process. The study focuses on the urban area of Daejeon in South Korea. Six perceptual indicators were adopted to reflect the street quality and people’s psychological state. A Bayesian multivariate spatial-varying coefficients model was introduced to simultaneously account for spatial random effect and the shared effect across various crash severity. Results indicate that four of six perceptual variables present significant associations with slight injury crash counts, and there is obvious spatial heterogeneity in their effect. Road segments exhibiting the strongest traffic safety effects from perceptual factors, combined with those with low performance on perceptual indicators, were identified as key areas for additional traffic safety-enhancing measures. Overall, the findings are expected to facilitate the safety-enhanced street planning project and contribute to a human-oriented city.

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Sponsoring Committee	ACS10
Session Number	3039
Session Title	**Transportation Safety Management Systems from Start to Finish**
Paper Number	TRBAM-25-03180
Paper Title	**Do Riding Behavior, Speeding, and Law Adherence Differ between Professional and Non-professional Riders?**
Abstract	Bangladesh has experienced a rapid rise in the use of motorcycles in recent years. The surge in non-professional as well as professional riders is due to demand, ride-sharing opportunities, self-employment, and the affordable cost of motorbikes. Although riding behavior is identified as one of the most influential precursors of motorcycle safety, there is very little research comparing the riding behaviors of professional and non-professional riders. This study, therefore, aims to differentiate professional and non-professional riders based on their distinct riding behavior. Data from 624 motorcycle riders were collected via online and face-to-face questionnaire surveys in Dhaka. Following the feature selection through mean decrease accuracy and mean decrease Gini, this study developed a random forest model to delve deeper into riders' behavior. Furthermore, the SHAP-based feature importance technique was employed to determine the differential factors like overtaking vehicles from the wrong side, carrying passengers without helmets, no speed reduction on intersections of clear roads, and riding without proper fitness in differentiating riders. Additionally, this study focused on the law adherence, alertness, and speed behaviors of the rider groups.

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Sponsoring Committee	ACS10
Session Number	3039
Session Title	**Transportation Safety Management Systems from Start to Finish**
Paper Number	TRBAM-25-03225
Paper Title	**Effect of Traffic Characteristics on Pedestrian Crash Risk Around School--—A Micro-level Pedestrian Casualty Model**
Abstract	Pedestrians are a vulnerable group of road users who are directly exposed to complex traffic conditions, thereby increasing their risk of injury or death. Traffic characteristics play a crucial role in pedestrian safety, but the impact of micro-scale features has not been fully recognized. To address these issues, this study developed a micro-crash model using pedestrian count data to assess the impact of traffic characteristics on pedestrian injuries. In addition, the effects of spatial dependence and correlation between pedestrian casualties of different injury severities were considered using a multivariate Bayesian spatial approach. The effects of roadway geometry, exposure, traffic characteristics and road conditions were also considered. The results show that exposure characterized by pedestrian counts is significantly and positively correlated with pedestrian casualties. And other values such as speed limits and average speed are positively correlated with pedestrian casualties. Results of the study provide insights for developing traffic management measures to improve pedestrian safety.

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Session Number 3039

Session Title **Transportation Safety Management Systems from Start to Finish**

Paper Number TRBAM-25-03255

Paper Title **<u>Safe Route to Landels Elementary School in the City of Mountain View California</u>**

Abstract The Safe Routes to School (SRTS) program promotes walking and bicycling through infrastructure improvements, enforcement, safety education, and incentives to encourage walking and bicycling to school. This study aimed to enhance the SRTS program through an initiative led by high school students who volunteered to paint paw print markings on sidewalks leading to Landels Elementary School. Using survey data analyzed through Structural Equation Modeling (SEM), we identified that aesthetics such as attractiveness, creativity, and enjoyment were more influential in encouraging walking than safety or ease of use. Following modifications to address multicollinearity and model specification issues, the final SEM showed a significantly improved fit, with an excellent range of fit statistics. These findings emphasize the importance of integrating visual appeal into SRTS programs and pedestrian walkways. The study suggests that future research should involve larger sample sizes and longitudinal data to better understand the long-term effects. Incorporating advanced analytical techniques, community feedback, and participatory approaches, can further enhance SRTS initiatives. This research highlights the potential for aesthetic enhancements to significantly influence walking behavior, promoting safer and more enjoyable routes to school. By engaging the community, especially teen volunteers, Safe Routes to School Programs can foster a culture of safety and health, making the journey to school safer and more enjoyable for all students. This collaborative approach not only benefits individual communities but also sets a precedent for effective community-driven safety and active transportation initiatives nationwide.

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Sponsoring Committee ACS10

Session Number 3039

Session Title **Transportation Safety Management Systems from Start to Finish**

Paper Number TRBAM-25-03313

Paper Title **<u>Transferability and Temporal Heterogeneity of Motorcyclist Injury Severity in Wet and Dry Season: A Case Study in Cambodia</u>**

Abstract Motorcyclists are particularly vulnerable to crashes as they lack sufficient protection, exposing them to a high risk of injury. Despite this, the specific impact of the wet season on motorcyclist injury severity in Southeast Asian developing countries remains largely unexplored. In recent years, the random parameter logit model with heterogeneity in means and variances has emerged as a significant tool in road safety research. To this end, this study investigates factors that influence the severity of motorcycle accidents both in wet and dry season of Cambodia by utilizing the random parameter logit models with heterogeneity in means and variances approach. These models were estimated based on motorcycle crash data of Cambodia, from the year 2015 through 2017. Effects of variables are compared by estimating their marginal effects on the injury severity outcomes. The results indicate that motorcycle-to-motorcycle crashes significantly increase the likelihood of motorcyclist casualties suffering from severe injuries during the wet season. Furthermore, accidents involving elderly motorcyclists are more likely to result in severe and fatal injuries compared to young riders during the wet season. In contrast, during the dry season, riders face a greater risk of severe injury compared to pillion riders, and crashes occurring on national roads have a higher probability of resulting in casualties suffering fatal injuries. Moreover, the transferability and temporal stability tests indicate that the effects of exogenous variables on the motorcyclist injury severity are different across year-wise models. Detailed policy-related recommendations are provided based on these analysis results to improve safety for motorcyclists.

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Sponsoring Committee	ACS10
Session Number	3039
Session Title	**Transportation Safety Management Systems from Start to Finish**
Paper Number	TRBAM-25-03318
Paper Title	**Integrating Crowdsourced Speed Data and Crash data for statewide Traffic Management and Road Safety Enhancement**
Abstract	The integration of crash data with speed segment data represents a pivotal advancement in the domains of traffic management and road safety. Current approaches often lack the real-time insight necessary to proactively address traffic issues and prevent crashes. Integrating these datasets addresses a significant knowledge gap, allowing for a more nuanced understanding of traffic patterns and crash causation. Crowdsourced real-time traffic flow and speed information offer the capability to identify congestion-prone areas and forecast potential crashes, presenting a transformative tool for traffic authorities. When integrated with crash data, this amalgamation provides unique insights into possible causes of crashes, facilitating the creation of effective preventative strategies. This research presents a comprehensive methodology for integrating crash data with Crowdsourced speed data from INRIX and utilizing crash data sourced from the Arizona Crash Information System (ACIS) database, which records crashes throughout the state of Arizona. The methodology outlined in this research encompasses the intricate process of integration and its practical application in the identification of crash hotspots. Additionally, it aids in pinpointing high-risk periods and regions necessitating countermeasures. The methodology presented serves as a valuable resource for traffic management and safety endeavors using real-time data. This research offers a critical roadmap for achieving efficient data integration and provides insights into how regions can record and harness real-time data for improved traffic management and road safety.

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Sponsoring Committee	ACS10
Session Number	3039
Session Title	**Transportation Safety Management Systems from Start to Finish**
Paper Number	TRBAM-25-03364
Paper Title	**Development of Composite Risk Index (CORSI) to evaluate risky situations while MTWs decide whether to follow or filter**
Abstract	Since Motorized Two Wheelers (MTWs) are compact and highly maneuverable, they often show filtering behavior in mixed traffic conditions. However, owing to their low visibility and lack of physical protection, this behavior poses substantial risks. This study proposes the development of an index to quantify and evaluate the risks that the MTWs face when choosing whether to follow or filter through mixed traffic. Composite Risk Index (CORSI) is a normalized index ranging from 0 (safest interactions) to 1 (riskiest interactions) and is calculated using key parameters: Clear Lateral Gap (CLG), Relative Speed, Speed of MTW, and Acceleration of MTW. Each parameter is normalized between 0 and 1, and the weights assigned to them represent how much of an impact they have on risk. Based on CORSI values, the study uses the K-means clustering technique to classify 803 interactions into "Safe," "Moderately Risky," and "Risky" clusters. According to the data, younger riders, men, and non-helmet wearers are more likely to engage in dangerous exchanges, which also tend to involve filtering behavior and higher accelerations and speeds. Safer encounters are correlated with larger leader vehicles. This research contributes to better safety tactics by improving understanding of MTW behavior in urban mixed traffic and offering a strong tool for real-time risk assessment.

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Sponsoring Committee	ACS10
Session Number	3039
Session Title	**Transportation Safety Management Systems from Start to Finish**
Paper Number	TRBAM-25-03526
Paper Title	**Crash data availability and best practices across the United States**
Abstract	While fatal crashes are available through the Fatality Analysis Reporting System (FARS) and are readily available to the public, many states do not make their crash data easily accessible for the public and the research community. The public has an interest in knowing when and where crashes occur, partly so they can demand that authorities improve safety. Researchers have an interest in being able to download data and conduct analyses to better understand mechanisms that lead to crashes and assist decision makers in designing effective policies. The objective of our study is to document the state of crash data availability throughout the country and to determine the best practices for crash data management and procedures for making data open and easily accessible. We compiled a comprehensive nationwide dataset of open crash data characteristics for states and cities that provide such data. We followed this with structured interviews with crash data experts across the country to provide insights on both the challenges and solutions needed to make crash data accessible. Key themes from our analysis include: (1) the importance of linking crash data with other datasets (e.g., injury surveillance data), (2) the need for partnerships and collaborations between universities, advocates, and agencies, and (3) challenges with data ownership and quality control. We present the results of our quantitative and qualitative work to offer best practices and Vision Zero guidance for state policy makers and traffic crash data experts.

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Sponsoring Committee	ACS10
Session Number	3039
Session Title	**Transportation Safety Management Systems from Start to Finish**
Paper Number	TRBAM-25-03718
Paper Title	**Spatial Variations in the Relationship Between Built Environment and Severe Crashes: A Case Study in Florida**
Abstract	Traffic crashes are known to be one of the significant contributing factors to the fatalities globally, with an increasing pace of accidents occurring in urban areas. This increased pace and higher risk clearly indicates the need to assess the relationship between the built environment and traffic safety. The focus of this study is to analyze the relationship between severe traffic crashes and urban built environment by global and local spatial models to reveal the spatial variations in contributing factors. We aim to investigate this relationship at the macroscopic level within a spatial regression modeling framework in which spatial lag (SLM), spatial error (SEM), geographically weighted regression (GWR), multi-scale geographically weighted regression (MGWR), and spatially lagged multi-scale geographically weighted regression (MGWRL) models are employed for a case study of Leon County, Florida. According to the results, SLM outperforms OLS, SEM and GWR models. The lagged versions of local models outperform both the global models and the generic versions of the local models in all performance measures whereas MGWR and MGWRL outperform GWR and GWRL. According to the MGWRL model, annual average daily traffic (AADT) is found to be positively related to crash rate for all block groups but motor vehicle percentage for commuting has mixed relationships (positive and negative) with crash rate, and the significance of the relationship varies spatially. The proposed approach can be used as a route map while investigating the relationship between severe crashes and urban built environment factors within a spatial framework.

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Sponsoring Committee ACS10

Session Number 3039

Session Title **Transportation Safety Management Systems from Start to Finish**

Paper Number TRBAM-25-03881

Paper Title **A spatial analysis of safety perceptions across different transport modes: Insights from Athens and Munich**

Abstract Perceived unsafety, particularly in car-dominated environments, induces mental stress, fear, and anxiety, thereby limiting the use of modes like e-bikes and e-scooters. As this factor seem to be related to the provided road infrastructure, it has a spatial dimension has not been extensively studied in the past. This study investigates the spatial patterns of safety perceptions considering four different modes, namely: private car driving, e-bike or e-scooter riding and walking. It uses Athens and Munich as study case and applies an already developed model to estimate safety scores per network link based on road infrastructure type, pavement conditions, existence of pedestrian crossings, and obstacles. Safety scores are visualized and compared between the two cities. Findings reveal that Munich's extensive cycling infrastructure and 30 km/h zones contribute to more balanced safety perceptions across transport modes. Walking received higher perceived safety scores compared to car driving. Conversely, Athens' insufficient infrastructure create significant disparities in perceived safety, particularly disadvantaging micromobility modes. Notably, high safety scores in Athens are concentrated in the city center, while Munich demonstrates a more uniform spatial distribution of safety perception. The results underscore the critical role of perceived safety in redistributing the urban road space. This will encourage the safe use of alternative transport modes leading to higher accessibility and more equitable conditions.

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Sponsoring Committee ACS10

Session Number 3039

Session Title **Transportation Safety Management Systems from Start to Finish**

Paper Number TRBAM-25-03897

Paper Title **A Context-sensitive Roadway Classification Framework for Speed Limit** Setting in the US

Abstract In the US, speed limit setting (SLS) procedures have historically relied on driver-behavior-based methods, such as the 85th percentile speed, which are considered objective and allow for consistent application. This approach has notable shortcomings, including drivers' tendency to underestimate their speeds, speed creep, and insufficient consideration of vulnerable road users, which may conflict with the Safe System Approach and Vision Zero initiatives endorsed by the USDOT (US Department of Transportation). In contrast, context-sensitive approaches, which classify roads based on roadway typologies, have been developed in countries like New Zealand, Sweden, the Netherlands, and Australia. While effective, these approaches have largely been applied outside the US, leaving many US roads with speed limits that may not fit their surroundings or adequately address pedestrian and cyclist safety. Drawing on New Zealand's One Network Framework, we developed a US-based, context-sensitive roadway classification framework that incorporates "Place," which captures surrounding land uses and locational contexts, and "Movement," which relates to the road's transport function. Our work employs nationally available data from the Smart Location Database (SLD) and the Highway Performance Monitoring System (HPMS). We validated our roadway classification framework through internal reviews by our research team and external interviews with state-level practitioners, uncovering both opportunities and challenges in adopting a context-sensitive SLS approach in the US. Our findings demonstrate the feasibility of creating an objective context-sensitive roadway classification in the US and offer insights for developing new speed-limit guidance aligned with the Safe System framework.

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Sponsoring Committee	ACS10
Session Number	3039
Session Title	**Transportation Safety Management Systems from Start to Finish**
Paper Number	TRBAM-25-03996
Paper Title	**Comparison of Segment Ranking and Sliding Window Ranking Methods for Rural Two-lane Undivided Roadways in North Carolina**
Abstract	For network screening purposes, Empirical Bayes (EB) method has been used for some decades now. Agencies may use the expected number of crashes or the potential for safety improvement (PSI) as ranking criteria by the EB method. These ranking measures could be implemented in different ways, including ranking individual segments or using a sliding window approach. For the approaches based on the EB method, traffic volume and other site characteristics are required for developing and applying the safety performance functions. However, due to unknown traffic volumes or other site characteristics on certain segments, there may be gaps along a route. Accounting for these gaps increases the complexity in implementing a sliding window algorithm. Additionally, the sliding window method is computationally more complex than the segment-level ranking method, and consequently has been less utilized in extant research. To this end, this study compared the performance of ranking individual segments versus the sliding window approach using data from rural two-lane undivided roadways in North Carolina. For the sliding window method, the sliding and window lengths were 0.1 miles and 0.3 miles, respectively. Overlaps between top ranked window segments were removed for comparing the performance of these two methods. Between the two approaches, we compared the sum of estimated EB expected crashes and PSIs for the ranked top 10, 20, 40, 50, 60, 80, and 100 miles. The results of this study show that these two methods are fairly comparable with the sliding window method being arguably better at identifying the hazardous locations.

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Sponsoring Committee	ACS10
Session Number	3039
Session Title	**Transportation Safety Management Systems from Start to Finish**
Paper Number	TRBAM-25-04039
Paper Title	**Motorcycle Following Distance and its Relationship to the Risk of Rear-End Collisions**
Abstract	This study classified motorcycle (MC) following distance based on trajectory traffic data and validated results using actual MC rear-end collisions. A total of 8,223 events of a MC following a vehicle were investigated in Pathum Thani, Thailand, and 41 cases of MC rear-end crashes were analyzed between 2017 and 2021. Time headway (TH), safe stopping distance (SSD) and time to collision (TTC) were applied to the proposed concept to determine safe following distance (SFD). Speed and following distance for actual rear-end crashes were applied to validate SFD. Results showed that the proposed SFD model identified the causes of MC rear-end collision events as mostly due to longitudinal critical area (38 cases, 92.68%), implying insufficient MC rider reaction and decision time for evasive action. The longitudinal warning area had relatively few chances for rear-end collisions to occur, with only 3 cases recorded. VDO clip extracts from MC rear-end crashes illustrated 11 cases (26.83%) of rider fatality. The study findings revealed that the SFD concept can help to prevent MC rear-end collision events by developing reminder systems when the rider reached the following distances of both warning and critical areas.

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Sponsoring Committee ACS10

Session Number 3039

Session Title **Transportation Safety Management Systems from Start to Finish**

Paper Number TRBAM-25-04043

Paper Title **Multi-Faceted Walkability Analysis for School Zone Safety in Delhi**

Abstract Pedestrian walkability in school zone areas for children and adults accompanying them is crucial to encourage walking trips in the daily commute to and from school. School zones demand extra caution from the stakeholders during design due to the presence of vulnerable road users. The case study chosen is the South Delhi region of New Delhi. A multi-faceted approach toward the assessment of walkability in a school zone is carried out with the help of community perception surveys, pedestrian walkability inventory analysis, pedestrian volume counts, and a microscopic simulation using the Social Force Model (SFM) model to compare the base scenario and a re-design scenario is done. This will enable the study of built environment changes, the impact of roadway geometric design modifications, and traffic management interventions on pedestrian walking behavior. The results reveal the influence of several factors that impact the walkability and vehicular speeds in a school zone. It adds to the research on child pedestrian safety in school zone settings, especially in the often-overlooked school zones in developing nations, and offers a replicable methodology for enhancing walkability. This study will benefit the policymakers, local government agencies, school zone communities, urban planners, researchers, and traffic management professionals by helping them understand how they can assess the walkability of a school zone area using a simple, multi-faceted, and effective approach.

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Sponsoring Committee ACS10

Session Number 3039

Session Title **Transportation Safety Management Systems from Start to Finish**

Paper Number TRBAM-25-04271

Paper Title **Investigating Factors Affecting Pedestrian Fatalities in the US: A Comparative Study of Pre-Pandemic, Pandemic, and Late-Pandemic Periods**

Abstract The rising pedestrian fatalities were already a public health concern which has been exacerbated by the disruptions caused by the COVID-19 pandemic. The existing literature offers valuable insights into the general trends and factors influencing pedestrian crashes and fatalities, however, there is a significant gap in understanding how these dynamics have changed in the pandemic-affected years. As such, this study aims to conduct a comprehensive analysis to identify the factors that have differential impacts on pedestrian fatalities across three periods: pre-pandemic (2019), pandemic (2020-2021), and late-pandemic period (2022). For this, the data were obtained from various sources including the Fatality Analysis and Reporting System, National Transit Stop Maps, Smart Location Database, and disadvantaged community database. This study utilized a twofold approach, first, the analyses were conducted at the pedestrian level using a mixed effects multinomial logit model, and second, the analyses were conducted at the census tract level using mixed effects negative binomial models. The results showed some variables exhibited a temporal shift and were associated with a higher likelihood of pedestrian fatalities such as pedestrian and driver age (25-45 years), impairment, failure to yield, jaywalking, weekend evenings/nights, proximity to transit stops, population density, and non-intersections. Analyses revealed that urban areas, lower-income neighborhoods, transit stop density, auto-oriented road network density, percent population with poor mental health, and population below 17 years were associated with an incremental increase in pedestrian fatalities across the three periods.

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Sponsoring Committee ACS10

Session Number 3039

Session Title **Transportation Safety Management Systems from Start to Finish**

Paper Number TRBAM-25-04351

Paper Title **A Data-Driven Framework for Evaluating the Effectiveness of Traffic Safety Countermeasures**

Abstract Conducting before-after safety evaluations is essential for road safety programs to identify and address safety issues through the installation of effective traffic safety countermeasures. Traditionally, these evaluations rely on historical crash data to estimate benefits through reductions in crash frequency. However, crash data often have quality issues, and long periods of data are needed before and after treatment for performing statistical analysis. To address these limitations and the need for short-term safety evaluations, this study proposes a framework using multiple real-world datasets. First, a Gower distance-based control site selection procedure was developed using probe speed data, crash data, and segment data to account for confounding bias and regression to the mean in statistical analysis. Interrupted time series (ITS) and difference-in-differences (DiD) methods were then introduced to evaluate safety using probe speed data and Michelin driving event data. A case study demonstrated the application of these methods to assess the effectiveness of installed countermeasures on MD 210 in Prince George's County, Maryland. Finally, the study discusses the robustness and performance of the datasets and statistical methods used in the analysis, highlighting their potential for providing reliable safety evaluations.

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Sponsoring Committee ACS10

Session Number 3039

Session Title **Transportation Safety Management Systems from Start to Finish**

Paper Number TRBAM-25-04485

Paper Title **Examining School Bus Stop-Arm Violation Reporting and Enforcement: A Minnesota Case Study**

Abstract Drivers put the lives of children at risk when they illegally pass school buses displaying their stop-arm. Mitigating these egregious and dangerous offenses with preventative measures, education, and proactive enforcement requires a deep understanding of the circumstances under which they occur. Documentation and accurate data such as when and where they occur, when they are reported to police, and when police issue citations to violating drivers are all valuable metrics that inform the development of different safety measures. This study aimed to determine the prevalence of stop-arm violations in Minnesota, the extent to which the events are documented, and the extent to which police enforce violations. A mixed-methods approach was taken to analyze three main datasets of stop-arm violation event, reporting, and citations from 2021-2024. Analyses of estimated base rates concluded that 113,426 to 473,112 stop-arm violations occur across the state each year. Reports submitted to Minnesota State Patrol captured only 1-3% of these estimated violations. Further, the number of statewide citations issued each year were estimated to represent less than 1% of the estimated violations statewide. Violation reporting by community moderately predicted citations, but neither were predicted by population, population density, size of police force, or number of injury crashes, indicating a potential breakdown in the current reporting and enforcement process. Interviews and observational analyses were synthesized to determine common issues related to complex processes for documentation, inaccurate knowledge or improper application of the law, and strained communication processes that attribute to both under-reporting and under-enforcement in the state.

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Sponsoring Committee	ACS10
Session Number	3039
Session Title	**Transportation Safety Management Systems from Start to Finish**
Paper Number	TRBAM-25-04640
Paper Title	**Recent Trends and Factors Associated with Risky Motorcyclist Behaviors**
Abstract	Motorcycle safety is an important public health concern. As increasingly more motorcyclists are killed in traffic crashes, it is essential to understand trends in motorcyclists' risky behaviors to better enhance their safety. This study examines data from three annual surveys conducted in Florida from 2021 to 2023, focusing on six unique risky behaviors reported by motorcyclists, including riding after alcohol consumption, helmet non-use, speeding, distracted riding, riding fatigue and riding anger. The analysis aimed to identify recent trends and factors associated with these behaviors. Results of this study reveal that several risky behaviors are linked to each other, although the at-risk group for each risky behavior differs. In particular, motorcyclists who engaged in "nontraditional" risky riding behaviors—anger, fatigue, and distraction—were also more likely to ride after alcohol consumption and exceed speed limits. Furthermore, rider anger is strongly linked to motorcyclists' perceptions of a decline in drivers' awareness of motorcycles in recent years. These findings highlight the importance of considering these nontraditional risky riding behaviors in safety interventions and the need for further research into crashes associated with these behaviors. The study concludes with tailored recommendations for addressing each specific risky behavior.

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Session Number	3039
Session Title	**Transportation Safety Management Systems from Start to Finish**
Paper Number	TRBAM-25-04703
Paper Title	**Prioritizing Safety Treatment of Rural Corridors using Curve Context**
Abstract	Horizontal curves are a significant source of crash risk on rural road networks. Historically, high-risk curves are identified reactively, based on examination of crash history. However, to reduce the influence of random variation in observed crashes, proactive approaches, which estimate underlying crash risk, are increasingly preferred. To efficiently target road safety investment, a scalable, proactive approach to estimating rural crash risk is required. This paper presents a proactive corridor prioritization framework for rural roads in the United States, based on horizontal curve risk. Road centerline geometry and speed limit data is used to estimate typical operating speeds and "curve context" – the degree to which the estimated operating speed of a curve differs from its safe traversal speed. A crash prediction model is used to estimate underlying risk, based on curve context and other geometric and traffic variables. Estimation and validation of the model using Arkansas and California datasets indicates that poor curve context is a significant predictor of crash risk. Variables used in the model are readily available for the entire continental United States, allowing estimation of crash risk without reliance on crash or detailed roadway data. Corridors are prioritized according to predicted crash risk for out-of-context curves per unit of corridor length. This approach highlights corridors where treatments to address curve context are expected to deliver the greatest crash reductions relative to treatment costs. Targeting safety improvements on prioritized corridors is expected to produce significant reductions in rural road crashes.

Authors	Weijing Wang, University of California, Davis
Sponsoring Committee	ACS10
Session Number	3039
Session Title	**Transportation Safety Management Systems from Start to Finish**
Paper Number	TRBAM-25-04729
Paper Title	**Safe System for Whom? Quantifying the Impacts of Transport Infrastructure Using a Systematic Analysis**
Abstract	In this paradigm shift to the safe systems, empirical research lacks a systematic analysis of the safety impacts of transport infrastructure. This study contributes to the literature by asking (1) What are the impacts of transport infrastructure on the likelihood of fatalities (versus socioeconomic factors)? (2) What are the heterogeneous effects of transport infrastructure on fatalities for cyclists, pedestrians, relative to vehicle occupants? (3) To what degree does one traveling in areas outside the city boundaries impact the likelihood of fatality, relative to cities? In doing so, I measured the prevalence of transport infrastructure across California using three indicators: the presence, lane miles, and density, and quantified the effects of three types of infrastructure (major roads, residential streets, and cycling infrastructure) on fatalities using the logistic regression. Results show that increases in the lane miles of major roads is associated with increases in the likelihood of fatalities for all - vehicle occupants [ORs: 2-2.4], cyclists [ORs: 1.3-1.4], and pedestrians [ORs: 1.4]; yet, one unit increase in the density of cycling infrastructure is associated with a 6% and 3% decrease in the likelihood of fatality for cyclists and pedestrians, respectively. I also found that a larger proportion of Black and Hispanic residents is associated with increases in the likelihood of fatalities for all [ORs: 1.01-1.02]; cyclist fatalities are 1.3 times as likely to occur in non-cities as in cities. Findings highlight the heterogenous effects of transport infrastructure on fatalities and sociodemographic disparities, which merits attention in the policy intervention processes.

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Sponsoring Committee	ACS10
Session Number	3039
Session Title	**Transportation Safety Management Systems from Start to Finish**
Paper Number	TRBAM-25-04774
Paper Title	**How Can We Ensure Traffic Safety Funds Improve Safety? A Conversation with Transportation Engineering Professionals.**
Abstract	Traffic related crashes are a leading cause of death among children in the United States. Improving children's safety in school zones is an efficacious means of mitigating children's injuries. Federal funding for pedestrian and bicycle infrastructure has increased, yet fatal traffic injuries are on the rise. How can we ensure that funded projects achieve safety goals? We analyzed projects that used federal transportation funds to see what sort of improvements were implemented. We found that just 10% of the 48 school zone infrastructure projects had implemented some traffic calming measure. With that, we sought to conduct focus groups with transportation engineering professionals who are in positions of implementing change. We presented case studies of infrastructure projects to elicit expert opinion on how to focus on protecting vulnerable populations most effectively during project development and implementation. While participants were knowledgeable of traffic calming measures and the Federal Highway Administration (FHWA)'s Proven Safety Countermeasures, there appeared to be a disconnect between theory and practice. Participants expressed that they often faced barriers to implementing safety countermeasures, whether political, structural, or financial. They emphasized the importance of crossing guards within school zones, noting that they would not feel comfortable allowing children to cross alone at most intersections. Participants urged the need for increased collaboration with and engagement of communities, schools, and elected officials during all aspects of school zone infrastructure improvements.

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Sponsoring Committee ACS10

Session Number 3039

Session Title **Transportation Safety Management Systems from Start to Finish**

Paper Number TRBAM-25-04805

Paper Title **Community Perceptions of Vision Zero: A case Study of Tacoma, Washington**

Abstract Vision Zero initiative gained momentum in the United States in the 2010s after successfully being implemented across European countries. The city of Tacoma adopted Vision Zero in 2020 and is planning to achieve zero traffic deaths and serious injuries by 2035. As part of its outreach plan to engage the local community, the city of Tacoma's Vision Zero team surveyed critical issues affecting traffic safety as perceived by road users. One of the Vision Zero strategies is to implement safer speeds across streets by reducing speed limits that are too high. This study analyzes the community's perceptions of speeding and high-speed limits in Tacoma using Bayesian Networks to understand community safety concerns. Narratives from respondents who perceive speeding and high-speed limits as safety concerns were analyzed using a text-mining approach. Bayesian Networks results show that responders familiar with Vision Zero and those who used active transportation were more likely to perceive speeding and high-speed limits as affecting their level of safety. Specifically, the likelihood to attribute speeding and high-speed limit to safety increased by 3.01% and 101.99%, respectively, for respondents familiar with Vision Zero, and for respondents who walk around Tacoma, the likelihood increased by 20.26% and 6.45%. Text network results revealed that driving at high speeds and on roadways with high-speed limits are perceived as critical safety issues in Tacoma. This study informs policymakers on promoting traffic safety through engineering solutions, law enforcement, and public knowledge outreach. Keywords: Vision Zero, Safety, Speeding, High-speed limits, Bayesian network, Text network

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Sponsoring Committee ACS10

Session Number 3039

Session Title **Transportation Safety Management Systems from Start to Finish**

Paper Number TRBAM-25-04862

Paper Title **Analyzing School Bus-Related Crashes in New Jersey Using Machine Learning Techniques**

Abstract Despite various safety initiatives, school bus-related crashes remain a significant concern in the United States. National data from the NHTSA reveals that from 2007 to 2016, 4% of fatal motor vehicle crashes were school-transportation-related, resulting in 1,282 deaths, including 281 school-age children. In 2018, 117 fatalities and 13,000 injuries were reported due to school bus-related crashes in the U.S., with three fatalities in New Jersey. This issue underscores the urgent need to study the safety of school bus passengers and crashes involving school buses. This paper investigates school bus crashes in New Jersey from 2016 to 2024. Advanced machine learning models, including XGBoost, Random Forest (RF), Support Vector Machine (SVM), Decision Tree and AdaBoost, were employed to evaluate the contributing factors to these crashes. The models were trained and tested to predict crash factors, with their effectiveness assessed based on performance metrics and accuracy. Additionally, SHapley Additive exPlanations (SHAP) analysis was conducted to interpret the impact of various factors on different crash outcomes, such as property damage, injury, and fatality. Our findings provide critical insights into the dynamics of school bus-related crashes and offer data-driven recommendations for enhancing safety measures, contributing to the protection of school children, and informing future safety policies and interventions.

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Sponsoring Committee	ACS10
Session Number	3039
Session Title	**Transportation Safety Management Systems from Start to Finish**
Paper Number	TRBAM-25-04997
Paper Title	**Investigating Trends in High-Risk Driving Behaviors Before and After the Onset of the COVID-19 Pandemic**
Abstract	The COVID-19 pandemic brought about significant changes in day-to-day life, including people's travel behavior. This included significant reductions in travel due to travel restrictions that were imposed to contain the pandemic. Surprisingly, despite marked reductions in travel, fatal and severe injuries significantly increased post-pandemic. Various explanations have been provided for this result, including higher travel speeds due to lower levels of congestion, as well as increases in various types of high-risk behaviors, such as impaired driving and the non-use of seatbelts. Interestingly, even after the travel restrictions were relaxed, these negative trends have continued to persist to varying degrees in the subsequent years. This study investigates trends in various high-risk driving behaviors before and after the onset of the COVID-19 pandemic using data from the National Highway Traffic Safety Administration Crash Reporting Sampling System for the years 2018 to 2022. The study examines changes in alcohol-impaired driving, seatbelt usage, and speeding, before and after the pandemic, in addition to evaluating changes in the level of injury sustained by crash-involved drivers. Results indicated a significant increase in each of these high-risk behaviors, which persisted after the pandemic. Several groups of drivers were at elevated risks for these behaviors, particularly male and younger drivers. There were also interesting regional and temporal variations across the United States. The findings underscore the need for targeted road safety interventions to mitigate the long-term impacts of the pandemic on driver behavior and crash outcomes.

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Sponsoring Committee	ACS10
Session Number	3039
Session Title	**Transportation Safety Management Systems from Start to Finish**
Paper Number	TRBAM-25-05447
Paper Title	**Analysis of Motorcycle Riders' Gap Acceptance at Unsignalized Mid-Block Crosswalks**
Abstract	Unsignalized mid-block crosswalks can often lead to conflicts between motorcyclists and pedestrians especially in Thailand where a high number of motorcycles exist in the road system. Generally, motorcyclists must yield to the crossing pedestrians. However, many pedestrian-motorcycle crashes occurred due to unstop or unyielding behavior of motorcyclists. This risky decision of motorcyclists is caused by too short gap acceptance which may cause damage on lives for both motorcyclists and pedestrians. This study aims to investigate critical gap of motorcyclists when facing pedestrian crossing at unsignalized mid-block crosswalks and to determine the significant factors influencing motorcyclists' decision when passing unsignalized mid-block crosswalks. The critical gap was estimated by using Raff's Methods, Wu's Method, and binary logistic regression, and then the influencing factors on motorcyclists' decision were analyzed by using the binary logistic regression model. From the results of this study, the motorcyclists' critical gaps when facing a single movement of pedestrian are very short (0.54-1.07 sec.). It was found that the factors influencing motorcyclists' decision to stop or not to stop at the crosswalks include headway time, direction of pedestrians' movement, availability of nearby obstacles, pedestrian crossing locations, number of crossing pedestrians, and crosswalk colors. The interaction effect between crosswalk colors and median types was also significant to the model. The short critical gap reflects the risky behavior of motorcyclists in Thailand. To improve safety of motorcyclists and pedestrians, the findings in this study are very important for the improvement of geometric design and law enforcement at the unsignalized mid-block crosswalks.

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Sponsoring Committee	ACS10
Session Number	3039
Session Title	**Transportation Safety Management Systems from Start to Finish**
Paper Number	TRBAM-25-05595
Paper Title	**ROADFIRST: A Comprehensive Enhancement of the Systemic Approach to Safety for Improved Risk Factor Identification and Evaluation**
Abstract	As an essential supplement to the traditional hotspot crash analysis, the systemic approach to traffic safety, which develops region-wide safety projects based on identified risk factors, has been widely adopted. However, this approach focuses on specific crash and facility types, causing inefficient use of crash and inventory data and a non-optimal risk evaluation and countermeasure selection for each location. To improve the comprehensiveness of the systemic approach to safety, we develop an enhanced process, ROADFIRST, that allows users to identify all potential crash contributing factors at any location. As the knowledge base for such a process, the quantitative relationships between the contributing factors and features of interest, such as traffic-related and environment-related features, are identified using Random Forest and analyzed with the SHapley Additive exPlanations (SHAP) analysis. This study identifies and ranks features impacting the likelihood of three sample contributing factors, i.e., alcohol-impaired driving, distracted driving, and speeding, according to crash and road inventory data from North Carolina, and quantifies state-wide road segment risk for each contributing factor. The introduced models and methods serve as a sample for the further development of ROADFIRST by state and local agencies, which benefits the planning of more comprehensive region-wide safety improvement projects.

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Sponsoring Committee	ACS10
Session Number	3039
Session Title	**Transportation Safety Management Systems from Start to Finish**
Paper Number	TRBAM-25-05599
Paper Title	**Safety Contributing Factors Analysis of Elderly Vulnerable Road Users: Global and Local Perspectives**
Abstract	Increasing attention to elderly traffic safety is necessary to understand the relationship between elderly traffic safety and contributing factors on a spatial scale. However, zero crashes exist at the analysis unit for some specific types of crashes, and few studies have considered the spatial heterogeneity between elderly crash frequency and influencing variables. To fill these gaps, this study developed an approach to explore the effects of contributing factors for elderly vulnerable road users' (VRUs) crashes from global and local perspectives. Socio-economic, road network, public facility, and elderly VRU crashes were collected in the grids. The gradient tree-boosted Tweedie compound Poisson models (TDboost) were employed to address zero-inflated crash data from the global aspect and geographically weighted random forests (GWRF) models were employed to reveal the spatial heterogeneity from the local aspect. The results showed that population and healthcare played an important role in predicting elderly VRU crashes. Major influencing factors showed nonlinear effects on elderly VRU crashes. They had a positive correlation with both elderly pedestrian crashes and non-motorized vehicle (NMV) crashes. The variable importance of major contributing factors for VRU crashes showed a spatial clustering tendency and a block distribution tendency, respectively. The findings provided important insights into reducing elderly crashes; for example, the concentration areas for elderly people, including healthcare facilities, markets, and bus stops, could be selected to make safety improvements. The proposed approach emphasizes that countermeasures for improvement should be formulated based on the spatial distribution of the variable importance, that is, "adapt to local conditions".

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Sponsoring Committee	ACS10
Session Number	3039
Session Title	**Transportation Safety Management Systems from Start to Finish**
Paper Number	TRBAM-25-05636
Paper Title	**Using Probe Data to Model Speeding on Interstate Horizontal Curves and Ramps**
Abstract	Lane departure collisions account for many roadway fatalities across the United States. Many of these crashes occur on horizontal curves or ramps and are due to speeding. This research investigates factors that impact the odds of speeding on Interstate horizontal curves and ramps. We collected and combined two sources of data. The first database involves comprehensive curve and ramp characteristics collected by an automatic road analyzer (ARAN) vehicle; the second database includes volume, average speed, and speed distribution gathered from probe data provided by StreetLight Insight®. We evaluated the impacts of the level of service (LOS), which reflects the level of congestion, time of the day (morning, evening, and off-peak hours), time of the week (weekdays and weekends), the month of the year (Jan-Dec), and geometric characteristics, such as curve radius, arc angle, and superelevation, on odds of speeding. The results show that the odds of speeding increases at horizontal curves with improved LOS, as well as those with larger radii and superelevation, and decreases on curves with larger arc angles and during the winter months. The findings indicate a reduction in odds of speeding at diagonal/loop ramps with larger arc angles and narrower lane widths. The results show the importance of speed enforcement and other countermeasures to reduce speeding on curves with low traffic volumes, high speed limits, and large radius and superelevation, especially in rural areas. Findings could be used to prioritize locations for the installation of speed countermeasures or dispatch enforcement resources to high-priority locations and times.

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Sponsoring Committee	ACS10
Session Number	3039
Session Title	**Transportation Safety Management Systems from Start to Finish**
Paper Number	TRBAM-25-05732
Paper Title	**Understanding the Association Between Transportation Safety and Quality of Life in Austin Using Bayesian Networks**
Abstract	Improving the quality of life is among the key focus of various jurisdictions. In doing so, various projects, including transportation-related projects, have been implemented each year to improve residents' lives. However, studies that evaluate the link between transportation attributes and quality of life are relatively scarce. Thus, this study used community survey data collected in 2018 and 2019 in Austin, Texas, to fill that gap by using the Bayesian Networks approach. The safety perception was measured using the resident's perception of walking in their neighborhood day and night and sharing the road with other road users. Results indicate that residents who feel safe walking in their neighborhood during that time are more likely to be satisfied with their quality of life. Other key indicators are safe walking downtown during the daytime and walking downtown during nighttime, while feeling safe walking in their neighborhood during nighttime was the least contributor to the quality of life. Furthermore, income was the key factor for safety perception, while street conditions and traffic flow on major streets were the key indicators of safety perception when sharing the road with other drivers. The findings suggest prioritizing transportation projects to improve residents' safety and quality of life.

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Session Number 3039

Session Title **Transportation Safety Management Systems from Start to Finish**

Paper Number TRBAM-25-05800

Paper Title **Understanding Pedestrian and Bicyclist Safety Trends in the Post-Pandemic Era**

Abstract This study investigates trends in pedestrian and bicyclist fatalities across the U.S. and fatalities and serious injuries (FSIs) within California, before and after the COVID-19 pandemic. It particularly focuses on varying community settings, including urban, rural, and disadvantaged communities. Utilizing multiple data sources, the study analyzes fatalities nationwide through the Fatality Analysis Reporting System (FARS) and FSIs from the California Statewide Integrated Traffic Records System (SWITRS). Descriptive statistics were applied to the data to explore fatality trends across the U.S. and FSIs trends across California. Additionally, a random-effects negative binomial regression model with panel data was employed to assess FSIs in California. This study illuminates significant shifts in pedestrian and bicyclist safety trends across the U.S. and California in the post-pandemic era. Nationwide, there was an 18.76% increase in pedestrian and bicyclist fatality rates with notable regional variations: urban areas saw a 21.02% increase, rural areas 7.29%, disadvantaged communities 20.02%, and non-disadvantaged communities 17.46%, highlighting a substantial increase in disadvantaged areas. In California, the results demonstrated a 6.74% rise in FSIs rate, with 5.55% in disadvantaged communities and 8.00% in non-disadvantaged communities. Wilcoxon tests indicate that all rises are statistically significant. The analysis identifies significant disparities in safety outcomes influenced by various disadvantaged burden factors, with transportation and health disadvantages being the most impactful. These findings underscore the complexity of pedestrian and bicyclist safety in the post-pandemic era and highlight the necessity for targeted safety improvements tailored to regional characteristics to address safety disparities and enhance safety effectively.

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Session Number 3039

Session Title **Transportation Safety Management Systems from Start to Finish**

Paper Number TRBAM-25-06096

Paper Title **Two-wheelers trajectory prediction in complex crowded intersection scenarios considering driving style and vehicle interaction forces**

Abstract Autonomous vehicles (AVs), driving in complex environments is a significant challenge, especially interacting with two-wheelers at intersections because the trajectories of two-wheelers are difficult to predict. Two-wheelers usually interact with multiple traffic participants at the same time in intersections, where conflicting interactions between two-wheelers and vehicles often lead to sudden changes in their trajectories. At the same time, cyclists with different driving styles will make different driving behaviors for the same interaction, resulting in different driving trajectories. In addition, due to the characteristics of "learning average behavior", the current deep learning model cannot learn the sudden behavior of two-wheelers during conflict interactions well.Based on these observations, this study proposes a random forest-based two-wheelers driving style identification model for identifying the driving styles of different two-wheelers. In addition, this study also proposes an interaction force model between two-wheelers and vehicles in the intersection area, which is used to represent the conflicting force of vehicles on two-wheelers. Finally, the driving style recognition model and the interaction force model were integrated into the edge set and weighted adjacency matrix of the space-time graph to construct a two-wheelers trajectory prediction model based on spatio-temporal graph convolutional network(ST-GCN). In the experiment, two-wheelers trajectory data at evening peak hours at multiple intersections in Nanjing were obtained to verify the rationality of the proposed model. Compared with the state-of-the-art models, the proposed model has lower errors, especially in conflict interaction scenarios.

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Session Number	3039
Session Title	**Transportation Safety Management Systems from Start to Finish**
Paper Number	TRBAM-25-06141
Paper Title	**Prioritization and Implementation of Safe Routes to School (SRTS) in Austin, Texas**
Abstract	In the early 2000s, various jurisdictions across the U.S. initiated safe routes to school projects (SRTS) to improve students' safety when walking or biking to school. In different areas, various criteria are considered when prioritizing such projects. In Austin, Texas, the main criteria are the project's overall benefit or the cost-benefit. However, less is known about what projects will likely have high benefits or high cost-benefits, as one project recommendation could have multiple improvement suggestions. Austin's SRTS data between 2016 and 2023 includes about 4,600 observed safety issues along school routes, ranked on a 5-Likert scale in terms of overall benefit and cost-benefit. Therefore, this study applied mixed-effects ordered and binary logit models to determine the likelihood of the recommendations being ranked as high benefit or high cost-benefit. In addition, the study identified the likelihood of the recommendations being reviewed and implemented after that. Results indicate that recommendations involving bike facilities, trails, and speed-related measures are more likely to be ranked with high overall benefits. Projects that mitigate difficult crossings improve faded crosswalk markings, and speed-related improvements will likely be ranked with high cost-benefits. The findings also indicate that recommendations likely to be ranked high in cost-benefit are likely to be reviewed and implemented, suggesting that cost-benefit might outweigh the overall benefits when it comes to prioritization. The practical applications of the findings are summarized and can be crucial to guide other SRTS projects in Texas and across the United States

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Sponsoring Committee	ACS10
Session Number	3039
Session Title	**Transportation Safety Management Systems from Start to Finish**
Paper Number	TRBAM-25-06278
Paper Title	**The Designation of School Zones Using a Mathematical Framework Based on a Simulated Annealing Algorithm**
Abstract	This research aims to provide framework to promote the designation of school zones by applying the mathematical solution. We employ the simulated annealing algorithm to determine whether to designate each link as a school zone by finding the global optimum that minimizes social costs in a traffic network. Social costs are composed of both accident costs and congestion costs which are directly affected by enhancing speed limits. To confirm the utility of the suggested framework, we apply it to a study site in Seoul, South Korea. The results indicate that school zones are expanded compared to the current situation, while reducing social costs on both weekdays and weekends. This study identify the outcomes enhance the safety of children and provide basis of less deterioration in traffic to persuade drivers who are skeptical of the expanding school zones. We believe that the framework using objective, quantitative, and easily obtainable evidences assist road authorities in the more rational and secure designation of school zones by resolving social conflicts.

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Sponsoring Committee	ACS10
Session Number	3039
Session Title	**Transportation Safety Management Systems from Start to Finish**
Paper Number	TRBAM-25-06361
Paper Title	**Assessment of vehicle age as a contributor to temporal shifts in single-vehicle driver injury severities**
Abstract	Vehicle age plays a crucial role in crash occurrence and occupant injury severity, with older vehicles historically associated with more severe injury outcomes compared to newer models. This study investigates the temporal instability of specific injury contributing factors for single-vehicle, single-occupant crashes involving vehicles less than 5 years old at the time of the crash, using data from Alabama's Critical Analysis Reporting Environment (CARE) system. The analysis spans four time points: 2010, 2014, 2018, and 2022. Preliminary data analysis indicates a reduction in new vehicle severe injury crashes from 8.63% in 2010 to 3.99% in 2022. Random parameters multinomial logit models with heterogeneity in means were developed to identify crash factors significantly related to injury outcomes. Key findings highlight the consistent trend of higher severity in crashes involving completely damaged vehicles. However, there was a notable decrease in severe injuries for 5-year-old vehicles involved in crashes in 2022 compared to previous years. Similarly, the reduced impact of deployed frontal airbags on severe injury outcomes points to significant improvements in occupant protection. The results further revealed that this benefit is particularly evident in the reduced likelihood of severe injury among drivers older than 65 years over the years. The study indicates the importance of advancements in vehicle technology in enhancing occupant safety. It also emphasizes the need for ongoing research into driver behavior, road conditions, and the evolution of safety standards to fully leverage these technological improvements.

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Session Number	3039
Session Title	**Transportation Safety Management Systems from Start to Finish**
Paper Number	TRBAM-25-06437
Paper Title	**Investigating the Association of Post-Crash Medical Conditions and Human Factors with Motorcyclists Injuries: Insights from Fine Injury Data From Hospital Records**
Abstract	This study investigates the factors influencing the injury severity score (ISS) in motorcycle crashes, utilizing a comprehensive dataset from the Road Traffic Injury Research and Prevention Center (RTIRPC) in Karachi, Pakistan. The analysis focuses on the post-crash medical conditions of crash victims as well as factors related to the roadway, environment, crash, and post-crash events. Specifically, the study examines the post-crash medical health conditions including Glasgow Coma Score (GCS), Systolic Blood Pressure (SBP), and their association with the ISS. Based on the distribution of dependent variables (ISS), after addressing the issue related to missing or inappropriate values in the dataset with synthetic data generation, a tobit regression was implied in a corner solution setup. The findings indicate that decreased GCS and SBP levels have a significant impact on the ISS signifying a more severe injury. Additionally, a positive association between the pre-hospital time and ISS was established, underscoring the critical influence of emergency response time on injury outcome. The study also highlights several significant characteristics contributing to the severity of injuries in motorcycle crashes, such over-speeding, wrong-way riding, nighttime crashes, and crashes involving multiple vehicles. Furthermore, the study emphasizes the significance of specific actions, including focused interventions, improved enforcement of traffic laws, and enhanced emergency medical services in mitigating injury severity in motorcycle crashes. It also calls for future research to consider real-time data collection at crash sites and account for the socioeconomic elements formulating comprehensive safety measures.

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Sponsoring Committee	ACS10
Session Number	3039
Session Title	**Transportation Safety Management Systems from Start to Finish**
Paper Number	TRBAM-25-06465
Paper Title	**Characterizing Behavioral Differences and Adaptations of Automated Vehicles and Human Drivers at Unsignalized Intersections: Insights from Waymo and Lyft Open Datasets**
Abstract	The integration of autonomous vehicles (AVs) into transportation systems presents an unprecedented opportunity to enhance road safety and efficiency. However, understanding the interactions between AVs and human-driven vehicles (HVs) at intersections remains an open research question. This study aims to bridge this gap by examining behavioral differences and adaptations of AVs and HVs at unsignalized intersections by utilizing two comprehensive AV datasets from Waymo and Lyft. Using a systematic methodology, the research identifies and analyzes merging and crossing conflicts by calculating key safety and efficiency metrics, including time to collision (TTC), post-encroachment time (PET), maximum required deceleration (MRD), time advantage (TA), and speed and acceleration profiles. The findings reveal a paradox in mixed traffic flow: while AVs maintain larger safety margins, their conservative approach can lead to unexpected situations for human drivers, potentially causing unsafe conditions. From a performance point of view, human drivers exhibit more consistent behavior when interacting with AVs versus other HVs, suggesting AVs may contribute to harmonizing traffic flow patterns. Moreover, notable differences were observed between Waymo and Lyft vehicles, which highlights the importance of considering manufacturer-specific AV behavior in traffic modeling and management strategies for the safe integration of AVs. The processed dataset utilized in this study is openly published to foster the research on AV-HV interactions.