International Co-operation on Theories and
Concepts in Traffic Safety

Behavioral adaptation to automated speed enforcement: a study using naturalistic smartphone-based data from car drivers and motorcyclists

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Speeding in road traffic is known as one of the most significant influences on crash occurrence and crash outcome severity. Automated speed enforcement is a widely applied road safety countermeasure; yet its influence on driving behavior in real traffic conditions is still not fully understood. Many evaluations rely on aggregated speed or crash data, which provide limited insight into short-range behavioral responses and potential secondary effects, such as abrupt braking or changes in acceleration patterns. This limitation is particularly relevant when considering different road user groups, such as passenger car drivers and motorcyclists, whose behavioral responses to enforcement may differ. Advances in naturalistic data collection and AI-supported analytical methods offer new opportunities to examine such behavior at an acceptable spatial and temporal resolution.

This work-in-progress study uses naturalistic driving data collected within the TWIN-SAFE project using the TOECAN mobile application, which was developed under the Horizon i-DREAMS project. The application passively monitors driving behavior through smartphone sensors. It automatically detects safety-relevant indicators, including speeding (assessed using digital speed maps), rapid acceleration and deceleration (based on G-force thresholds), and mobile phone use during driving. Data were collected continuously throughout 2024 and 2025 in Croatia, with each trip automatically recorded and evaluated across multiple behavioral parameters.

The final dataset comprises 31,615 trips from 71 participants, including 27,392 trips by passenger car drivers and 3,728 trips by motorcycle riders. All participants provided informed consent, and the study was conducted in accordance with institutional ethical approval. Data were pseudonymized at collection and fully anonymized for analysis, with no personally identifiable information retained.

Speed camera locations are integrated with trip-level data to examine observable driving and riding behavior in the immediate vicinity of automated enforcement. Spatial buffering techniques are applied to analyze speeding prevalence, speed levels, and acceleration and deceleration events in the speed camera zones. The analysis focuses on local behavioral responses within defined spatial zones and does not aim to assess long-term behavioral adaptation or enforcement effectiveness in terms of crash reduction.

AI-supported exploratory methods are employed to analyze non-linear relationships and interaction effects between vehicle type and behavioral indicators. The emphasis is placed on

interpretability and behavioral insight, with AI used as a complementary tool alongside established traffic safety concepts rather than as a purely predictive approach.

The ongoing analysis examines: (i) differences in behavioral responses to speed cameras between passenger car drivers and motorcyclists; and (ii) changes in speeding occurrence and acceleration and braking patterns in the vicinity of automated enforcement that may be relevant from a surrogate safety perspective.

By focusing on observable behavior derived from naturalistic data, this work-in-progress study contributes to a more nuanced understanding of how different road user groups respond to automated speed enforcement in real traffic conditions. The findings are intended to inform further methodological development and a subsequent full-paper submission with extended analysis.

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Gaze behavior of male and female drivers at crosswalks

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This study investigates gender differences in drivers' gaze behavior while driving through crosswalks, with a focus on fixation duration, distribution, and visual strategies. Eye-tracking glasses provided detailed gaze recordings, which were examined to reveal gender-specific patterns in visual behavior. Results reveal statistically significant differences between male and female drivers. Female drivers demonstrated a higher number of fixations with longer average fixation durations, particularly in frontal areas and dashboard, suggesting more concentrated visual attention and deeper cognitive processing in zones of potential risk. Male drivers, by contrast, exhibited less fixations with shorter fixation durations and broader horizontal and vertical gaze distribution, indicative of faster and wider scanning strategies that may be effective in complex traffic environments. These findings support the hypothesis that females apply a more cautious and risk-sensitive approach, whereas males rely on dynamic scanning strategies. The study contributes to understanding gender-specific cognitive mechanisms in driving behavior and highlights research and practical conclusions for road safety and driver training programs.

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Cycling the edge: state-of-the-art review on hard shoulder cycling practices across EU and USA.

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Abstract

Across the European Union, cycling is increasingly promoted as a key element of sustainable and safe mobility, yet on interurban and rural roads cyclists are often forced to mix with high-speed motor traffic because continuous, dedicated cycling infrastructure is missing. In several EU countries, paved hard shoulders are used or adapted to accommodate cyclists, whereas in Croatia current regulations generally prohibit cycling on hard shoulders outside settlements, effectively pushing cyclists into the main traffic lane and, where present, reserving the shoulder strictly for emergency use. This paper presents a comparative review of legal, design and operational practices related to cycling on hard shoulders on interurban and rural roads in EU Member States and selected jurisdictions in the United States, with a particular focus on cyclist safety and the transferability of international experience to the Croatian context. A scoping review of scientific and grey literature is combined with a targeted examination of national road design standards, traffic codes and guidance from road authorities and cycling organisations. Available evidence indicates substantial heterogeneity across Europe and North America: some countries and states allow or recommend cycling on paved shoulders on specific road categories when separate cycle tracks are not feasible, often with complementary measures such as reduced lane widths, buffer markings or local speed management, while others explicitly ban shoulder cycling even where no alternative exists. Existing evaluation studies, though limited, indicate that appropriately designed shoulder-cycling solutions can reduce overtaking conflicts and perceived risk compared with cyclists using the main traffic lane, especially on high-speed roads with moderate traffic volumes, but also reveal single-bicycle crash risks linked to discontinuities, debris and drainage elements. For Croatia, the findings highlight how the current regulatory stance constrains the use of paved hard shoulders as a pragmatic interim safety measure on many interurban corridors. Overall, the paper argues that hard shoulder cycling, when supported by clear legal provisions and context-sensitive design, can provide a safer and more attractive alternative to mixed-traffic riding, while longer-term investments in fully separated cycling infrastructure are developed.

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Investigating the hybrid approach of anomaly detection and EVT for conflict-based crash estimation with safety hierarchy variations

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1. Introduction

The hybrid framework of Extreme Value Theory (EVT) models and machine learning-based anomaly detection methods shows considerable promise in addressing challenges of traffic conflict analysis, which has emerged as effective surrogates for road safety assessment. However, the current research predominantly relies on single-source data collected exclusively at signalized intersections, raising concerns about the generalizability of the hybrid framework across different data scenarios. In addition, heterogeneous traffic environments inevitably lead to different safety hierarchies, which is the theoretical foundation of using traffic conflicts as the surrogate of crashes for road safety analysis. Two typical safety hierarchy are safety pyramid and diamond-shaped severity hierarchy.

To overcome these limitations, this study: *i*) utilizes two distinct datasets to characterize features associated with two typical safety hierarchy, *ii*) systematically investigates traffic safety hierarchy variations to analyze the impact of different data scenarios, sizes, and distributions on the hybrid framework, *iii*) proposes adaptation mechanisms to enhance the hybrid framework's generalizability, enabling improved efficiency of extreme sampling.

2. Data description

HighD dataset (a public dataset for highway) is selected as the representative data for safety pyramid and the data that is of diamond-shaped distribution was collected from two signalized intersections in the city of Surrey, British Columbia, Canada. The traffic safety hierarchy and frequency distribution histograms of two datasets are shown in Figure 1.



Figure 1 Traffic safety continuum and corresponding data representatives.

3. Research methodology

EVT is typically applied in a unified framework consisting of three phases: (i) identifying conflict extremes, typically using the BM or POT approaches, (ii) fitting models with the GEV distribution for BM or the GPD for POT, and (iii) evaluating crash risk. The hybrid framework is established by replacing the BM or POT with machine learning-based anomaly detection methods, as schematically illustrated in Figure 2. This study adopts IForest and MCD for conflict extreme identification. In addition, POT method, which is better than BM on condition

of short time observations, is chosen as the representative of conventional sampling methods and corresponding GPD is used to model the extremes. The Goodness-of-fit for extreme value sampling methods is evaluated both by graph-based methods (probability density plot and Q-Q plot) and statistic-based methods (estimated crash frequency and relative error).

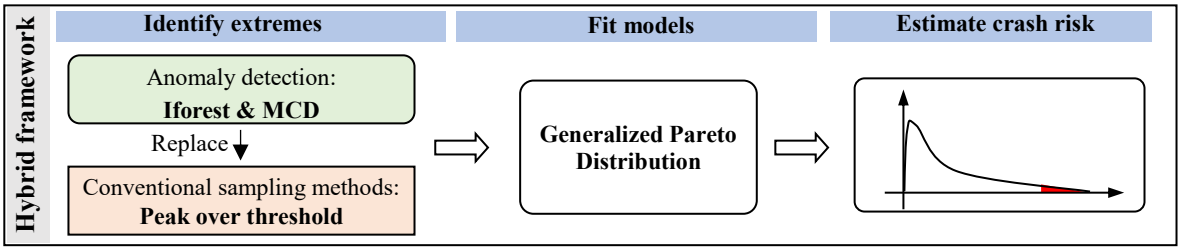


Figure 2 The schematic of hybrid framework of anomaly detection and EVT

4. Results and discussion

The results reveal that IForest and MCD perform similarly to POT when applied to pyramid-shaped data (highD dataset) with large sample sizes. However, both anomaly detection methods face challenges when applied to diamond-shaped data. IForest performs similar sampling on both sides of the diamond-shaped distribution, while MCD focuses solely on the tail. According to the asymptotic principle, the sampled data should be as close as possible to the severe event side of the distribution. Clearly, the samples selected by IForest and MCD, with configurations consistent with the highD dataset, do not meet the requirements for extreme extrapolation.

To address this issue, a natural approach would be to reshape the diamond-shaped distribution into a pyramid-shaped distribution by removing data from the middle and beyond. The specific value for the middle is determined from the probability density plot of the empirical fitting. The results show an improving performance when the data was reshaped to a pyramid shape. However, both sampling methods are less effective than POT due to the very limited data scale in the truncated Surrey dataset. Contamination rate is a critical parameter in the anomaly detection setting, which influence the number of anomalies directly. When dealing with smaller datasets, increasing the contamination rate for IForest and MCD enhanced performance, surpassing POT in certain cases. The study also reveals that MCD is less sensitive than IForest to changes in contamination rates, and more robust to data arrangement order.

5. Conclusions

This study, serving as the first comprehensive investigation into hybrid framework generalizability in traffic safety analytics, reveals that the hybrid framework's superiority manifests in processing large-scale pyramid-structured data. However, when handling diamond-shaped distributed data, conversion to pyramid-type structures becomes necessary. Under small-data scenarios, adjustments are required to enhance the contamination rate of model configuration, thereby augmenting sampling data acquisition. Overall, the generalizability of the hybrid framework is critically influenced by both the safety hierarchy and the scale of the dataset. MCD would be a better choice due to its low sensitivity to contamination rate, robustness to data order, and superior performance compared to POT under reasonable parameter settings.

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Gender differences in intention to use shared micromobility (SMM)

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Introduction

The use of shared bikes and e-scooters (SMM) has been increasing rapidly as cities work toward more sustainable transport systems. SMM supports first- and last-mile travel, offers a strong alternative to cars for short trips, and provides flexible, on-demand use for added convenience. However, such benefits are often not translated equally across gender groups. Some groups are disproportionately impacted by barriers such as accessibility and personal safety when using various transportation modes. While bodies of literature on SMM are growing, the research on SMM often treats users homogeneously, overlooking behavioural differences amongst gender groups. By combining the Knowledge-Attitude-Behaviour (KAB) model, the Self-Determination Theory (SDT), and the Unified Theory of Acceptance and Use of Technology (UTAUT) framework, this study aimed to examine behavioural intentions of SMM uptake across gender groups.

Research methodology

An online survey was used to collect data from a total of 206 respondents living in Norway (104 male, 102 female) in 2024. Respondents included both users (129) and non-users of SMM (77). On average, the respondents with prior SMM use experience were 35 years old, and those without prior SMM use experience were 43 years old. The questionnaire included three parts: participants' SMM experience (classifying users and non-users, usage frequency, and reasons for non-use), items measuring constructs of KAB, SDT, and UTAUT models using a 5-point Likert scale, and basic socio-demographic questions such as age, gender, and income. Partial least squares structural equation modelling (PLS-SEM) and multi-group analysis (MGA) were used for analyzing the data.

To analyze the data, a six-step process was followed. First, the study data were standardized for Multi-Group Analysis (MGA). Measures such as identifying and comparing groups (in this case, male and female) and minimum sample sizes for each group were determined. Next, the measurement model was assessed, with tests such as indicator loadings, composite reliability, convergent validity, and discriminant validity. Before running the actual MGA test, the measurement invariance test was conducted to determine the need for the MGA test. In the measurement invariance test, a partial measurement invariance was conducted in order to show

the legitimacy for the study to run MGA. Finally, MGA was conducted to identify which relationship path shows a significant relationship.

Results

MGA results showed that the impact of Environmental Knowledge on Environmental Attitude (EK → EA) was higher amongst males, while the effect of Environmental Knowledge on Effort Expectancy (EK → EE) and Facilitating Conditions (EK → FC), respectively, was greater amongst females. Other paths were found to show insignificant results.

As for the structural model result, the path from Environmental Knowledge to Environmental Attitude (EK → EA) showed the strongest effect across all groups (complete: $\beta = 0.571$; female: $\beta = 0.446$; male: $\beta = 0.644$; all $p < 0.01$). The second-strongest effect was the path from Intrinsic Motivation to Behavioural Intention (IM → BI) for all datasets (complete: $\beta = 0.380$; female: $\beta = 0.381$; male: $\beta = 0.366$; all $p < 0.01$).

Discussion and conclusions

Findings from MGA suggest that men's attitude towards the environment is more likely to be shaped by their environmental knowledge, as compared to their female counterparts. Also, women with environmental knowledge are more inclined to find SMM: a) compatible with their daily mobility, and b) supported via formal (service providers) and informal (fellow SMM users) assistance structures, as compared to men. Since men's environmental attitudes are more strongly shaped by environmental knowledge, campaigns aimed at male users can focus on data, facts, and cause-and-effect logic—for example, quantifying CO_2 savings, demonstrating efficiency gains, or showing evidence-based environmental benefits of SMM. For women, environmental knowledge translates more into ease-of-use and perceived support, so communication should highlight practical guidance, user-friendliness, and supportive environments (tutorials, safety instructions, navigation tips). This gender-sensitive framing can increase the effectiveness of outreach and help reduce gender disparities in SMM adoption.

It is also important to note that only three relationship paths show significant gender differences, while the remaining do not portray similar observations. As for the other remaining paths that were found to be statistically insignificant, this signifies that MGA did not indicate gender-specific variations for those relationships. These recorded associations may reflect the influence of a gender-equal Nordic context, causing many of the insignificant results to be displayed. Nonetheless, even within a Scandinavian context known for its commitment to gender equality, masculine norms seem to shape the transportation sector and influence how women navigate and experience mobility.

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Psychological quality of urban public space: towards a methodology to evaluate inclusive and resilient urban environments

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Introduction
Urban public spaces play a crucial role in shaping everyday mobility, social interaction, and psychological well-being in cities. Recent research increasingly emphasizes the concept of psychological quality of urban public space, which refers to the extent to how urban environments support comfort, safety perception, restoration, and positive social experiences. Despite growing scholarly attention, the concept remains methodologically fragmented and difficult to operationalize for urban planning and policy.

Background
This paper presents work in progress within the interdisciplinary research project URBANITA, which investigates inclusivity, perception, and conflict in urban public spaces in European cities. The study aims to develop a research framework and methodological approach to assess the psychological quality of urban public space in relation to urban mobility, spatial use, and user diversity.
The research builds on a recent systematic literature review that identifies key determinants of psychological quality, including perceived safety, walkability, environmental comfort, accessibility, human-scale design, and the presence of natural elements. These factors influence stress reduction, social interaction, and the overall experience of public space. Building on these insights, the ongoing project seeks to translate theoretical knowledge into a mixed-methods evaluation framework combining spatial analysis, perception-based surveys, and qualitative observation.

Aims and Scope
Current work in progress focuses on two complementary directions:
(1) to identify and present good practices and exemplary solutions for public spaces, which support psychological well-being and inclusive use, and
(2) to design/ develop a replicable research methodology, which can cover both spatial characteristics and user perceptions of public space quality.

Results
The expected outcomes of the project is not only a conceptual clarification, but the development of practically applicable tools for urban public space evaluation. These include:

- a structured set of indicators of psychological quality, valuable for empirical assessment and linked to spatial and mobility-related variables;
- a multi-method evaluation framework, which integrates quantitative (e.g., surveys, spatial metrics) and qualitative (e.g., observations, user narratives) approaches;
- a comparative database of good practices, documenting spatial configurations and design interventions, which could essentially enhance perceived safety, comfort, and inclusivity.

The proposed methodology will be tested in selected European cities within the URBANITA project: Olomouc (Czech Republic), Krakow (Poland), and Lund (Sweden). Results of these verification tests will be discussed.

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Improving Young Novice Drivers' Hazard Anticipation Skills: Simulator and Questionnaire Evaluations of the impacts of Driver Training over time

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Introduction

In the United Kingdom (UK), young novice drivers are disproportionately involved in road traffic crashes (Department for Transport, 2024), and addressing this issue has been identified as a priority in the recent Road Safety Strategy (Department for Transport, 2026). Inadequate hazard anticipation skills or ineffective visual scanning for potential hazards have been identified as a significant factor contributing to these crashes (Crundall et al., 2016). While many training interventions have been developed to address this skill deficit, one in particular has shown great promise. This Risk Awareness and Perception Training (RAPT) has proven effective in enhancing hazard anticipation skills (Glassman & Yamani, 2026; Thomas et al., 2016).

Although the RAPT-US training has demonstrated effectiveness in improving trainees' visual scanning patterns across numerous studies, it has not reached a ceiling effect, indicating that further improvement is possible. To address this, Madigan and Romano (2020) conducted a proof-of-concept study, adapting the RAPT materials to the UK context and delivering the training via Head-Mounted Display (HMD) technology. It was anticipated that the head movements required while using the HMD would more closely align with those needed while driving. Comparisons between pre- and post-training showed improvements for all trainees, regardless of whether the delivery mode was PC or HMD-based. The group using the HMD-based method required more attempts to pass the training but achieved better hazard perception scores on the UK Hazard Perception Test, suggesting potential additional benefits of using an HMD. While this proof-of-concept study successfully delivered a training package, its impact on drivers' behavioural responses and long-term effects remains untested. The objective of the current study is to address this using a driving simulator and a longitudinal survey.

Research methodology

As part of the Road Safety Trust-funded project, we have conducted a study involving 61 participants aged 17 to 19, all of whom had obtained their driving licenses within the last six months. Participants were allocated to either a training (n = 29) or a control group (n = 32). Participants engaged in a three-stage research process, which involved visiting the University of Leeds Driving Simulator at Virtuocity twice (completed), followed by completing a short online survey once a month for the next four months (still underway). In the first stage, participants completed a baseline drive. Subsequently, the training group received the updated HMD-based RAPT-UK training, while the control group engaged in an HMD-based puzzle game as a control. Immediately after this, they completed a second drive. Approximately one month after the first stage, participants were invited for a third simulator drive. Following this,

they will complete monthly self-reports that include the short Driver Behaviour Questionnaire (Martinussen et al., 2013) and questions about their driving incident history.

Results

Data analysis is ongoing. Results presented at the conference will offer comparisons of vehicle-based (e.g., speed) and gaze-based (e.g., gaze dispersion and time to first fixation) data across conditions. We will also assess the programme's effectiveness by focusing on both near (i.e., scenarios similar to the training content) and far (scenarios that are considerably different from the training content) transfer scenarios. Finally, questionnaire results will provide an evaluation of the short- and long-term effectiveness of the training programme.

Discussion and conclusions

The results are anticipated to demonstrate the impact of the updated RAPT-UK programme on novice drivers' hazard anticipation skills in the driving simulator, as well as long-term self-reported evaluation. These results will offer insights into improvements to driver education, the use of new technologies in road safety, and intervention evaluation, along with further theoretical and methodological contributions (e.g., Glassman & Yamani, 2026).

References

Crundall, D. (2016). Hazard prediction discriminates between novice and experienced drivers. *Accident Analysis & Prevention*, *86*, 47-58.

Department for Transport (2025). *Reported road casualties in Great Britain: younger driver factsheet, 2024.* https://www.gov.uk/government/statistics/reported-road-casualties-great-britain-older-and-younger-driver-factsheets-2024

Department for Transport (2026). *Road Safety Strategy.* https://assets.publishing.service.gov.uk/media/695e2cff8832ab3a48513809/road-safety-strategy.pdf#page=18.99

Glassman, J., & Yamani, Y. (2026). Comparable effectiveness of risk awareness and perception training (RAPT) in young drivers with diverse socioeconomic status: A driving simulator study. *Transportation Research Part F: Traffic Psychology and Behaviour*, *116*, 103397.

Madigan, R., & Romano, R. (2020). Does the use of a head mounted display increase the success of risk awareness and perception training (RAPT) for drivers? *Applied Ergonomics*, *85*, 103076.

Martinussen, L. M., Lajunen, T., Møller, M., & Özkan, T. (2013). Short and user-friendly: The development and validation of the Mini-DBQ. *Accident Analysis & Prevention*, *50*, 1259-1265.

Thomas, F. D., Rilea, S., Blomberg, R. D., Peck, R. C., & Korbelak, K. T. (2016). *Evaluation of the safety benefits of the risk awareness and perception training program for novice teen drivers.* https://rosap.ntl.bts.gov/view/dot/1986

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Safe Speed for Roads with Mixed Cars and Motorbikes

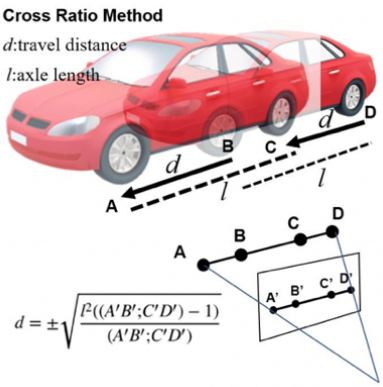
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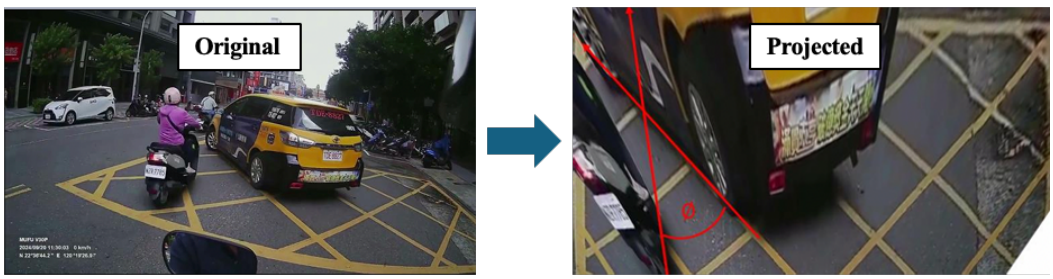
Speed management is critical, as crash severity is closely linked to impact speed and human biomechanical tolerance. Existing Safe Speeds thresholds, derived from the Wramborg Curve (Wramborg, 2005), primarily address car-car and car-vulnerable road user interactions, with limited applicability to motorbike-dominant environments. Specifically, motorcyclists face disproportionately high injury risks due to direct exposure to impact forces (CROW, 2009), particularly in regions where motorcycles constitute a large share of mixed traffic. However, current frameworks provide limited guidance on car-motorcycle interactions, leaving gaps in road design and speed control.

This study, under the "Road to *MISS* – Multimodal Inclusive Sustainable Safety" project, aims to: 1) estimate Safe Speed thresholds for car–motorcycle interactions using empirical crash data and 2) derive policy implications for road design and speed management, including conditions for safe mixed traffic and the need for physical separation.

To examine the relationship between collision conditions and crash severity in car–motorcycle crashes, *MISS* has reconstructed two key parameters from camcorder footage.

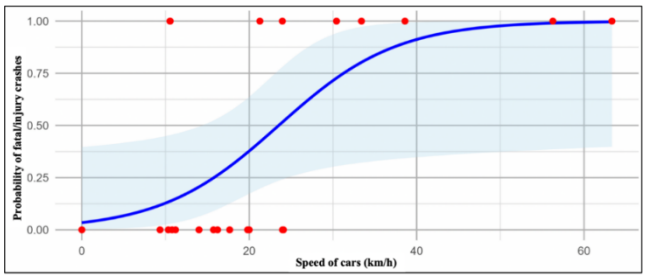
- **Vehicle speeds** were estimated using the cross-ratio method (Yang et al., 2023; Liao, 2025), which infers real-world displacement from image coordinates based on a known reference (e.g., wheelbase) and frame-by-frame tracking prior to impact. Combined with video frame rates, pre-impact speeds were obtained.
- **Collision angles** were estimated using a perspective-projection approach, in which roadway features were used to transform the image into a ground-plane coordinate system, enabling measurement of the relative angle between the car and the motorcycle.





Reconstructed crash parameters were linked to police records to identify outcomes (fatality, injury, or none). A logistic regression model was then developed to quantify the relationship between collision conditions and crash severity, estimating injury probability as a function of

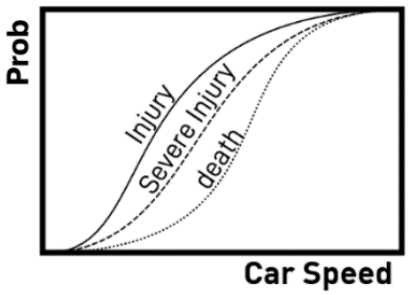
impact speed and collision angle, and providing empirical Safe Speed insights for car–motorcycle interactions. Results show that vehicle speed is a key determinant of injury risk. For small collision angles, the relationship between car speed and injury probability follows a Wramborg-type curve, expressed as:



$$\text{Prob(injury+)} = \frac{\exp(U)}{1+\exp(U)}, \qquad U = -3.80289 + 0.15314\,CarV + 0.02828\,Angle$$

Variable	Estimate	Std. Error	z value	p-value
Intercept (1)	-3.80289	1.84831	-2.057	0.0396*
Car Speed (*CarV*)	0.15314	0.07585	2.019	0.0435*
Collision Angle (*Angle*)	0.02828	0.05797	0.488	0.6257

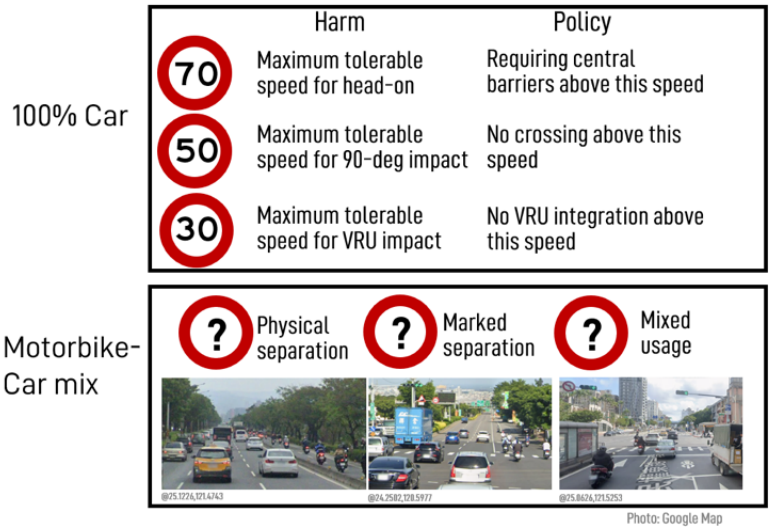
Note: Small-angle (<30 deg) samples only. The star * indicates statistical significance at the 5% level. The collision angle is not significant in itself but serves as a control variable in the Econometrics convention.



Due to limitations in current police records, the analysis is restricted to *Injury+* outcomes, and only the corresponding Wramborg-type curve can be identified. Further integration with medical data is underway to capture *Severe Injury* or *Death* conditions.

Policy Implications

While preliminary results have not yet provided definitive guidance, the estimated Safe Speeds will inform future road design strategies. In motorbike-dominant environments, measures such as physical separation or speed limits may be required to mitigate injury risks.



References

C.R.O.W. (2009), Road Safety Manual, The Netherlands.

Liao, H.-Y. (2015). Investigation [of] Motorbike Collisions with 130 Cases: Documentation for the Kinetic Energy Management Method, National Taiwan University Master's Thesis.

Wramborg, P. (2005). A new approach to a safe and sustainable road structure and street design for urban areas. Road Safety on Four Continents Conference. 13, 12p-12p.

Yang, W.C., Jiang, J., Mao, A., Su, K.-A., Chen, C.-H. (2023), "The study on the estimation of vehicles speed using a dashboard camera," *Multimedia Tools and Applications,* Vol. 83.

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The Turkish adaptation of the Cycling Anger Expression Inventory (CAX) and its associations with cycling behavior and risk perception

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Introduction

Anger expression is recognized as a significant psychological response (Love et al., 2023). Examining anger among drivers and other road users can help predict behavioral outcomes. Similar to driver behavior, cyclist behavior encompasses both deviant and positive actions (Useche et al., 2022). The observed negative correlation between positive behaviors and violations or errors supports the protective role of positive behaviors (Özkan & Lajunen, 2005). Accordingly, the main objectives of this study were to: 1)adapt the developed Cycling Anger Expression Inventory (CAX) (Møller & Haustein, 2017) to the Turkish language with a sample of cyclists from Türkiye, and 2)examine the relationship between self-reported anger expression, cycling behavior, and risk perception among Turkish cyclists.

Research Methodology

The research protocol received approval from the Ethics Committee (E-99711239-050.04-648360). A total of 223 volunteer cyclists (66.8% male, 30% female, and 3.1% other) participated in the study. Data were collected using LimeSurvey. Participants completed the Cycling Behavior Questionnaire (CBQ), the Cycling Anger Expression Inventory (CAX), the Cyclist Risk Perception and Regulation Scale (RPRS), and a demographic questionnaire. Data were analyzed using IBM SPSS 29 and Jamovi. The adaptation of the CAX into Turkish followed a rigorous five-step procedure (Beaton et al., 2000): forward translation, synthesis, back-translation, expert panel review, and pilot testing.

Results

The participants had a mean age of 37.4 years (SD = 13.5), ranging from 18 to 71 years. Regarding educational attainment, 45.9% held a bachelor's degree, 23.6% a master's degree, 19.1% a high school diploma, 10% an associate's degree, and 1.4% had completed middle school. On average, cyclists reported using bicycles for 6.89 hours per week (SD = 9.41). The primary reasons for cycling included commuting between home and work (25.1%), short-distance travel within the city (37.2%), leisure or recreation (65.9%), sports (69.5%), and other purposes (8.1%).

Validity and reliability analyses of the CAX were performed with Turkish cyclists. The exploratory factor analysis (EFA) identified a three-factor structure in the Turkish sample, consistent with the original findings (Møller & Haustein, 2017). Cronbach's alpha coefficients were 0.84 for the Verbal factor, 0.77 for the Physical factor, and 0.74 for the Constructive factor.

Confirmatory factor analysis (CFA) further supported the three-factor structure and indicated a good model fit (CFI > 0.90, SRMR, <0.10 and RMSEA, <0.10). CFA results for the CBQ (O'Hern et al., 2021; Useche et al., 2022) and RPRS (O'Hern et al., 2021) scales also indicated support for the original structures. For this study, Cronbach's alphas were 0.74 (violations), 0.85 (errors), and 0.78 (positive behaviors) for the CBQ. For the RPRS, the values were 0.79 for knowledge of traffic rules and 0.63 for risk perception.

To examine the effects of age, anger expressions and risk perception and regulation factors, three separate hierarchical regression analyses were conducted for violations, errors and positive behaviors. The analyses revealed statistically significant correlations. The final model accounts for approximately 25% of the variance in violations ($R^2 = .254$, Adjusted $R^2 = .226$). Significant predictors of violations include age, verbal expression, physical expression, and risk perception. The adjusted R^2 is 0.10 for errors and 0.15 for positive behaviors. Verbal expression and physical expression are significant predictors of errors, whereas age and physical expression are significant predictors of positive behaviors.

Discussion and conclusions

The emotions and personality traits of cyclists in traffic have only recently begun to receive scientific attention (Oehl et al., 2019). Previous research indicates that anger, hostile attributions, and aggressive communication styles are associated with risky behaviors and violations among road users, including cyclists (Møller & Haustein, 2017; Useche et al., 2018).

The findings indicate that the CAX can be reliably applied to Turkish cyclists, as it supports the original factor structure. Additionally, age, anger expression, and risk perception significantly influence cycling behavior. Specifically, verbal and physical expressions of anger were positively associated with violations, whereas elevated risk perception was associated with fewer violations. The findings should be evaluated within the context of Turkey's traffic environment, which is generally not conducive to cycling. For instance, cyclists may violate traffic rules to ensure their own safety.

References

Beaton, D. E., Bombardier, C., Guillemin, F., & Ferraz, M. B. (2000). Guidelines for the Process of Cross-Cultural Adaptation of Self-Report Measures. *Spine*, *25*(24), 3186–3191. https://doi.org/10.1097/00007632-200012150-00014

Love, S., Truelove, V., Rowland, B., Kannis-Dymand, L., Ross, D., Sullman, M., & Davey, J. (2023). The antecedents, regulation and maintenance of anger on the road: A qualitative investigation on the factors influencing driver anger and aggression. *Transportation Research Part F: Traffic Psychology and Behaviour*, *93*, 118–132. https://doi.org/10.1016/j.trf.2023.01.002

Møller, M., & Haustein, S. (2017). Anger expression among Danish cyclists and drivers: A comparison based on mode specific anger expression inventories. *Accident Analysis & Prevention*, *108*, 354–360. https://doi.org/10.1016/j.aap.2017.09.016

Oehl, M., Brandenburg, S., & Huemer, A. K. (2019). Cyclists' anger experiences in traffic: The Cycling Anger Scale. *Transportation Research Part F: Traffic Psychology and Behaviour*, *62*, 564–574. https://doi.org/10.1016/j.trf.2019.02.008

O'Hern, S., Estgfaeller, N., Stephens, A., & Useche, S. (2021). Bicycle Rider Behavior and Crash Involvement in Australia. *International Journal of Environmental Research and Public Health*, *18*(5), 2378. https://doi.org/10.3390/ijerph18052378

Özkan, T., & Lajunen, T. (2005). A new addition to DBQ: Positive Driver Behaviours Scale. *Transportation Research Part F: Traffic Psychology and Behaviour*, *8*(4–5), 355–368. https://doi.org/10.1016/j.trf.2005.04.018

Useche, S. A., Alonso, F., Boyko, A., Buyvol, P., Castañeda, I., Cendales, B., Cervantes, A., Echiburu, T., Faus, M., Feitosa, Z., Gene, J., Gonzalez-Marin, A., Gonzalez, V., Gnap, J., Ibrahim, M. K., Janstrup, K. H., Javadinejad, A., Makarova, I., McIlroy, R., … Montoro, L. (2022). Cross-culturally approaching the cycling behaviour questionnaire (CBQ): Evidence from 19 countries. *Transportation Research Part F: Traffic Psychology and Behaviour*, *91*, 386–400. https://doi.org/10.1016/j.trf.2022.10.025

Useche, S. A., Montoro, L., Tomas, J. M., & Cendales, B. (2018). Validation of the Cycling Behavior Questionnaire: A tool for measuring cyclists' road behaviors. *Transportation Research Part F: Traffic Psychology and Behaviour*, *58*, 1021–1030. https://doi.org/10.1016/j.trf.2018.08.003

International Co-operation on Theories and
Concepts in Traffic Safety

Cycling Infrastructure at Permissive Signalized Intersections: A Simulator Study on Objective and Subjective Safety of Cyclists and Drivers

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Urban street space is limited, and how it is allocated among different road users has important implications for both traffic safety and perceived fairness. These challenges become particularly salient at signalized intersections with permissive turning, where motor vehicles and cyclists receive a green signal simultaneously and must navigate the shared conflict space simultaneously. Two commonly discussed and widely implemented design levers to improve cyclists' perceived safety are increasing the width of cycling infrastructure and spatially separating cycling facilities from motor vehicle lanes, for example by means of parking lanes or green strips. Importantly, these factors should not be considered in isolation when assessing how infrastructure design shapes visibility, conflict dynamics, and users' subjective experience at intersections.

The present work-in-progress study examines how the design of cycling facilities at permissive signalized intersections affects objective and subjective indicators of safety. The experiment examines four infrastructure conditions defined by (a) the width of the cycling lane and (b) its alignment relative to motor traffic, contrasting a roadway-adjacent and a spatially separated design. In a within-subjects design, participants experiences all four conditions twice - once from a cyclist's perspective in a bicycle simulator and once from the driver's perspective in a passenger car simulator - resulting in eight simulated intersection encounters per participant. To reduce order effects, simulator order is counterbalanced across participants and scenario order randomized. Figure 1 provides an overview of the four experimental scenarios from the cyclist's perspective during the approach to the intersection. Across all conditions, signal control remains permissive, with simultaneous green for cyclists and turning motor vehicles. After each scenario, participants provide ratings of subjective safety and perceived fairness in the allocation of road space. A final questionnaire captures retrospective evaluations of the different infrastructure layouts as well as participants' knowledge of relevant traffic rules.

To assess objective safety, the analysis combines surrogate safety indicators derived from the simulated interactions, including Time to Collision and Post-Encroachment Time, with additional behavioral measures such as cyclists' lateral position in the conflict area and the turning behavior and speed of motor vehicles. The goal is to identify infrastructure characteristics that support safer interactions while also being experienced as safer and fairer by users.

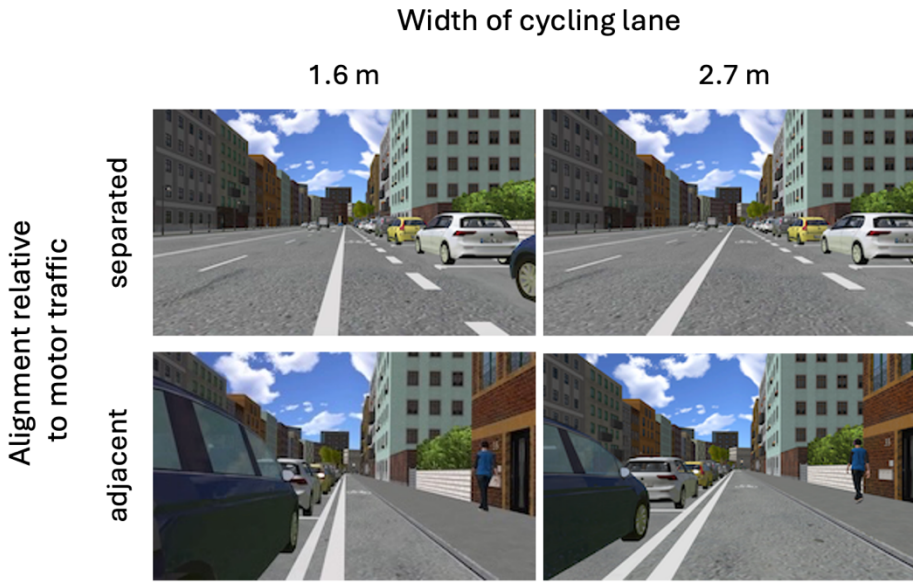


Figure 1. Experimental scenarios defined by cycling facility width and alignment relative to motor traffic (shown from the cyclist's perspective during the approach to the intersection).

Pretest data from a small preliminary sample (N = 6; exclusively from the perspective of cyclists) provide initial indications that wider cycling facilities are likely perceived as safer and that spatial separation from motor traffic may have an even stronger positive effect on perceived safety. The preliminary pattern also suggests a possible interaction, with spatial separation potentially offsetting some disadvantages of the narrower profile. Given the small pretest sample, these observations are interpreted cautiously as tentative trends rather than robust findings. The ongoing main study (planned N = 30) will allow a more reliable analysis of these effects, which will be reported in the conference presentation. The findings are intended to contribute to evidence-based recommendations for the design of cycling infrastructure at urban intersections that are both safety-promoting and perceived as equitable.

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International Co-operation on Theories and Concepts in Traffic Safety

Why do drivers misidentify whether their vehicles have ADAS?

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Introduction

Mode confusion, defined as drivers' misjudgment regarding which automation functions are available or currently active, is a recognized safety concern in vehicles equipped with Advanced Driver Assistance Systems (ADAS). Prior research shows that many drivers misidentify whether ADAS such as Adaptive Cruise Control (ACC) and Lane Keeping Assistance (LKA) are present in their own vehicles. However, the mechanisms underlying this misalignment in ownership awareness remain largely unexplored. This study, conducted as part of a larger research project[1], investigates why drivers are aligned or misaligned in their awareness of owning ACC and LKA. We introduce a confidence–accuracy framework to distinguish ownership-awareness states and identify the experiential and informational factors associated with each.

Method

We surveyed 1,487 U.S. vehicle owners (model year 2021+) whose manufacturers list both ACC and LKA as standard equipment, recruited via Prolific. Ownership awareness was measured by asking whether the vehicle has ACC and LKA (Yes/No), and responses were compared with an external model–trim catalogue. Accuracy was defined as answering "Yes." Respondents also rated confidence (1–5 Likert) in each ADAS feature ownership. Participants were classified into four ownership-awareness states by combining accuracy (accurate vs. inaccurate) and confidence (confident ≥4; doubtful ≤3): Confident & Accurate (aligned), and three misaligned states—Confident & Inaccurate, Doubtful & Accurate, and Doubtful & Inaccurate. Participants selected reasons explaining their confidence (≥4) or doubt (≤3) from a checklist of experiential and informational factors. Two analyses were conducted: (1) Holm-adjusted Fisher exact tests ($\alpha = .05$) to identify over- or under-represented reasons within each state relative to its confidence counterpart, and (2) association-rule mining (ARM) to identify frequently co-occurring reason combinations.

Results

Among Confident & Accurate respondents, experiential factors dominate: "I used it" is the most frequent and over-represented reason for both ACC and LKA (Figure 1), often co-occurring with "Feedback clear" and "I understand." Experience with one system frequently coincides with experience with the other. Among Confident & Inaccurate respondents, experiential and informational grounding is lacking: "I used it" and "Dealer explained" are under-represented, while "I don't know" is over-represented (particularly for ACC), indicating misplaced confidence. Among Doubtful & Accurate respondents, uncertainty persists despite correct ownership awareness. "Naming confusing" is over-represented for

[1] Mohammad, S.H.A. et al. (2026). *Do I have it? How drivers shape their awareness of ADAS ownership*. Manuscript in preparation.

both systems, and “Feedback unclear” for ACC, suggesting that ambiguous terminology and interface feedback hinder certainty. Among Doubtful & Inaccurate respondents, both informational and experiential deficits are evident. “I never tried it” and “No prior information” are over-represented and frequently co-occur with low perceived need. Non-use of one ADAS feature is strongly associated with non-use of the other.

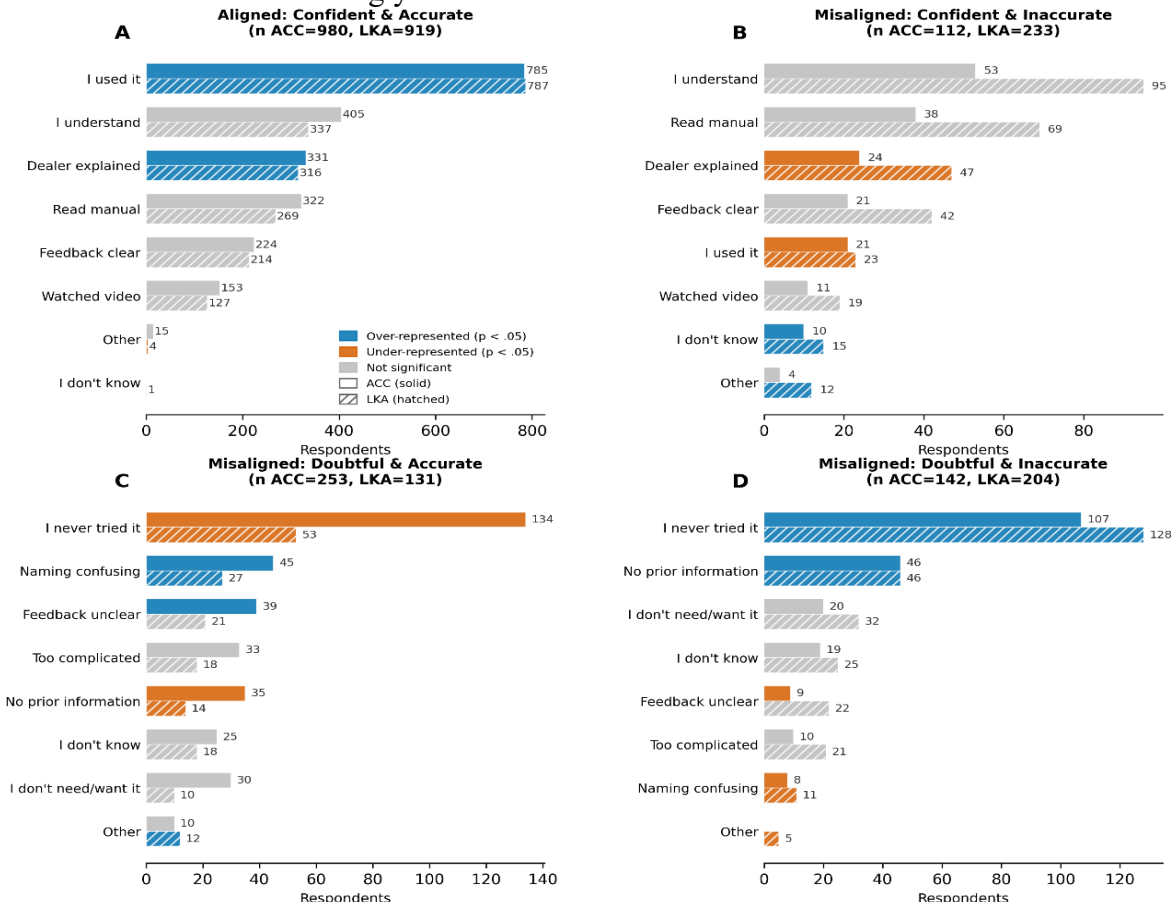


Figure 1. Stated reasons for ADAS ownership awareness grouped by confidence–accuracy state.

Discussion and Conclusion

This study provides a confidence–accuracy framework for understanding ADAS ownership awareness and identifies key mechanisms underlying misalignment. Two reinforcing deficits—lack of information and lack of first-use experience—emerge as primary associations of incorrect or uncertain ownership awareness, while other reasons such as unclear naming and feedback may sustain doubt even when awareness is correct. Based on these findings, we suggest three opportunities for mitigating mode confusion. First, improving in-vehicle interfaces, particularly by clearly indicating LKA availability and status, as ownership accuracy is lower for LKA. Second, leveraging dealer interactions at the point of sale to provide clear explanations and encourage guided first use of ADAS. Third, introducing in-vehicle onboarding to support drivers who miss initial instruction. Limitations include reliance on external model-trim data and a U.S.-based online sample, which may affect generalizability. Future research should examine other regions and older vehicle cohorts.

International Co-operation on Theories and Concepts in Traffic Safety

Cycling in Türkiye: Gendered Use Patterns, Risks, Interactions, and Perceived Stigma

Introduction

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Introduction

Cycling is widely recognized as a sustainable and health-promoting mode of transport, whose regular practice has been associated with a 10%–28% reduction in mortality risk, alongside benefits such as improved cardiovascular fitness, weight management, better cognitive functioning, stress reduction, and longer life expectancy (Götschi et al., 2016; Kaplan, 2021; Useche et al., 2026). However, choosing cycling as a travel mode depends not only on infrastructure, but also on socio-economic conditions and psychosocial factors, including attitudes, social norms, and travel habits (Heinen et al., 2010). Turkish studies have linked cycling to health, stress relief, convenience, socialization, and sustainable urban mobility, while also identifying infrastructure deficiencies, safety concerns, and socio-cultural and legal constraints on bicycle use (Aydar et al., 2025; Çeyiz & Koçak, 2015; Yıldız & Bektaş, 2021). However, evidence integrating cycling patterns, safety experiences, and social perceptions remains limited in Türkiye, where cycling is not yet fully integrated into everyday transport. Against this background, the present study aimed to provide a descriptive overview of cycling in Türkiye by examining bicycle-use patterns, gender differences in cycling purposes, exposure, crash involvement, conflicts with road-user groups and perceived stigma toward cyclists.

Research methodology

Data were collected from cyclists in Türkiye through a self-report survey. The sample included 473 participants (*M* age = 34.39 years, *SD* = 11.58); 57.7% were male, 41.4% female, and 0.8% other. Participants reported their main reasons for cycling, weekly exposure, trip duration, bicycle crash involvement, conflict frequency with different road-user groups, and perceived stigma. Bicycle-use reasons were assessed as five dichotomous yes/no items: commuting, short urban trips, leisure, exercise/fitness/sport, and job-related use. Gender differences in these reasons were examined with chi-square analyses. Crash involvement was recoded as a dichotomous variable (no crash vs. one or more crashes) for selected analyses. Weekly exposure and average trip duration were compared by gender using Mann–Whitney *U* tests. A two-step hierarchical binary logistic regression examined whether the association between gender and crash involvement was reduced after accounting for weekly cycling exposure. Conflict

frequency with eight road-user groups was rated on a 5-point scale and compared using Friedman and Bonferroni-corrected post hoc tests.

Results

Leisure riding was the most frequently endorsed bicycle-use reason, followed by exercise/fitness/sport and short urban trips, whereas job-related cycling was least frequently endorsed. A Cochran's Q test confirmed that endorsement rates differed significantly across the five reasons, $Q(4) = 797.84$, $p < .001$.

Men were significantly more likely than women to report cycling for commuting, short urban trips, and exercise/fitness/sport, whereas leisure-related cycling was similarly common in both groups. Men also reported significantly greater crash involvement than women, $\chi^2(1, N = 374) = 18.81$, $p < .001$, $\varphi = .22$; 57.0% of men and 34.4% of women reported at least one crash.

Men reported higher weekly cycling exposure than women (*Mdn* = 6.00 vs. 2.00 hours), $U = 39{,}780$, $p < .001$, and longer average trip durations (*Mdn* = 12.00 vs. 6.00 minutes), $U = 35{,}390$, $p < .001$. In the hierarchical logistic regression, women had 60% lower odds than men of reporting at least one crash in Step 1 (*OR* = 0.40, 95% *CI* [0.26, 0.60], $p < .001$). After weekly cycling exposure was added, the gender effect was reduced but remained significant (*OR* = 0.52, 95% *CI* [0.33, 0.81], $p = .004$), while weekly cycling exposure significantly increased the odds of reporting at least one crash (*OR* = 1.12, 95% *CI* [1.07, 1.17], $p < .001$). This suggests that exposure partly accounted for the observed gender difference in bicycle crash involvement.

Cyclists reported the most frequent conflicts with private cars and taxis/ride-hailing vehicles, whereas conflicts with other bicycles were least frequent. Conflict frequency differed significantly across road-user groups, $\chi^2(7) = 386.00$, $p < .001$, Kendall's $W = .155$. Bonferroni-corrected post hoc comparisons indicated that private cars and taxis/ride-hailing vehicles were associated with the highest conflict frequency, whereas other bicycles were associated with the lowest. Regarding stigma, the most frequent response was that stigma toward cyclists existed but was weakening (39.0%), followed by the view that there was no current stigma but one might emerge in the coming years (37.9%). Only 8.1% reported that stigma existed and had become stronger.

Discussion and conclusions

The findings suggest that cycling in Türkiye is characterized by a mixed but uneven pattern of use, with leisure and exercise more prominent than utilitarian purposes such as commuting or job-related cycling. This pattern suggests that cycling is still more established as a recreational activity than as an everyday transport mode, consistent with Turkish research (Aydar et al., 2025). Leisure cycling may provide a potential entry point into commuter cycling, as Park et al. (2011) found that 57% of commuter cyclists had previously been leisure cyclists.

Men reported greater cycling exposure and higher bicycle crash involvement, and the attenuation of the gender effect after adjustment for exposure suggests that this difference may be partly related to greater time spent cycling. This pattern is in line with evidence from Türkiye suggesting that women's cycling may be more constrained by safety concerns and infrastructural conditions than men's (Öztürk & Gündüz, 2020). In particular, conflicts with

private cars and taxis or ride-hailing vehicles align with previous Turkish research identifying driver behavior, limited cycling facilities, and safety concerns as recurrent barriers to bicycle use (Çeyiz & Koçak, 2015; Noyan & Güçlütürk Baran, 2024). These conflicts highlight the salience of motorized traffic in cyclists' everyday safety experiences and point to specific targets for road safety interventions in mixed-traffic environments. The stigma-related findings suggest that barriers to cycling in Türkiye extend beyond infrastructure and traffic risks, pointing to the role of broader social perceptions and persistent negative stereotypes toward cyclists. Overall, these descriptive findings may inform road safety interventions, cyclist-inclusive urban planning, and gender-sensitive policies, while also supporting future research on the broader safety-related and social conditions shaping bicycle use in Türkiye.

References

Aydar, R., Çelik, O. N., & Afşar, A. (2025). The impact of traffic infrastructure, environment, and user behavior on urban bicycle use: A literature review. *Pamukkale University Journal of Engineering Sciences, 31*(5), 849–864. https://doi.org/10.5505/pajes.2024.09804

Çeyiz, S., & Koçak, F. (2015). Ankara ilinde bisiklet kullanan bireylerin karşılaştıkları sorunlar ve çözüm önerileri. *Mediterranean Journal of Humanities, 5*(2), 203–221. https://doi.org/10.13114/MJH.2015214567

Götschi, T., Garrard, J., & Giles-Corti, B. (2016). Cycling as a part of daily life: A review of health perspectives. *Transport Reviews, 36*(1), 45–71. https://doi.org/10.1080/01441647.2015.1057877

Heinen, E., van Wee, B., & Maat, K. (2010). Commuting by bicycle: An overview of the literature. *Transport Reviews, 30*(1), 59–96. https://doi.org/10.1080/01441640903187001

Kaplan, S. (2021). Cycling as a mode choice: Motivational psychology. In R. Vickerman (Ed.), *International encyclopedia of transportation* (Vol. 7, pp. 136–143). Elsevier. https://doi.org/10.1016/B978-0-08-102671-7.10675-X

Noyan, E., & Güçlütürk Baran, G. (2024). Bisiklet kullanıcılarının karşılaştıkları sorunların incelenmesi. *Trafik ve Ulaşım Araştırmaları Dergisi, 7*(1), 19–30. https://doi.org/10.38002/tuad.1368970

Öztürk, S., & Gündüz, E. (2020). Sürdürülebilir ulaşımda bisiklet kullanımını engelleyen sebepler: Manisa örneği. *Düzce Üniversitesi Bilim ve Teknoloji Dergisi, 8*, 2164–2182. https://doi.org/10.29130/dubited.723266

Park, H., Lee, Y. J., Shin, H. C., & Sohn, K. (2011). Analyzing the time frame for the transition from leisure-cyclist to commuter-cyclist. *Transportation, 38*(2), 305–319.

Useche, S. A., Llopis, P., Alonso, F., & Pablos, A. (2026). Two wheels, better years? A systematic review on Health-Related Quality of Life (HRQoL) outcomes in older cyclists. *Journal of Transport & Health*, *47*, 102225. https://doi.org/10.1016/j.jth.2025.102225

Yıldız, S., & Bektaş, F. (2021). Bireylerin rekreatif amaçlı bisiklet kullanma deneyimlerinin nitel bir bakış açısıyla değerlendirilmesi. *Spormetre: Beden Eğitimi ve Spor Bilimleri Dergisi, 19*(2), 14–31. https://doi.org/10.33689/spormetre.709329

International Co-operation on Theories and Concepts in Traffic Safety

What makes a bicycle simulator valid for experimental research - a state-of-the art review

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Introduction, including research aim and objectives

Cycling is a key component of sustainable transport. Recently, there has been a surge in the development of bicycle simulators (BSs) as a safe environment for traffic safety research across Europe. Intended applications of BSs range from examining cyclists' behaviour and perceptions when interacting with other road users to exploring new infrastructure treatments and safety concepts.

BSs show ample variations in mechanical design, visual displays, and virtual environments, affecting opportunities and limitations for experimental evaluation of traffic safety. This paper provides a state-of-the-art review of BSs organized around three main dimensions: (1) the technical and functional characteristics of existing BSs, (2) the applications and resulting validation needs and efforts of BSs, and (3) the limitations and future needs regarding the interpretation of BSs experimental results.

Research methodology

This paper focuses on simulator designs in which participants play an active role, i.e., where their behavioural input affects the simulator's behaviour and its outputs. The literature review followed the PRISMA guidelines. As a result, 72 papers were included in the final review through a rigorous screening process. Data was extracted directly from the selected papers and organized into a structured database. For verification, pre-filled online surveys were used,

which were checked by the authors of 38 out of the 72 included studies (52.8%). The database categorized simulators across the following key dimensions: basic information; demographics; scenographic conditions; physical fidelity; inertial fidelity; rotation cueing; visual fidelity; vibration; audio; subjective fidelity; behavioural fidelity; and subjective assessment. The final database can be accessed at https://zenodo.org/records/18734855.

Results

The review revealed a diverse range of technological configurations and research applications.

- Primary applications: The majority of studies (61.1%) focused on application-oriented research, while validation-specific papers accounted for only 29.2%.
- Technological trends: Unity was the most common software platform used (48.6%). Visualization was split between Head-Mounted Displays (HMDs) in 28 studies and projection/CAVE systems in 29 studies.
- Layout and construction: The vast majority of setups (87.5%) use "mock-ups", typically consisting of a home trainer (63 instances). Most systems are fixed-base (52 papers), with dynamic or passive moving-bases appearing in only a small fraction of the research.
- Fidelity and metrics: While behavioural fidelity (primarily steering and speed) was examined in 72% of reports, subjective fidelity remains an underreported item. Audio was integrated into 40 studies, but vibration devices were rarely utilized.
- Validation gaps: 43 of the 72 studies (nearly 60%) did not report whether the simulator used had undergone any prior validation. When validation was mentioned, researchers often faced uncertainty regarding absolute validity (matching exact real-world values) versus relative validity (matching behavioural patterns).

Discussion and Conclusions

The findings indicate that while bicycle simulators are widely employed to evaluate infrastructure designs, interaction scenarios, and safety interventions, there is a significant lag in standardized validation procedures.

- Validation gaps: There is significant uncertainty regarding "Absolute" vs. "Relative" validity. Many studies rely on indirect benchmarking rather than direct real-world comparisons.
- Standardization needs: Inconsistent reporting on simulator descriptors and small sample sizes limit the generalizability of findings.
- Future directions: To improve scientific reliability, researchers must address potential confounding factors such as simulator sickness and presence. There is an urgent need for a unified framework for "verification and validation" to ensure simulator data accurately reflects real-world cycling behaviour.

International Co-operation on Theories and Concepts in Traffic Safety

Crowdsourced Pavement Intelligence for Safer Urban Cycling Infrastructure: Platform Development and Pre-Pilot Evaluation within the CAMBER Project

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1. Introduction, including research aim and objectives

Urban cycling safety is often compromised by pavement defects and inadequate maintenance of cycling networks and may also discourage active travel. However, authorities frequently lack timely and detailed spatial data on infrastructure conditions. Traditional inspection methods are resource-intensive, conducted periodically, and offer limited coverage, creating an information gap in which risks are often identified only after they have affected users. To address this gap, continuous, cost-effective monitoring approaches are required to support maintenance planning and enhance safety management. In this context, the EU-funded CAMBER project (GA 101146800) explores new-generation data sources and tools for road infrastructure monitoring. One key CAMBER demonstration, based in Trikala, Greece, focuses on a Crowdsourced Pavement Intelligence mobile platform that leverages cyclist-generated data for continuous, network-wide condition monitoring. This study presents the platform high level architecture and data processing methodology, while it reports on its current operational state ahead of the full-scale pilot commencing in summer 2026. The objectives are to: (i) describe the platform design and AI/ML-based processing pipeline; (ii) assess its technical readiness and early performance during pre-pilot testing; and (iii) discuss the platform's potential contribution to infrastructure safety management and the challenges anticipated during the pilot phase.

2. Research methodology

The Crowdsourced Pavement Intelligence platform is a mobile-based system, which enables cyclists to contribute data related to infrastructure condition, collected during their regular rides. Once a user activates a recording session via the platform's mobile app, the data collection proceeds automatically, i.e. without requiring users to report defects manually. The platform captures video footage (MP4 format) synchronised with georeferenced trajectory data (GPX/GeoJSON). Upon upload, data are

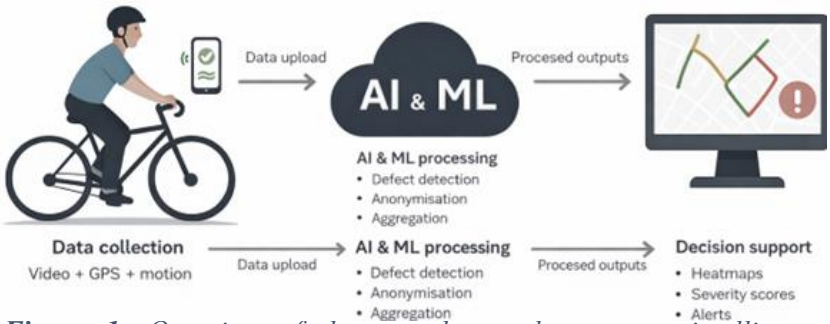


Figure 1: *Overview of the crowdsourced pavement intelligence pipeline, illustrating data collection from cyclists, AI/ML-based processing with anonymisation and the generation of aggregated infrastructure conditions for decision support.*

processed through an automated AI/ML pipeline using a YOLO-based computer vision model to detect three categories of defects: potholes, manholes, and speed breakers. The model uses a confidence threshold of 0.45, samples every third frame, and requires at least five consecutive frames to confirm a detection. Spatial and temporal deduplication filters reduce the redundant detections of the same defect. The detected defects are localised through GPS interpolation and visualised via dashboards and interactive maps. Then, the processed datasets are automatically published as open data in Zenodo, complete with DOI and structured metadata. A structured data dictionary governs variable definitions, and a two-stage validation workflow allows users (via the mobile app) and municipal operators (via the platform's web-based dashboard) to confirm or reject the automated detections. Privacy is safeguarded by restricting access to raw data and by providing anonymised and aggregated outputs.

3. Results

At the time of writing, the platform is operational, with core functionalities fully implemented and undergoing pre-pilot evaluation with a limited number of test users. The full-scale pilot, involving broader community participation across the urban cycling network of Trikala, is scheduled to commence in summer 2026. The system currently supports user-driven data collection as intended, via the dedicated mobile application, automated video and GPS processing, multi-class defect detection, and georeferenced visualisation via a web-based dashboard. Pre-pilot testing showed successful processing of uploaded recordings, generating spatially referenced detections visualised on interactive maps. Automated publishing to Zenodo with DOI assignment has been validated, and the two-stage validation workflow (user and operator confirmation) is functional. Current efforts focus on retraining the AI/ML model with an expanded annotated image dataset (over 2,000 images), optimising the performance under varying environmental conditions, and enriching the metadata. Features planned for the pilot phase include severity scoring, trend analysis, real-time alerts and alignment with the CycleRAP framework in collaboration with CAMBER partners IRAP and FPZ.

4. Discussion and conclusions

The pre-pilot findings indicate that the platform is technically ready for deployment and offers a viable, low-cost approach to continuous monitoring of infrastructure conditions, focusing on the cycling network. By leveraging routine cyclist journeys, the system can achieve higher detection frequency and spatial coverage, comparing to what conventional inspections can provide in terms of cost and effectiveness. The combination of automated detection, open data publishing, and structured validation, are considered to position this platform as a valuable decision-support tool for road authorities. Within CAMBER, the platform contributes to the project's objective of integrating new-generation data sources into safety management. However, some limitations remain: detection accuracy seems to be affected by environmental conditions and camera placement; the current model addresses three defect types, potentially missing other relevant hazards and network coverage during the pilot depends on user participation and may be uneven. Moreover, the link between detected defects and safety outcomes is indirect, relying on how the operators respond to the findings, and therefore requires further analysis. The forthcoming pilot phase, starting on summer of 2026, will enable a systematic before-after evaluation across the Trikala cycling network, with the aim of providing empirical evidence on the platform's potential impact on safety management, while informing deployment guidelines for similar urban contexts across Europe and beyond.

International Co-operation on Theories and
Concepts in Traffic Safety

Real Eyes, Realize, Real Lives: Do Smart Crossings Actually Guide Driver Attention?

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Keywords: *pedestrian safety; gaze behaviour; smart pedestrian crossing; visibility; fixations*

Introduction

Despite the decline in the number of fatalities among pedestrians in the last decade, almost one in five of all road fatalities across the EU were pedestrians. In Hungary, the number of pedestrian fatalities per million inhabitants (14.3) is still above the EU average (9.3). This drives the country towards implementing innovative solutions to improve pedestrian safety, particularly at crossings. Several smart pedestrian crossing (SPC) solutions have been installed across the country. One of these solutions is the SafeXOne Smart Pedestrian Crossing System, which detects pedestrians at crossings and warns approaching drivers visually through flashing lights installed on both roadsides (https://visiblecrossing.net/en/safexone/). The aim of this study is to investigate the impact of implementing SafeXOne on drivers' attention and gaze behaviour under different light conditions and pedestrian positions.

Research methodology

The study followed a 3 x 3 factorial design. A total of 9 experimental scenarios were created by combining 3 light conditions (daylight, dusk, and night) and 3 pedestrian positions (no pedestrian, pedestrian crossing from left, and pedestrian crossing from right). In the first stage, nine videos were recorded from a driver's perspective of an approach to an SPC in Abda, Hungary (47.696944◦N, 17.543074◦E) (Figure 1). In the second stage, 54 participants (17 female and 37 male) watched those videos in a controlled environment. The physical display was a 70-inch UHD LED screen with a native resolution of 3840 × 2160 pixels. Participants were seated at a fixed viewing distance of 1.5 m from the screen, wearing Pupil Labs Neon eye-camera glasses to collect their gaze data. Each group of 18 participants was exposed to one light condition and three pedestrian positions. These were randomised and counterbalanced so that each scenario appeared equally often across the sample. The final dataset consisted of 162 observations. After watching the recordings, participants completed a questionnaire.



Figure 1. SPC in Abda, Hungary (47.696944◦N, 17.543074◦E)

To evaluate gaze metrics (fixations, dwell proportion, time to first hit, switch rate, entropy, etc.,) we defined four areas of interest (AOIs) using YOLO: the pedestrian, the pedestrian crossing (the pavement marking), signal 1 (on the right side of the pedestrian crossing), and signal 2 (on the left side of the pedestrian crossing).

Preliminary results

Based on the questionnaire results, in terms of attention accuracy, 89% of participants detected the pedestrian approaching from the left, but only 52% noticed the flashing signals. Similarly, when the pedestrian approached from the right, 96% of participants detected the pedestrian, but only 52% noticed the flashing signals.

Regarding the evaluation of the usefulness of the SPC on the 7-point Likert scale, using the Kruskal-Wallis test, we found no significant difference in the SPC usefulness score across light conditions (chi-squared = 4.3943, p-value = 0.1111). Even so, participants rated the usefulness of the SPC during the night condition with a higher average score (5.4) than during the daylight (4.88) and dusk (4.05) conditions. Furthermore, Kendall's tau correlation revealed no statistically significant association between usefulness score and familiarity with either the location (τ = -0.06, p = 0.61) or the SafeXOne system (τ = 0.21, p = 0.08).

The results indicate that across all AOIs, fixation duration increases significantly at night, confirming that low visibility compels drivers to fixate longer. Overall, across each light condition, participants showed comparable shares of total fixation duration for signals (1+2), pedestrians, and pedestrian crossings.

We also found a clear association between active scanning and broader attentional distribution. Across all trials, switch rate and AOI entropy showed a strong positive relationship (r = 0.66), indicating that participants who switched more frequently between scene elements also distributed their attention more widely. Pedestrian-present scenarios increased attentional dispersion relative to no-pedestrian conditions, confirming that the presence of a hazard expanded the visual search space.

Across several pedestrian-present scenarios, the right-side signal region was among the earliest fixated scene elements, indicating that the adaptive crossing signal contributed to rapid initial alerting. However, this attentional engagement was not persistent. The gaze pattern typically shifted from the signal toward the pedestrian or the pedestrian crossing area, suggesting that the signal served as a trigger for a safety-oriented search rather than a competing visual distractor. This pattern was especially relevant in scenarios involving reduced visibility, where signal-driven orienting may support earlier recognition of the critical scene structure. The spatial heatmap analysis also supported these findings. Pedestrian-present scenarios produced broader, more elongated gaze distributions than no-pedestrian conditions, especially at dusk and night.

Discussion and conclusions

The findings suggest that smart pedestrian crossing signals can support driver attention in a functionally meaningful way. The adaptive signalling elements appear to initiate an early orienting response, but they do not hold attention in a persistent manner. Instead, drivers' gaze tends to move on to the pedestrian or the crossing area itself. This indicates that the smart crossing signal may facilitate hazard-related visual search without causing substantial distraction. The present study demonstrates that both light conditions and pedestrian position influence how drivers scan the scene, and that objective eye-tracking can be utilised to evaluate these effects.

International Co-operation on Theories and Concepts in Traffic Safety

Black Box on Two Wheels: ABiDA as a Multimodal Platform for Cyclist Behaviour and Physiological Monitoring

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Introduction

Cyclist behaviour depends on motion dynamics, situational awareness, physiological load, and environmental context. Single-source measurements often study these dimensions separately, yielding incomplete data on cyclist reactions. In safety-critical situations, changes in attention or physiological state often precede visible trajectory alterations.

To address this, the study introduces ABiDA (Automatized Bicycle Dynamics and Behaviour Analyzer), an onboard research platform for synchronized real-time data acquisition. The system integrates behavioural, dynamic, physiological, and contextual data into a unified workflow. This paper presents the ABiDA platform's measurement architecture and its application in investigating the links between riding behaviour, motion data, and physiological indicators.

Research methodology

The completed application supports participant preparation, questionnaire-based input, sensor initialization, real-time recording, and unified export. In this way, the system functions not merely as a logging interface, but as a full measurement workflow tailored to behavioural and traffic-safety-related cyclist research. To quantify the multimodal cyclist state, the system records synchronized data across five primary dimensions, summarized in Table 1. The platform's architecture allows the cyclist's state to be examined as a multimodal construct rather than as a set of isolated variables. The system was developed and refined in a controlled bicycle simulator environment, which supported technical integration, synchronization testing, and workflow validation before broader empirical application.

The study is based on the completed platform and on an initial series of cyclist measurements designed to explore physiological associations under controlled conditions. The measurements aim to examine whether selected physiological responses can be meaningfully interpreted together with cyclist dynamics and behavioural context. Rather than treating physiology as an isolated outcome, the research frames it as part of a broader multimodal state description that may contribute to the interpretation of cyclist workload, attention, and behavioural adaptation.

Table 1. recorded metrics in ABiDA

Data Category	Specific Metrics	Sensor / Source	Unit / Format
Dynamics & Trajectory	Acceleration, Angular velocity	Smartphone (Accelerometer, Gyroscope)	m/s², rad/s
	Speed, Position	Smartphone (GPS)	km/h, Coordinates
	Lean angle	Sensor fusion	Degrees
Physiological State	Heart rate	External HRM (e.g., Polar H9)	BPM
Visual Attention	Gaze position, Fixation frequency	External Eye-tracker	Coordinates, Hz
Environmental Context	Temperature, Noise level, Weather	Smartphone (Microphone, API)	°C, dB, Categorical
Self-Reported State	Rest level, Stress level, Trip purpose	Pre-ride in-app questionnaire	Likert scale (1-5), Text

Results

The study reports the implementation of the fully developed ABiDA platform and presents the first measurement results obtained from a pilot study recording 10 participants. These results focus on the feasibility of synchronized multimodal acquisition and on the initial identification of physiological relationships in cyclist measurements.

At this stage, the paper's main contribution is not limited to the presentation of a technical prototype. Instead, the study demonstrates how a completed, application-based measurement platform can serve as a research instrument for collecting structured cyclist data suitable for later behavioural and safety analysis. The empirical section of the paper, therefore, will introduce the first measurement outputs generated by the ABiDA workflow and discuss their value for future multimodal cyclist research.

Discussion and conclusions

The ABiDA concept contributes to cyclist research by shifting the focus from isolated measurements toward synchronized multimodal interpretation. This is particularly relevant in transport safety research, where cyclist behaviour is influenced simultaneously by physical motion, perceived demands and internal physiological state. By integrating these components into one platform, the system creates an opportunity for more comprehensive analysis of cyclist behaviour in both simulated and real-world contexts.

The paper positions ABiDA not simply as a device, but as a methodological platform for future cyclist-focused transport research. Its significance lies in enabling structured data capture across multiple domains while remaining sufficiently flexible for broader experimental deployment. The first measurements are being organised; these will provide the basis for subsequent empirical analyses.

International Co-operation on Theories and
Concepts in Traffic Safety

Assessment of Subjective Safety and Comfort in Cycling: Development and Validation of the SuSyCo Scale

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Introduction

Promoting cycling requires infrastructure that is not only objectively safe but also perceived as safe. The German "Recommendations for Cycling Facilities" (FGSV, 2010) already define subjective safety as a key design objective. The German National Cycling Plan 3.0 envisions that by 2030, people will use bicycles with joy and feel safe doing so (BMDV, 2022). However, current data reveal substantial need for improvement: according to the Bicycle Monitor (Jurczok et al., 2023), an average of 40% of cyclists feel unsafe, particularly women (49%) and individuals aged 50 and older (47%). Subjective insecurity can lead to acceptance problems, especially under conditions of high traffic volume, speed limits, and heavy goods vehicle proportion (e.g. Pejhan et al., 2021; Rivera Olsson & Elldér, 2023; Rubie et al., 2022). This can manifest in avoidance behavior such as using footpaths, taking detours, or choosing alternative modes of transport. Sole reliance on accident statistics means reacting only after accidents have occurred. This research aimed to develop and validate a standardized questionnaire (SuSyCo) for reliable and valid assessment of subjective safety and physical cycling comfort. Subjective safety is defined as personal evaluation of a specific cycling situation regarding its danger and manageability. Key indicators include overview, risk assessment, coping, safety for children (as a vulnerable group), willingness to use, and well-being. Cycling comfort represents a conceptually distinct, yet related, construct capturing physical aspects related to progress and physical exertion. The developed SuSyCo scale provides a standardized tool to define and empirically measure the key dimensions of subjective safety.

Research Methodology

Validation was conducted through an online video study with N = 3,947 participants. Eight video clips served as stimuli, showing different cycling infrastructures and traffic conditions from a cyclist's perspective. The videos were recorded using helmet-mounted cameras to enable realistic situation assessment. Psychometrically, a hierarchical Graded-Response Measurement Model was estimated and iteratively refined through theory-guided evaluation of global and local model fit as well as conceptual considerations and substantive discussion. Starting from an initial pool of 42 items, this process resulted in a final measurement model with 20 items. Items were formulated in first-person perspective and rated on a six-point scale ranging from "does not apply at all" to "applies completely". To examine validity, a structural equation model was estimated in which the video clips predicted the latent constructs Subjective Safety and Cycling Comfort. Additionally, a modified SEM was estimated in which the willingness to use facet was re-specified as an outcome of both superordinate constructs. The sample was diversified regarding age, gender, and cycling frequency to represent various cyclist groups.

Results

The final measurement model comprises 20 items distributed across two superordinate constructs: Subjective Safety (SuSy) and Cycling Comfort (Co). Subjective safety subscales include: Risk & Coping, Safety for Vulnerable Groups, Overview, Well-being, and Willingness to Use. In the structural equation model, video clips explained 43.3% of the variance in latent subjective safety and 51.1% of the variance in cycling comfort. In the modified SEM, both superordinate constructs (SuSy and Co) explained 82% of the variance in willingness to use. Subjective safety proved to be the decisive predictor of willingness to use, while cycling comfort made a smaller but independent contribution. Psychometric parameters confirm SuSyCo as a reliable and valid instrument for assessing subjective safety and physical cycling comfort. The hierarchical model structure enables calculation of both superordinate construct scores and a differentiated analysis of individual scales, depending on the research objectives.

Discussion and Conclusions

Results support SuSyCo as a practical instrument for evaluating cycling infrastructure and associated traffic conditions. Compared to pure accident statistics, SuSyCo offers the advantage of proactively identifying hazardous locations before accidents occur. Furthermore, the instrument systematically integrates cyclists' perspectives into planning, with relevance for vulnerable groups. The 'Safety for Vulnerable Groups' scale assesses whether infrastructure is manageable for users with lower functional capacities (e.g., children), providing a basis for inclusive cycling planning. Besides scientific use cases, various application scenarios are available for practice: variant comparisons for new construction, before-after measurements for reconstruction projects, existing infrastructure audits, or political monitoring. Surveys can be conducted on-site, within citizen participation formats, or online. SuSyCo thus contributes to evidence-based cycling planning. It enables professionals to measure subjective safety using scientifically sound methods and integrate findings into planning decisions. Cycling infrastructure that is both objectively and subjectively safe may encourage more people to choose cycling, an important step toward sustainable, healthy, and space-efficient mobility.

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References

BMDV. (2022). *Nationaler Radverkehrsplan 3.0: Fahrradland Deutschland 2030*. https://www.bmv.de/SharedDocs/DE/Anlage/StV/nationaler-radverkehrsplan-3-0.pdf?__blob=publicationFile

FGSV. (2010). *Empfehlungen für Radverkehrsanlagen: ERA* (FGSV R2 - Regelwerke FGSV-284). Forschungsgesellschaft für Straßen- und Verkehrswesen; Verband der Schadenversicherer.

Jurczok, F., Gensheimer, T., & Specht, F. (2023). *Fahrrad-Monitor 2023: Ergebnisse einer repräsentativen Online-Befragung.*

Pejhan, S., Agelin-Chaab, M., Yusuf, M., & Eng, D. (2021). Analysis of ebike dynamics and cyclists' anxiety levels and interactions with road vehicles that influence safety. *Accident; Analysis and Prevention*, *159*, 106272. https://doi.org/10.1016/j.aap.2021.106272

Rivera Olsson, S., & Elldér, E. (2023). Are bicycle streets cyclist-friendly? Micro-environmental factors for improving perceived safety when cycling in mixed traffic. *Accident; Analysis and Prevention*, *184*, 107007. https://doi.org/10.1016/j.aap.2023.107007

Rubie, E., Haworth, N., & Yamamoto, N. (2022). Passing distance, speed and perceived risks to the cyclist and driver in passing events. In *Contributions to the 10th International Cycling Safety Conference 2022 (ICSC2022)* (pp. 69–71). Technische Universität Dresden. https://doi.org/10.25368/2022.439

International Co-operation on Theories and Concepts in Traffic Safety

Between Feeling and Reason: A Scoping Review of Questionnaire-Based Measurements of Traffic Risk Perception

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Traffic risk perception (TRP) has received growing attention as a vital indicator of traffic-related behaviors, including route choice, mode choice, and driving style. Despite its relevance, an initial exploration of the field points to substantial variation in how TRP is operationalized and measured in questionnaire-based TRP research: some studies rely exclusively on affective responses, while others emphasize cognitive assessments of risk. This diversity is noteworthy, given that influential theoretical frameworks converge on the idea that behavior is mostly shaped by affective, and to a lesser extent cognitive processes. In addition, methodological heterogeneity is undesirable for the following reasons: 1) it complicates the comparability of research results between studies, (2) The absence of widely agreed upon measurement approaches may lead to a proliferation of suboptimal measurement tools. This 'work in progress' scoping review is a first attempt to systematically map questionnaire-based instruments of TRP published between 2019 and 2025, with special attention being given to the balance between the affective and cognitive components of TRP. With this work, we aim to provide further insight into the presence—or absence—of a broad spectrum of measurement approaches, and to examine how these approaches relate to what is known about risk perception, at the theoretical level as well as in other domains. Ultimately, this study aims to contribute to scientific discourse and to provide recommendations for selecting or developing TRP questionnaires.

International Co-operation on Theories and Concepts in Traffic Safety

Threading the needle: A study into gap acceptance for car-cyclist interactions

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Introduction

The gap choice of motorists in right-hook interactions with cyclists is relevant for safety since a misjudgement of the gap between two cyclists increases the risk of a crash occurring. The gap choice of motorists is also relevant in relation to the concept of safety-in-density, where the safety-in-numbers effect is assumed to be driven by the closeness in time of cyclists. When the flow of cyclists is dense, gaps will be smaller than the critical gap needed by motorists, and the number of potential interactions per cyclist will be reduced. Although relevant for safety, much research on gap acceptance of motorists in relation to cyclists focuses on interactions with a single bicycle, limiting our understanding of the gap acceptance of motorists when interacting with multiple cyclists. This study aims to shed more light on this type of interaction by analysing how the speed, gap size, and waiting time of the motorist affect gap choices when making a right-hand turn.

Research methodology

For this study, we make use of video data collected using an infrared camera mounted on a light pole for 33 continuous days between 2017-06-02 and 2017-07-03. The data was collected at a single signalised intersection in Malmö, shown in Figure 1, with a bi-directional cycle path. Trajectories of road users were extracted using YOLOV8 and translated into real-world coordinates using the Tsai calibration logic. Gaps between cyclists travelling in the same direction were measured based on the time they entered the yellow polygon in Figure 1. For the interactions, we only consider cars making a right-hand turn, passing the blue line before the yellow polygon. To avoid excessively large or irrelevantly small gaps, we only consider gaps between 1 and 10 seconds for this study. In total, we retrieved 1.557 interactions fitting these criteria. It is worth noting that these are not unique interactions, as a single motorist can reject multiple gaps between pairs of cyclists before accepting a gap. Gap choice was modelled using a logistic regression with the response variable coded as accepted (1) and rejected (0). Additional variables are the speed of the car, the speed of both bicycles, the size of the gap in time, the direction of travel of the cyclists, and the waiting time of the car.

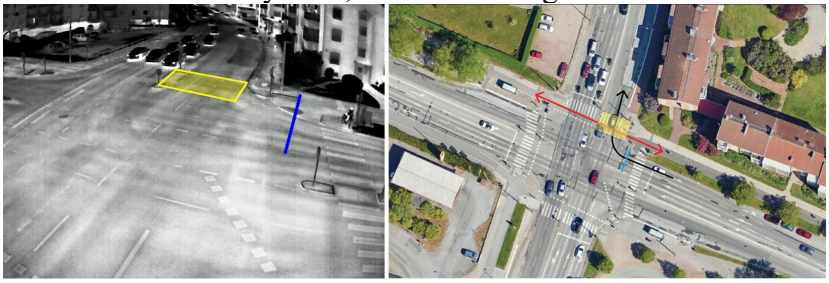


Figure 1: View of the camera (left) with interaction polygon (yellow) and commitment line (blue), and satellite view (right) of intersection with movements of car (black) and bicycles (red) indicated. Note: the commitment line spans the bike lane to account for height differences in bounding boxes for larger vehicles such as a van. Image source satellite image Google (2023).

Results

Regression coefficients along with odds ratios are shown in Table 1, and the average marginal effects on the probability of accepting a gap are shown in Table 2. Several interaction terms between the gap size and other variables were tested, but only significant interactions were kept. The results indicate that gap size has the largest influence on whether a motorist accepts a gap or not. On average, a one-unit increase in gap size increases the probability of someone accepting a gap by 7.2 percentage points. The effect is, however, not isolated and is moderated by both the speed of the leading bicycle and the direction of the cyclists. The odds ratio for the former suggests, however, that this effect is relatively small in practice. The interaction with the direction of the cyclists indicates that it is more likely for someone to reject a gap if cyclists travel in the same direction. As the gap size increases, the effect of the direction converges, however, suggesting that the direction of travel is less relevant when the gap between two cyclists is large.

Table 1: Coefficients of the logistic regression model. Success = gap accepted.

	Estimate	Std. Error	P value	Odds ratio	95% CI (OR)
(Intercept)	-1.168	0.263	8.86e-06***	0.31	0.18-0.52
Gap size in seconds	1.087	0.154	1.42e-12***	2.97	2.25-4.12
Speed of the leading bicycle	0.026	0.042	5.35e-01	1.03	0.95-1.11
Speed of the trailing bicycle	-0.019	0.033	5.70e-01	0.98	0.92-1.05
Speed of car at commitment line	0.025	0.048	6.01e-01	1.03	0.93-1.12
Cyclist direction = same as car	-0.988	0.395	1.24e-02*	0.37	0.17-0.8
Waiting time of car in seconds	-0.454	0.073	6.22e-10***	0.64	0.55-0.73
Gap size * Speed leading bicycle	0.071	0.025	5.18e-03**	1.07	1.02-1.13
Gap size * Cyclist direction	0.513	0.214	1.68e-02*	1.67	1.1-2.55

*Significance levels: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1*

Table 2: Average marginal effect on probability of accepting a gap

Gap size	Cyclist direction	Waiting time	Leader speed	Car speed	Follower speed
0.072	-0.052	-0.024	0.003	0.001	-0.001

Discussion and conclusion

This study aims to assess the factors influencing gap choices made by motorists interacting with cyclists when making a right-hand turn. In line with expectations, our results suggest that the main determinant of whether someone accepts or rejects a gap is the gap size. In terms of safety, this provides some evidence for the safety-in-density hypothesis, as cyclists being closer together (i.e., a higher density) reduces the probability of a driver passing between two cyclists, thus reducing the interaction per bicycle. A surprising finding is that the speed of cyclists alone does not have a statistically significant effect on gap choices. It is worth noting that the gaps considered here a time based, not distance-based. This choice is made since some cases did not allow an accurate distance due to the field of vision of the camera. It is also worth noting that the results presented here rely on data from a single intersection in Sweden, and the generalizability is unclear. Future studies should include a wider selection of study sites, including different intersection designs and countries, to understand whether the results presented here are location dependent and to study the role of infrastructure in gap choices.

International Co-operation on Theories and Concepts in Traffic Safety

Effects of Bicycle Infrastructure on Cyclists' Experience and Behaviour in Roundabouts

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Introduction

Roundabouts have demonstrated positive effects on improving overall road safety for typical road users (Elvik, 2003; Jensen, 2017), yet research reveals ambivalent results specifically for cyclists. Mixed-traffic roundabouts without dedicated bicycle facilities are particularly perceived as unsafe and uncomfortable by many cyclists (Møller & Hels, 2008; Poudel & Singleton, 2022), potentially discouraging bicycle usage. While objective safety data exists (Daniels et al., 2009; Jensen, 2013), cyclists' subjective experience remains under-researched, especially regarding innovative pavement designs and the influence of approach infrastructure. This study investigated the research question: What is the effect of roundabout design, approach infrastructure type, and traffic volume on cyclists' subjective experience and behaviour?

Research Methodology

A bicycle simulator experiment was conducted at the German Federal Highway Research Institute (BASt). It employed a 3×2×2 mixed experimental design with two within-subject factors (roundabout pavement design: basic, pictograms, red colouring; bicycle facility in the approach: advisory lane vs. separated path) and one between-subject factor (motor traffic volume: low vs. high). Participants (N = 71, aged 18-77 years) experienced standardized scenarios in BASt's bicycle simulator with 300-degree visual field. The simulator featured a bicycle mock-up with mechanical derailleur, enabling realistic steering and speed control. During simulator rides, participants responded to three questions after each roundabout traversal on a six-point Likert scale addressing subjective safety, acceptance, and mental demand. Additionally, performance data (lateral position, speed) were recorded throughout the simulator rides. Statistical analysis was conducted with mixed repeated-measures ANOVAs for questionnaire data and Linear Mixed Effects (LME) models for time-dependent performance data. Post-hoc tests with Holm-Bonferroni correction identified specific effects.

Results

Approach Infrastructure: Advisory bicycle lanes received significantly higher ratings than separated bicycle paths for subjective safety ($p = 0.003$, $dz = 0.418$), acceptance ($p = 0.003$, $dz = 0.418$), and mental demand ($p = 0.004$). This preference contradicts some existing literature favouring separated facilities. Additionally, there was a small but significant effect on lateral position in the roundabout: cyclists previously on advisory lanes positioned themselves 12.6 cm closer to the outer edge ($p = 0.042$).

Roundabout Pavement Design: No significant main effect of pavement design on subjective safety was found during simulator rides. However, red pavement colouring significantly increased mental demand compared to basic designs ($p < 0.001$).
Traffic Volume: Higher motor traffic volume significantly shifted cyclists toward the outer edge of the roundabout by 72.6 cm (p=0.020, d=0.618), raising safety concerns. Traffic volume had minimal influence on subjective safety and comfort ratings.

Discussion and Conclusions

The findings reveal a complex relationship between infrastructure design and cyclists' subjective experience. The preference for advisory bicycle lanes over separated paths in approach situations likely stems from the merging manoeuvre required when transitioning from bicycle paths to roadway before entering mixed-traffic roundabouts. This merging situation creates heightened mental stress and uncertainty, particularly at short approach segments. Regarding pavement designs, simulator exposure revealed increased mental demand due to unfamiliarity. This suggests that novel infrastructure elements require accompanying public information campaigns and education about priority rules before implementation. Indeed, 24% of participants expressed uncertainty about yielding behaviour at red-coloured roundabouts in the post-experiment questionnaire. The traffic volume effect on lateral positioning presents significant safety implications. Cyclists riding closer to the outer edge face increased accident risk from overtaking vehicles and reduced visibility. This supports current German design guidelines recommending mixed-traffic solutions only up to 15,000 vehicles per day, with separated facilities advisable beyond this threshold.
Practical Implications: For roundabouts where cyclist acceptance is a concern, advisory bicycle lanes may be preferable to separated paths in approach situations, particularly at lower traffic volumes, a recommendation consistent with current German design guidelines. Roundabouts with pictogram markings without full surface colouring could represent a promising intermediate solution. However, any novel pavement design requires thorough empirical investigation in general, as well as public communication about priority rules.
Limitations and Future Research: The sample showed skewed distribution of cyclist typologies (74.6% "Enthused and confident"), limiting generalizability. Field experiments with actual infrastructure implementation would provide valuable validation. Furthermore, the approach infrastructure findings raise questions regarding optimal design of merging situations preceding roundabouts. Future research should also examine motorists' behavioural responses to novel bicycle infrastructure, as successful implementation depends on all road users' understanding and adaptation.

References

Daniels, S., Brijs, T., Nuyts, E., & Wets, G. (2009). Injury crashes with bicyclists at roundabouts: Influence of some location characteristics and the design of cycle facilities. *Journal of Safety Research*, *40*(2), 141–148. https://doi.org/10.1016/j.jsr.2009.02.004

Elvik, R. (2003). Effects on Road Safety of Converting Intersections to Roundabouts: Review of Evidence from Non-U.S. Studies. *Transportation Research Record: Journal of the Transportation Research Board*, *1847*(1), 1–10. https://doi.org/10.3141/1847-01

Jensen, S. U. (2013). Safety Effects of Converting Intersections to Roundabouts. *Transportation Research Record: Journal of the Transportation Research Board*, *2389*(1), 22–29. https://doi.org/10.3141/2389-03

Jensen, S. U. (2017). Safe roundabouts for cyclists. *Accident; Analysis and Prevention*, *105*, 30–37. https://doi.org/10.1016/j.aap.2016.09.005

Møller, M., & Hels, T. (2008). Cyclists' perception of risk in roundabouts. *Accident; Analysis and Prevention*, *40*(3), 1055–1062. https://doi.org/10.1016/j.aap.2007.10.013

Poudel, N., & Singleton, P. A. (2022). Preferences for roundabout attributes among US bicyclists: A discrete choice experiment. *Transportation Research Part a: Policy and Practice*, *155*, 316–329. https://doi.org/10.1016/j.tra.2021.11.023

International Co-operation on Theories and Concepts in Traffic Safety

Safety of driver-pedestrian interactions along urban frontage roads with shared lanes

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Introduction. Frontage roads are a distinctive feature of major boulevards in large European cities, enabling the separation of traffic on the main carriageway from local traffic. Due to their layout and function, frontage roads operate as complex, mixed-use streets, comprising driveway access, parking, and roadside activities. Recently, most of these lanes have been converted to shared lanes with bicycles and e-scooters (Figure 1). Consequently, interactions among vehicles, cyclists, and pedestrians are frequent. Although the posted speeds are low (20 or 30 km/h), the mix of users creates critical and unsafe situations, particularly for drivers, who must respond to multiple external stimuli simultaneously. This driving simulation study investigates driver-pedestrian interactions on urban shared frontage roads, emphasising informal pedestrians crossing (i.e., outside designated crosswalks), a common behaviour on these roads. Using surrogate safety measures, we identified factors associated with vehicle-pedestrian interactions and assessed whether the presence of cyclists is associated with more critical conflicts.



Figure 1. Frontage roads with shared lanes in Turin, Italy.

Method. Thirty-two licensed drivers (16 women), aged between 25 and 65 years, performed four scenarios in a fixed-base driving simulator (SCANeRStudio®). These scenarios were obtained by combining two experimental factors: (i) the interaction type (simple vs complex) and (ii) the lighting conditions (day vs night). The simple interaction involved a pedestrian crossing in front of the ego-vehicle outside the designated crosswalk (Figure 2a), whereas the complex one added bike traffic travelling along the frontage road (Figure 2b). In both situations, the participants drove along the frontage road while the pedestrian crossed from the right side with a time gap acceptance of 3 s, without yielding to the ego-vehicle. The simulated scenarios reproduced a real road corridor in Turin, Italy. To enhance realism, background urban traffic was included, with a speed limit of 20 km/h. The severity of the vehicle-pedestrian conflict was assessed using post-encroachment time (PET) and minimum time-to-collision (MTTC). Along with gender- and age-balanced factors, the effects of the two main experimental factors were analysed using linear mixed-effects models, with test driver ID included as a random effect.

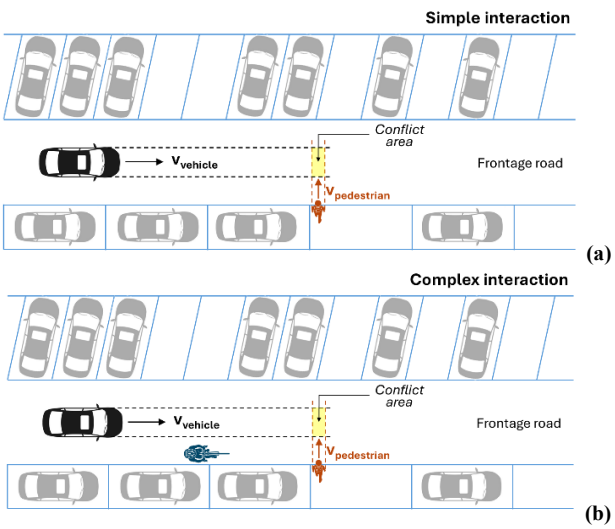


Figure 2. Simulated scenarios.

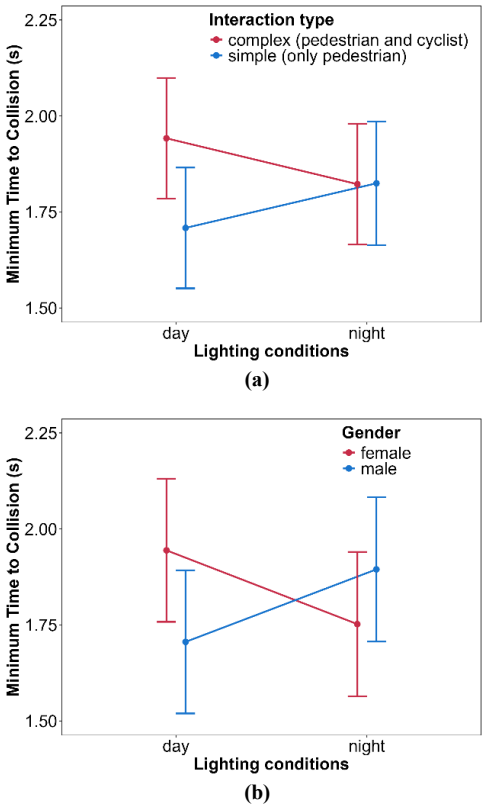


Figure 3. Effect plots of MTTC as a function of lighting condition, by (a) interaction type and (b) gender.

Results. Lighting conditions have a significant effect on the MTTC. Nighttime conditions were associated with significantly lower MTTC values compared to daytime (p = .005). The simple vehicle-pedestrian interaction resulted in lower MTTC values than the complex interaction involving both a pedestrian and a cyclist (p = .010). This suggests that drivers maintained narrower safety margins when interacting with a single user. Male drivers had slightly lower MTTC values than female drivers at 90% confidence level. Figure 3a shows that the effect of lighting conditions on MTTC varied by interaction type. Complex interactions were associated with higher MTTC values compared to simple interactions under daytime conditions (t_{90} = -2.641, p_{Holm} = .039), while no differences in MTTC between interaction types are evident under nighttime conditions. The effect of lighting conditions differed between male and female drivers (Figure 3b). Females showed lower MTTC values at night than during the day, whereas male drivers exhibited the opposite trend, with slightly higher MTTC values at night, suggesting different behavioural responses to reduced visibility. Fixed factors had no significant effect on PET, with variability explained only by the random effect. This is consistent with the nature of PET, which is computed after the interaction has occurred, and primarily reflects driver behaviour rather than the direct influence of external experimental factors. The presence of inter-individual variability in drivers' performance is confirmed by the highly significant random effect associated with participant ID for both MTTC and PET models (LRT for random effects: $p < .001$).

Discussion and conclusions. The combined effects of lighting conditions and interaction complexity influence safety margins during vehicle-pedestrian interactions on urban frontage roads with shared lanes. Lower MTTC values at night suggest reduced safety margins and greater vulnerability of pedestrians. This highlights the need for improved lighting in areas with frequent roadside activity and informal crossings. The presence of a cyclist travelling along the roadside induces compensatory driving behaviours, such as lateral repositioning within the lane or reducing speed, which indirectly increases the temporal distance from the pedestrian. Furthermore, the position of the cyclist on the driver's right might have caught the driver's attention, allowing the pedestrian on the same side to be detected sooner.

Infrastructure design and traffic management strategies should therefore aim to accommodate a wide range of driver behaviours, especially in low-visibility conditions. The analysed scenario represents just one of many potential interaction patterns. Extending the analysis to other conflicting scenarios would provide a more comprehensive safety assessment and support robust design decisions to reduce crash risks for active users on urban roads.

International Co-operation on Theories and
Concepts in Traffic Safety

Automatic Detection of Geometric Anomalies in Speed Humps Using Machine Learning on Vehicle Dynamics Data

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Abstract

Speed humps are widely used traffic calming devices. However, geometric non-compliance with standards such as the French standard NF P98-300 (maximum height 10 cm, ramp slopes ≤10%) may generate safety risks, vehicle damage, and increased emissions. This study proposes a machine learning framework for the automatic detection and quantification of geometric anomalies (height, length, slopes) using smartphone-based vehicle dynamics data collected during driving tests on 12 speed humps. Unlike existing accelerometer-based approaches that focus on speed hump detection, our method extracts quantitative geometric indicators and evaluate their compliance with normative thresholds. The models were calibrated using 281 labeled vehicle passages, and the end-to-end performance of the complete detection pipeline was evaluated on 137 passages from this dataset, yielding 85.4% accuracy in geometric anomaly detection. This AI-driven approach opens new possibilities for large-scale monitoring of traffic calming infrastructure and proactive road maintenance.

Keywords: Speed humps, geometric anomalies, machine learning, accelerometer data, road safety, NF P98-300, moderating speed.

1. Introduction

International traffic calming programs reduce injury accidents by 39% across 33 studies [1]. In France, local authorities heavily rely on speed humps for speed moderation, with an estimated 450,000 speed installed across the road network. Several studies suggest that a large proportion of them may deviate from NF P98-300 standards [2], generating discomfort, noise pollution, increased fuel consumption, and potential safety risks [3].

This widespread non-compliance justifies the implementation of an automated geometric compliance verification system. Several smartphone-based detection methods have been proposed, including accelerometer analysis with fuzzy thresholds achieving 92% detection accuracy [4], genetic algorithms reaching 95% precision [5], deep learning in several contexts [6], hump type characterization [7, 8], and ML-based anomaly detection [9]. These methods focus exclusively on presence and severity classification rather than compliance assessment against standards.

This study addresses this gap with an ML pipeline that extracts geometric indicators from smartphone inertial data across 12 real-world French sites, comparing them to normative thresholds (Table 1). The NF P98-300 standard [2] specifies length, heights and ramp slopes

for both semi-circular and trapezoidal speed humps, while CERTU guidelines [10] provide reference dimensions for speed tables and Berlin cushions.

Table 1: Reference geometric standards and recommendations for traffic calming devices.

Hump type	Form	Norm	Length	Height	Ramp slopes
Semi-circular		NF P98-300	3.8-4.2 m	≤10 cm	≤10%
Trapezoidal		NF P98-300	4.5-6.8 m	≤10 cm	≤10%
Speed table		CERTU 2010	10-30 m	≤15 cm	≤10%
Berlin cushion		CERTU 2010	3-4 m	6-7 cm	≤14%

This study proposes a two-phase smartphone-based ML pipeline that detects speed humps, classifies their type, and assesses geometric anomalies from inertial data across 12 French sites. Phase 1 develops calibrated detection thresholds and optimized ML models for detection, type classification, and anomaly detection, using 281 passages. Phase 2 assesses the end-to-end performance of the complete pipeline on representative passages from the calibration dataset.

2. Methodology

2.1 Data Collection

Experimental tests were conducted using instrumented vehicles over 12 speed humps (semi-circular, speed table, trapezoidal, Berlin cushion) in a mid-sized city. The selected speed humps included both compliant and non-compliant designs per NF P98-300 standards; their geometric features (height, length, ramp slopes) were precisely measured using straight edge, precision spirit levels, inclinometers, and measuring wheels (Table 2). All humps were traversed unidirectionally to maintain consistent entry/exit slope references.

Four different vehicles were used, a Renault Clio IV, petrol and electric Peugeot 208s, and Peugeot 308. Some passages were performed at a set speed of 25, 30, and 35 km/h, while others used free speeds. Each vehicle carried a smartphone running our dedicated data acquisition app, which captured inertial data (triaxial accelerometer ±4g, gyroscope, GPS). The phone was mounted in a holder on the interior windshield in a fixed upright orientation, screen facing the driver (Figure 1). In total, 281 passages were labeled and their data preprocessed (filtering, feature extraction, calculation of relevant variables) to train our supervised machine learning models.

Table 2. Geometry and number of passages over the speed humps studied. Anomalies (>+10% reference thresholds) in red.[1]

	Length (m)	Height (cm)	Relative entry slope (°)	Relative exit slope (°)	N. passages
SC1 (Semi-circular)	4.1	9.5	5.1	4.2	23
SC2 (Semi-circular)	4.0	7.7	4.8	5.7	24
SC3 (Semi-circular)	5.2	11.6	7.4	8.6	24

[1] NF P98-300 applies only to semi-circular and trapezoidal speed humps. Thresholds applied analogously to speed tables and Berlin cushion for anomaly detection. Red highlighting indicates >+10% reference exceedance (technical criterion), not legal non-compliance.

	Length (m)	Height (cm)	Relative entry slope (°)	Relative exit slope (°)	N. passages
ST1 (Speed table)	12.7	11.0	4.1	8.1	24
ST2 (Speed table)	30.4	11.0	6.8	5	24
ST3 (Speed table)	22.0	13.7	8.4	5.9	24
ST4 (Speed table)	10.6	11.5	4.8	3.7	23
ST5 (Speed table)	22.2	12.3	5.2	6.3	24
ST6 (Speed table)	20.7	12.2	5.3	4.4	23
T1 (Trapezoidal)	3.9	14.0	7.0	8.1	24
T2 (Trapezoidal)	6.3	8.5	6.3	6.7	20
BC1 (Berlin cushion)	3.0	6.5	7.8	7.8	24

Figure 1 - Smartphone installation on the windshield.

2.2 Signal Processing and Feature Extraction

Raw inertial signals (tri-axial accelerations and angular velocities) were recorded at 200 Hz, while GPS speed was sampled at 1 Hz. The inertial data were low-pass filtered using a first-order Butterworth filter with a 5 Hz cut-off frequency prior to feature extraction. From the filtered signals, we derived the following descriptive variables around each hump passage, selected for their characteristic dynamic vehicle response to speed humps as identified in prior analysis [11]:

- actual vehicle speed (1)
- maximum magnitude of longitudinal vs. vertical acceleration (2)
- minimum and maximum vertical acceleration (3, 4)
- minimum and maximum pitch rate (5, 6)
- minimum and maximum integrated pitch angle (7, 8)
- time interval between two consecutive negative vertical acceleration peaks (9)
- travelled distance between these peaks (speed-integrated) (10).

2.3 Detection of speed humps and Machine Learning Model

These features feed a two-phase methodology for speed hump detection and anomaly assessment (Figure 2): Phase 1 consisted of threshold calibration and model selection using the full dataset of 281 passages. In Phase 2, the complete pipeline was applied to a subset of 137 passages from the same dataset in order to assess its end-to-end overall performance. Speed hump detection relied on fixed feature thresholds applied to five inertial features (2 to 6) within sliding 7-second windows, requiring at least three simultaneous exceedances to confirm presence. The 7-second window was chosen to cover multiple times the typical duration of a speed hump, smoothing the signal to capture the full event while minimizing false positives from minor road irregularities. The Berlin cushion served as a control, excluded due to its geometry allowing passage with only left/right wheels, or all four on lower edges, producing minimal dynamic response.

All predictive models used standardized features. Model selection was performed using 5-fold cross-validation on the calibration dataset (281 passages) in order to reduce overfitting. Hump type classification used multinomial logistic regression with the best predictor combination selected by exhaustive cross-validated search, refined by length-based post-processing rules.

Anomaly detection for height (>10% normative thresholds) and entry/exit slopes (>6°) employed binary logistic regression models, optimized with exhaustive search across all 2-5 predictor combinations from ten variables. The height threshold was further optimized to 12.2 cm via grid search (11-13 cm range) maximizing overall detection accuracy, balancing NF P98-300 compliance (≥11 cm) with minimized false positives on borderline cases.

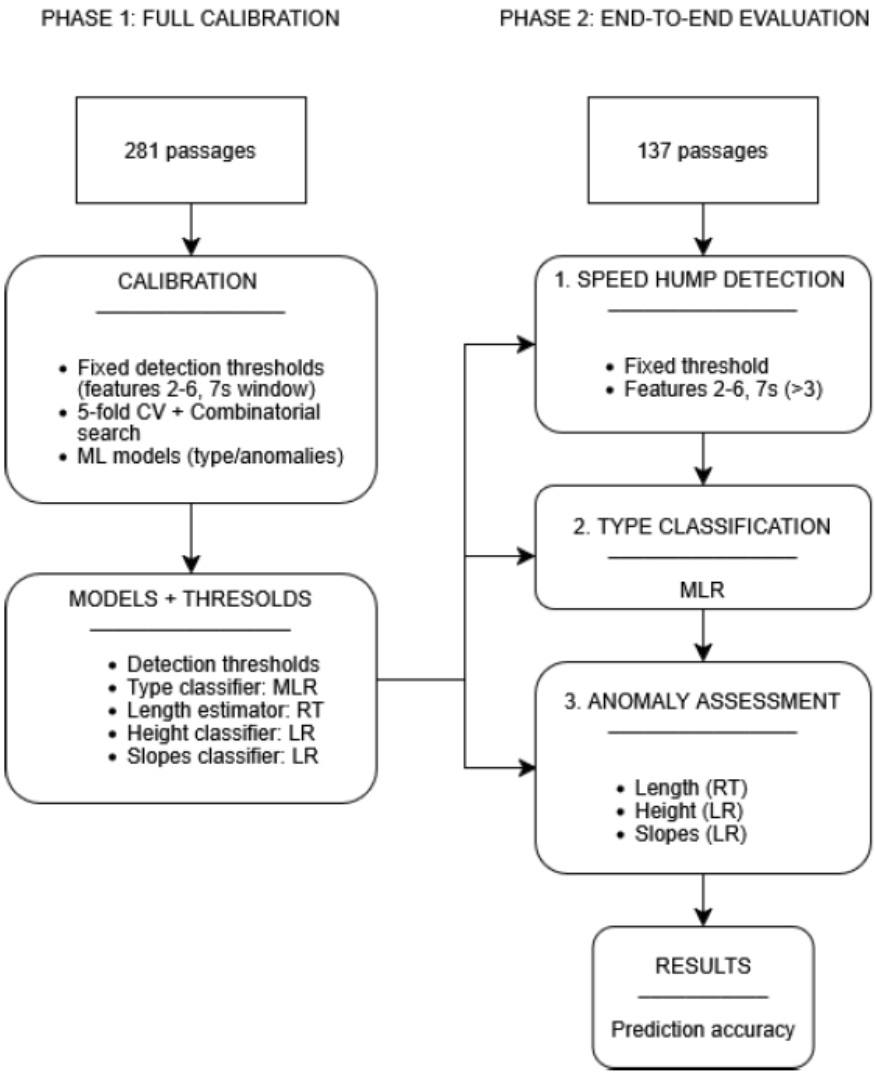


Figure 2 - Two-phase methodology for speed hump anomaly detection pipeline.

Length estimation used regression trees. Optimal models were selected through exhaustive combinatorial search maximizing mean cross-validated classification accuracy on the 281 calibration passages. The complete audit program was then evaluated on a 137-passage subset, testing end-to-end performance from detection through geometric anomaly assessment.

Logistic regression was preferred because of its interpretability and its ability to provide transparent decision rules suitable for engineering applications, while regression trees naturally handle non-linear relationships for length estimation.

3. Results

3.1 Method Validation Example

Figure 3 illustrates detection and type classification during a representative trip crossing two semi-circular humps followed by two speed tables, showing threshold exceedance patterns for variable 2 (longitudinal-vertical acceleration magnitude).

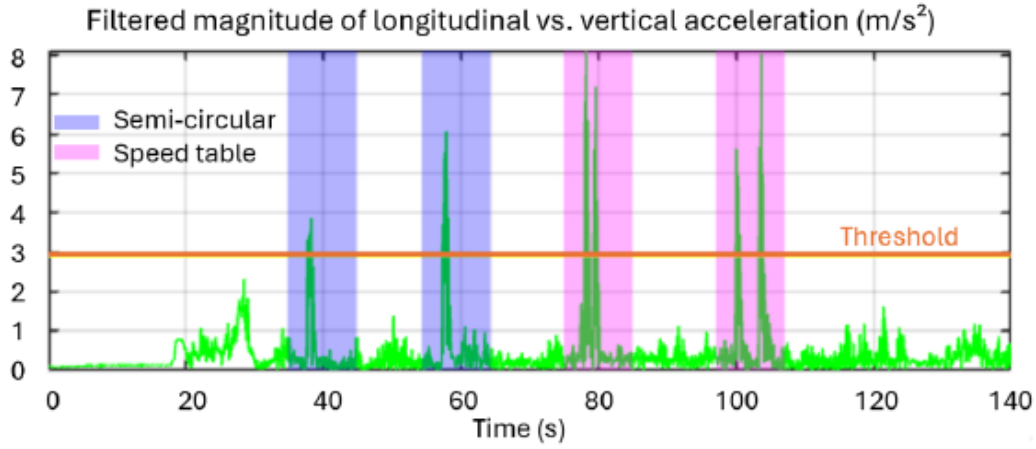


Figure 3 - Detection of hump and type: example of magnitude of longitudinal vs. vertical acceleration.

3.2 Per-Site Detection Performance

Table 3 presents true positive detection rates for geometric anomalies across 137 evaluation passages per speed hump, where each percentage represents passages with correctly detected anomalies when present; dashes ('-') indicate true negatives (no anomaly present or detected), while asterisks (") denote false positives (anomaly flagged despite no real anomaly). These results identify three priority maintenance sites (SC3, ST3, T1) with multi-parameter anomaly detections. Height detection reveals optimization trade-offs: ST1 shows false positives (18%*) despite measured height below threshold, while ST3 misses 27% true anomalies at 13.7 cm. Berlin cushion achieves perfect specificity (100% true negatives). These patterns enable targeted maintenance with 85.4% global accuracy (Table 3).

*Table 3. Per-site detection accuracies (true positives + true negatives). * = false detection.*

Speed hump	Type	Height > 12.2 cm	Length	Entry slope	Exit slope	N passages
SC1 (Semi-circular)	100%	-	-	-	-	11
SC2 (Semi-circular)	75%	-	25%	-	-	12
SC3 (Semi-circular)	100%	-	100%	75%	58%	12
ST1 (Speed table)	82%	18%*	-	18%*	100%	11
ST2 (Speed table)	100%	-	-	67%	100%*	12
ST3 (Speed table)	100%	73%	-	82%	91%	11
ST4 (Speed table)	100%	-	-	-	-	11
ST5 (Speed table)	100%	-	-	9%*	100%	12
ST6 (Speed table)	100%	-	-	-	36%*	11

Speed hump	Type	Height > 12.2 cm	Length	Entry slope	Exit slope	N passages
T1 (Trapezoidal)	100%	100%	100%	50%	100%	12
T2 (Trapezoidal)	100%	-	-	100%	0%	10
BC1 (Berlin cushion)	-	-	-	-	-	12

3.3 Global Pipeline Accuracy

The framework demonstrated robust end-to-end performance across 137 passages covering 12 speed humps (Table 4). Speed hump detection achieved perfect accuracy (100%) through the multi-threshold sliding window approach, successfully identifying all passages. Type classification reached 97.6% accuracy, correctly distinguishing semi-circular, trapezoidal, and speed table designs, with length-based post-processing helping resolve ambiguous cases.

Geometric anomaly detection resulted in 85.4% global accuracy across height, length, entry slope and exit slope assessments. Length anomaly detection performed best at 96.0%, followed by height at 86.4% and entry slope at 84.0%. Exit slope detection showed the lowest performance at 75.2%, possibly reflecting less pronounced dynamic signatures during downhill passages.

Table 4. Detection performance across 137 speed hump passages.

Stage	Accuracy (%)
Hump detection	100%
Hump type	97.6%
Height anomaly	86.4%
Length anomaly (too short/long)	96.0%
Entry slope	84.0%
Exit slope	75.2%

3.4 Spatial Anomaly Distribution

Figure 4 illustrates the operational output of the final audit program across 137 vehicle passages at 12 speed humps (11 conventional + 1 Berlin cushion, undetected as expected). The main map displays all passages colored by critical anomaly count (green=0, yellow=1, orange=2, red=3). Inset panels provide detailed views per speed hump, revealing good consistency within each speed hump: all passages at a given site show tightly clustered colors, demonstrating the method's reproducibility across different conditions (different vehicles, different speeds). While most sites exhibit good quality (predominantly green points), SC3, ST3, and T1 display elevated anomaly concentrations requiring targeted geometric interventions that should be prioritized for maintenance.

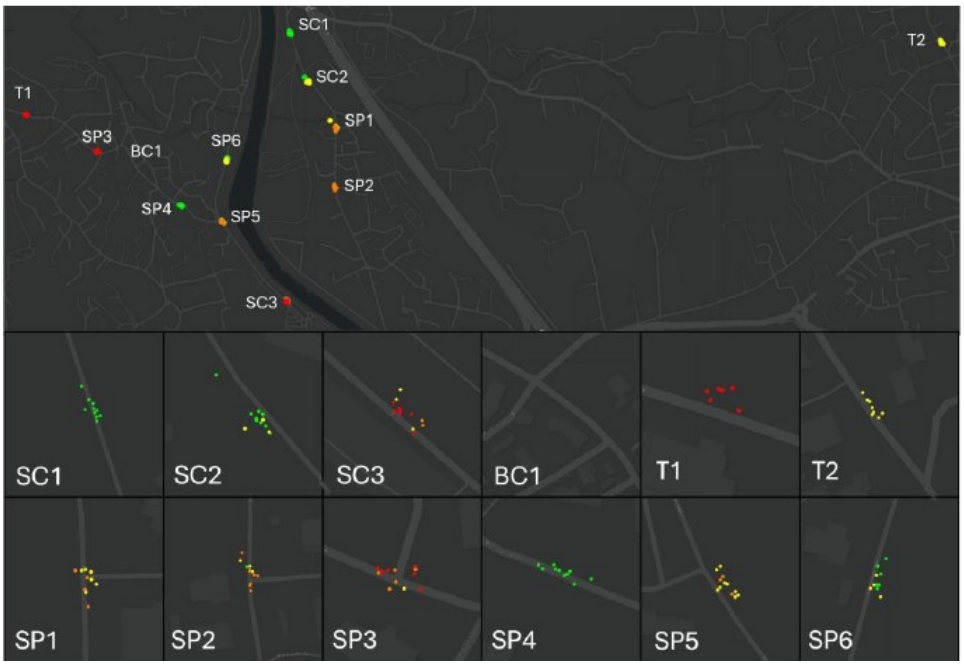


Figure 4 - Spatial distribution of geometric anomalies in 137 passages across 12 speed humps.

4. Discussion

The preliminary models successfully identified geometric anomalies on speed humps with 85.4% global accuracy across 137 passages, surpassing previous accelerometer-based methods [4-6,8], which were limited to binary presence/absence classification. This approach stands out through training on optimized thresholds: height exceeding 12.2 cm and slopes over 6°, determined through systematic grid search maximizing performance while respecting NF P98-300 standards (+10% exceedance). Three priority sites emerge with consistent detections across multiple parameters (length, height, slopes), while height detection reveals characteristic trade-offs: 18% false positives on borderline cases versus 27% false negatives at 13.7 cm despite clear exceedance.

The method also excels in speed hump type classification (97.6% accuracy) and offers exceptional scalability using standard smartphones. The Berlin cushion demonstrates perfect specificity (100% true negatives), validating algorithm discrimination capability. These site-specific patterns enable targeted maintenance prioritization for non-compliant speed humps contributing to safety incidents and vehicle damage.

Limitations remain, however. Since the end-to-end evaluation subset was drawn from the dataset used for model calibration, the reported performance should be interpreted as an internal assessment. Validation on fully independent sites and passages will be required to evaluate generalizability.

The dataset, collected at 12 sites, may reflect local design biases. Detection sensitivity for slope anomalies remains limited (75.2% accuracy for exit slope detection), and performance may vary with vehicle speed and loading conditions. However, the dataset includes passages

performed with four different vehicles and a range of operating speeds, providing an initial indication that the proposed features remain relatively robust to moderate variations in vehicle dynamics. Further validation across a broader range of infrastructures, vehicles, and operating conditions will be necessary to confirm the generalizability of the approach.

5. Conclusions

This study demonstrates that smartphone inertial sensors can reliably detect speed hump geometric anomalies, achieving 85.4% accuracy across 137 real-world passages. The method successfully identifies speed humps with multiple defects for prioritized maintenance, targeting urban safety hazards.

Performance includes 97.6% accuracy in speed hump type classification and perfect discrimination on control cases. Height detection maintains robust overall accuracy despite sensitivity trade-offs across borderline cases, guiding future threshold refinement for operational deployment.

These results support scalable road safety monitoring. Future work will extend measurements to 200 additional speed humps across varied vehicles and conditions, preparing the approach for practical implementation by transportation authorities.

References

[1] Elvik, R. (2001). Area-wide urban traffic calming schemes: A meta-analysis of safety effects. Accident Analysis & Prevention, 33(3), 327-336. https://doi.org/10.1016/S0001-4575(00)00046-4

[2] NF P98-300: Humpback or trapezoidal speed bumps. Geometric characteristics and situation parameters. June 1994. https://www.boutique.afnor.org/en-gb/standard/nf-p98300/humpback-or-trapezoidal-speed-bumps-geometric-characteristics-and-situation/fa028025/284

[3] Ligue de Défense des Conducteurs (2022). Les ralentisseurs illégaux : + d'accidents, + d'impact environnemental, + de carburant, + d'inconfort, + de bruit. UTAC. https://www.liguedesconducteurs.org/images/PDF/Infrastructure-routiere/LDC_Etude_Ralentisseurs_01072022_site.pdf

[4] Al-Shargabi, B., Hassan, M., Al-Rousan, T. (2020). A Novel Approach for the Detection of Road Speed Bumps using Accelerometer Sensor. TEM Journal, 9(2), 469-476.

[5] Celaya-Padilla, J.M., Galván-Tejada, C., López-Monteagudo, F.E., Alonso-González, O., Moreno-Báez, A., Martínez-Torteya, A., Galván-Tejada, J.I., Arceo-Olague, J.G., Luna-García, H., Gamboa-Rosales, H. (2018). Speed Bump Detection Using Accelerometric Features: A Genetic Algorithm Approach. Sensors, 18(2), 443. https://doi.org/10.3390/s18020443

[6] Menegazzo, J., & von Wangenheim, A. (2022). Speed Bump Detection Through Inertial Sensors and Deep Learning in a Multi-contextual Analysis. SN Computer Science, 4(1), 18. https://doi.org/10.1007/s42979-022-01438-w

[7] Bello-Salau, H.B., Onumanyi, A.J., Aibinu, A.M., Onwuka, E.N., Dukiya, J. J., Ohizeet, H. (2019). A Survey of Accelerometer-Based Techniques for Road Anomalies Detection and Characterization. International Journal of Engineering Science and Application, 3(1), 8-20.

[8] Salman, A., & Mian, A. N. (2023). Deep learning-based speed bumps detection and characterization using smartphone sensors. Pervasive and Mobile Computing, 92, 101805. https://doi.org/10.1016/j.pmcj.2023.101805

[9] Zareei, M., López Castañeda, C.A., Alanazi, F., Granda, F., Pérez-Diaz, J.A. (2025). Machine Learning Model for Road Anomaly Detection Using Smartphone Accelerometer Data. IEEE Access, 13, 122841-122851. https://doi.org/10.1109/ACCESS.2025.3586812

[10] CERTU (Centre d'études sur les réseaux, les transports, l'urbanisme et les constructions publiques). (2010). Guide des coussins et plateaux. https://doc.cerema.fr/Default/doc/SYRACUSE/14144/guide-des-coussins-et-plateaux

[11] Riahi, E., Naude, C., Canu, A., Serre, T., Martin, J-M., Menant, F., Garros, J-P. Projet FACER : détection des ralentisseurs non conformes grâce aux EDR. RGRA. N°1012. Oct. 2025 https://www.editions-rgra.com/revue/1012/securite-routiere/projet-facer-detection-des-ralentisseurs-non-conformes-grace-aux-edr

International Co-operation on Theories and Concepts in Traffic Safety

Highly automated vehicles' implicitly and explicitly communicated intents to interact with pedestrians and pedestrians' appraisals across different cultures – Is universal design of these interfaces appropriate, and what should be taken into account?

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Introduction, including research aim and objectives: Research has shown that highly automated vehicles (HAVs) pose new challenges for safe and efficient interactions with pedestrians in mixed-traffic (urban) scenarios, particularly regarding how vehicle intent (e.g., intent to stop to let a pedestrian cross the road) is communicated. Such intent can be signalled via the HAV's human-machine interfaces implicitly by its vehicle kinematics and / or explicitly by using external human–machine interfaces (eHMIs) such as light-bands on the vehicle's exterior. However, studies providing deeper understanding of the interplay and relative influence (in cases of disagreement) of implicit and explicit signals in the context of HAVs' communications with interacting pedestrians as vulnerable road users are missing so far, especially concerning the comparability of effects across different cultures. Such an understanding is essential for developing a universally applicable design and internationally standardized guidelines. To bridge this gap, our experimental online study replicated previous experiments from Germany, Japan, and Singapore now with samples from The Netherlands and United Kingdom to examine the generalizability of HAVs' kinematics and eHMI effects regarding their implicit and explicit communication with interacting pedestrians across cultures.

Research methodology: In our experimental online studies participants took the role of a pedestrian and were presented with videos of a shared-space interaction between them and an autonomous vehicle. The participant's view was directed at the vehicle and situated at the side of a road they intend to cross. Typically for a shared-space scenario no lane markings or other environmental features (e.g., traffic signs) were present to externally resolve the interaction, thus requiring the road users to negotiate priority simultaneously. Accordingly, the pedestrians needed to rely solely on implicit and explicit cues signalled by the HAV in order to decide on when to cross the road. The HAVs approached the pedestrian and varied in explicit (intention-based eHMI signalling yielding vs. static eHMI signalling only automation being active vs. eHMI being absent, i.e., no eHMI) and implicit communication (yielding vs. non-yielding). We assessed the pedestrian's willingness to cross (WTC), perceived safety, and perceived trustworthiness and support of the eHMI.

Results: Results across all five samples from Germany, Japan, Singapore, The Netherlands, and United Kingdom revealed similar patterns: Implicit (yielding) and intention-based explicit signals each produced higher WTC as well as higher ratings of perceived safety, perceived trustworthiness, and perceived support compared to the absence of both signals, with highest ratings for vehicles communicating intent implicitly (yielding kinematics) and explicitly (yielding via eHMI) at the same time. Comparing explicit eHMI communication variants, an intention-based light-band significantly increased WTC and perceived safety compared to a static or absent eHMI, and was rated as more trustworthy and supportive. However, when explicit and implicit signals contradicted each other, participants showed potentially dangerous overreliance on the explicit eHMI signal, as indicated by increased WTC, perceived safety, perceived trustworthiness, and perceived supportiveness evaluations for the intention-based (vs. static or absent) eHMI – which signalled yielding – even when vehicle kinematics showed no yielding. The national samples differed slightly in the extent of this potentially dangerous overreliance on explicit eHMI communication of HAVs.

Discussion and conclusions: Across all studied cultures, pedestrians made use of implicit and explicit cues when judging the intent of vehicles around them, such that perceived trust, perceived support, perceived safety, and willingness to cross increased when vehicles displayed implicit (kinematics) or explicit (eHMI) cues. Those explicit eHMI communication variants that provided additional information to a HAV's kinematics about the vehicle intent (here: pulsating light to indicate intent to yield, i.e., intention-based light band signals) produced elevated evaluations compared to static ones (here: static light to indicate only that the automation is active). These findings support the view that pedestrians incorporate the additional intention-based eHMI cues to anticipate vehicle actions and inform crossing decisions, providing better reassurance to pedestrians during shared-space interactions with HAVs. Although some cultural differences emerged in the extent of overreliance in cases of the HAV's disagreements between implicit and explicit signals, pedestrians of all cultures favoured explicit (eHMI) over implicit cues in these situations, suggesting that potentially dangerous automation bias and trust mis-calibration are key issues to consider in the design of eHMIs and underlining the need for alignment between explicit and implicit signals of intent, i.e., eHMI and vehicle kinematics. The cultural consistency of these results suggests that the effects are not driven by unique cultural environments, instead reflecting a shared response process and highlighting the suitability of these interfaces for use in systems intended to bridge cultural contexts. It further supports the suitability of universal design standards and guidelines for use across cultural environments. These findings emphasize both promises and risks of light-band eHMIs that should be taken into account and underscore the need for standardized design guidelines that mitigate overreliance while enhancing pedestrian safety in mixed-traffic environments.

International Co-operation on Theories and Concepts in Traffic Safety

Understanding behavioural factors contributing to risky riding among motorcycle taxi riders in Kampala, Uganda.

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Introduction

Uganda, located in East Africa, recorded 26,044 crashes in 2025, a 3.7% increase from the previous year, with motorcyclists (boda bodas), accounting for 47.5% of fatalities. (Uganda Police Force, 2025). This study examines behavioural factors contributing to risky riding among commercial motorcyclists in Uganda's capital, Kampala.

Research methodology

A 54-item modified Motorcycle Rider Behaviour Questionnaire (MRBQ) was administered to riders at boda boda stands across the city, yielding 362 valid responses. Data on crash near-crash involvement and traffic violations when riding with or without a passenger in past 12 months were collected. Data were analysed using SPSS v31, through descriptive statistics, Exploratory Factor Analysis (EFA) and logistic regression.

Results

Respondents were predominantly males (98.9%) with 72.6% aged 20-39 years and 65.5% lacking a valid motorcycle licence. In the past 12 months, 28.8% of riders reported at least one crash, while 49.5% reported a near-crash, with similar rates reported when riding with a passenger.
EFA revealed a four-factor MRBQ structure consisting of 38 items with good internal consistency. The factors include: errors, stunts/speed, passenger influence and traffic violations. The most frequently reported behaviours included carrying a passenger who wasn't wearing a helmet and carrying more than one passenger, as shown in Figure 1.



Figure 1: Evidence of riding behaviours.

Logistics regression revealed that when riding without a passenger, those riders who hold a licence had a significant reduction in the odds of crash and near-crash involvement, compared to those who do not hold a licence (28.8% and 49.5% respectively). This reduction was not found in situations where they were carrying passengers. Riders with 2-5years of experience had over 3 times higher odds of being involved in a near crash compared to those with less

experience. When riding with a passenger, the traffic violations factor was significantly associated with reduced odds of crash involvement (OR=0.46, $p < .001$). Passenger influence, errors, and stunts/speed significantly increased (between 37-76%) crash and near-crash likelihood with or without a passenger.

Discussion and conclusion

A key contribution of this study is the identification of a distinct "passenger influence" factor. Unlike previous research, this factor captures passengers' active role in shaping rider behaviour amongst motorcycle taxi riders. The findings indicate that passenger influence is predominantly negative, with the presence of passengers associated with increased rates of risky behaviours such as speeding, rule violations, and distraction (Orsi et al., 2013; Mwebesa et al., 2021). This reflects riders' economic dependence on passengers and positions passengers as active agents influencing riding behaviour, rather than passive participants.

In the absence of passengers, licence ownership and the MRBQ passenger influence factor significantly predicted crashes, while licence ownership, riding experience, errors, stunts/speed, and passenger influence predicted near-crashes. When passengers were present, traffic violations predicted crashes, while errors and passenger influence predicted near-crashes. Moreover, riding experience, errors, and passenger influence were significant predictors of being stopped twice or more for traffic offences. Notably, passenger influence demonstrated stronger effects than errors, underscoring its importance.

Licence ownership was not a significant predictor when carrying passengers, suggesting behavioural adaptation. Riders may act more cautiously due to perceived responsibility, social expectations, and the need to maintain customer relationships, consistent with Social Identity Theory (Tajfel and Turner, 1979). This is a similar possible explanation to traffic violations whose findings are contrary to expectations. Demographic factors were largely insignificant compared to behavioural factors, which was somewhat expected given that riders are a relatively homogenous group.

Despite limitations, including the focus on Kampala and data collection during a period of political unrest, which may have influenced riders' willingness to respond honestly due to fear of arrest, the findings highlight the importance of context-specific behavioural patterns in understanding motorcycle safety in Uganda, particularly the role of passengers. These insights suggest that interventions should extend beyond riders to recognise passengers as key stakeholders in improving road safety outcomes.

References

Mwebesa, M.E., Chou, C.C., Yoh, K. and Doi, K. 2021. A Cross-Sector Framework to Boost the Sustainable Implementation of Integrated Transport and Spatial Strategies to Improve Safety and Mobility of Moto-Taxi Riders. *Frontiers in Sustainable Cities*. **3**.

Orsi, C., Marchetti, P., Montomoli, C. and Morandi, A. 2013. Car crashes: The effect of passenger presence and other factors on driver outcome. *Safety Science*. **57**, pp.35–43.

Tajfel, H. and Turner, J.C. 1979. An integrative theory of intergroup conflict. Available from: https://api.semanticscholar.org/CorpusID:141114011.

Uganda Police Force 2025. *Annual Crime and Traffic/Road Safety Report. UGANDA POLICE FORCE*.

International Co-operation on Theories and Concepts in Traffic Safety

Introducing a Drone-based, Synthetic Road-user Trajectory Simulation for Road Safety Analysis

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Abstract
This study presents a data-driven probabilistic framework for generating realistic ensembles of vehicle trajectories from short UAV recordings for proactive traffic safety analysis. Although UAVs provide unobstructed, geometry-preserving observations of traffic, their limited flight duration restricts exposure to rare safety-critical events. As a result, direct UAV observations tend to underestimate latent safety risk. The variability captured in these short recordings is therefore leveraged to probabilistically model extended trajectory ensembles capable of representing such events. Drone-based trajectories are normalized, clustered by origin–destination (OD), and modelled using conditional multivariate Gaussian simulation. Temporal dynamics are incorporated through sampling of headways. Validation demonstrates strong agreement between observed and simulated speed distributions. Time-to-Collision (TTC) analysis reveals more frequent and lower-TTC interactions in the simulated data, reflecting a conservative, non-reactive worst-case scenario. This conservative expansion enables identification of latent safety risks that are unlikely to be observed directly in short UAV recordings.

Introduction
Proximal safety indicators such as TTC require high-resolution trajectory data, which traditional roadside camera systems often fail to provide due to occlusions and limited viewpoints (Outay et al., 2020). UAVs offer unobstructed aerial observations but are constrained by short recording durations, limiting the capture of rare safety-critical events (Rosenfeld & Maksimov, 2019).

To address this limitation, we propose a fully data-driven probabilistic framework that expands short UAV recordings into synthetic trajectory ensembles. Unlike traditional microsimulation, which relies on predefined rules and calibration parameters (Modi & Patel, 2023), the method learns variability directly from observed trajectories, yielding a conservative worst-case representation suitable for identifying latent geometric and operational risks.

Methodology
UAV-based traffic footage were collected at two sites in Hasselt, Belgium: a three-legged intersection and a roundabout, selected to represent contrasting geometries. Vehicle trajectories were extracted with an AI-based video analytics framework i.e. DataFromSky. The trajectories were grouped by entry–exit pairs using the IODF method, spatially normalized, and resampled

Betru et al. (2025). For each OD pair, mean and covariance structures were estimated and used to generate synthetic trajectories via conditional multivariate Gaussian simulation, with temporal variability introduced through empirical headway (Ortiz & Deutsch, 2022). Validation was performed by comparing observed and simulated speed distributions using Kolmogorov–Smirnov statistics and distribution overlap (Drew et al., 2000). TTC values were computed and classified as rear-end, lane-changing, or crossing.

Results

Simulated trajectories reproduced observed speed patterns and site-specific differences, with higher and more variable speeds at the intersection and lower, more uniform speeds at the roundabout. Speed distributions closely matched observations across vehicle classes (overlap ≥0.84), with minor deviations for buses due to small samples resulting from lower frequency.
TTC analysis showed rear-end conflicts were most frequent, with simulations producing more events and lower TTCs at both sites. At the intersection, mean rear-end TTC decreased from 1.28 s (observed) to 0.76 s (simulated), while at the roundabout it decreased from 1.36 s to 0.68 s, with more simulated events (269 vs. 172). Crossing conflicts were less frequent and showed higher TTCs, and simulated hotspots aligned with observed locations, reflecting a conservative worst-case behaviour.

Discussion and Conclusion

The framework shows that short UAV recordings can be expanded into realistic trajectory ensembles for proactive safety analysis by preserving observed spatiotemporal patterns. The resulting conservative worst-case representation generates plausible low-TTC interactions, enabling identification of latent geometric and operational risks.
Limitations include dependence on adequate OD-level samples and the lack of interaction modelling, which limits counterfactual evaluation. Despite this, the method offers a lightweight, data-driven complement to existing safety analysis tools and is particularly suited to risk-aware infrastructure design and traffic management under data scarcity.

References

Betru, A. M., Tran, T. M. D., & Ectors, W. (2025). Automating Composition of Origin-Destination Flows of Intersections Based on UAV Data. *Procedia Computer Science*, *257*, 233–240. https://doi.org/https://doi.org/10.1016/j.procs.2025.03.032

Drew, J. H., Glen, A. G., & Leemis, L. M. (2000). Computing the cumulative distribution function of the Kolmogorov–Smirnov statistic. *Computational statistics & data analysis*, *34*(1), 1–15.

Modi, R. N., & Patel, C. G. (2023). Traffic Microsimulation Models for Unsignalized Intersections: A Comprehensive Review of Key Components, Strengths, Limitations, and Future Research Directions. *Journal of Harbin Engineering University*, *44*(9).

Ortiz, R., & Deutsch, C. V. (2022). Multivariate gaussian distribution. *Geostatistics Lessons*.

Outay, F., Mengash, H. A., & Adnan, M. (2020). Applications of unmanned aerial vehicle (UAV) in road safety, traffic and highway infrastructure management: Recent advances and challenges. *Transportation Research Part A: Policy and Practice*, *141*, 116–129.

Rosenfeld, A., & Maksimov, O. (2019). Optimal cruiser-drone traffic enforcement under energy limitation. *Artificial Intelligence*, *277*, 103166. https://doi.org/https://doi.org/10.1016/j.artint.2019.103166

International Co-operation on Theories and
Concepts in Traffic Safety

Objective and subjective safety at urban signalized intersections: A simulator study on effects of infrastructure and traffic signal control for car drivers and cyclists

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Introduction

Cycling is a sustainable mode of transport addressing key challenges in urban mobility. However, ensuring the safety of vulnerable road users remains difficult, particularly in mixed traffic. Urban intersections are critical, as many cyclist crashes occur there. Traditional safety analyses rely on crash data, which are rare and provide limited insight. Therefore, surrogate safety measures (SSMs) are used to analyse interactions without collisions. In parallel, subjective safety has gained importance as a psychological proxy for objective safety. In Germany, intersection design is characterized by heterogeneous practices. Guidelines differ between federal states and are frequently adapted at the local level, resulting in a lack of consistent, evidence-based design strategies. Consequently, there is limited knowledge regarding the effectiveness of different infrastructure and signal control configurations.

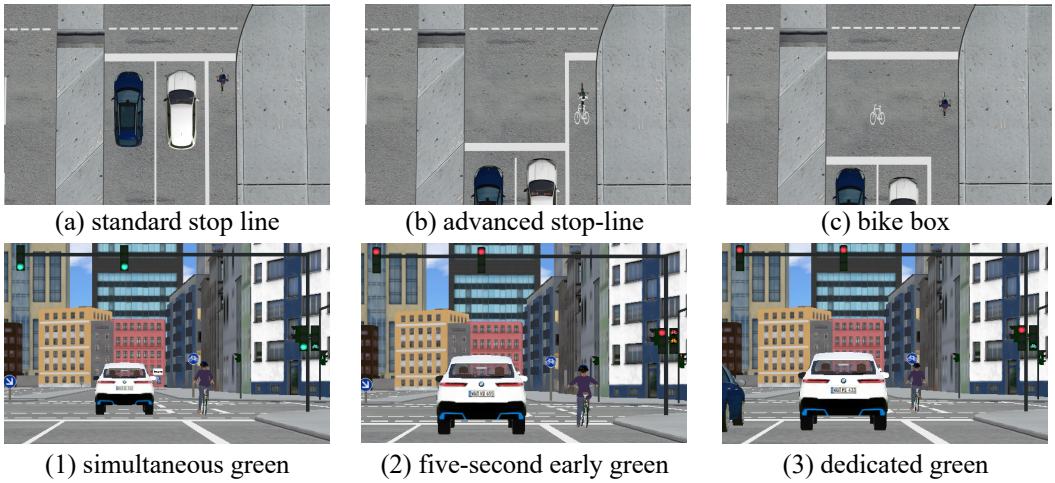
Aim

The aim of this study is to evaluate both objective and subjective safety of urban intersection designs in Germany. Specifically, the study investigates different stop line infrastructures and traffic signal control strategies in a simulated environment. By integrating subjective and objective safety measures, the study addresses a gap in the literature, as both dimensions are rarely examined in a combined framework. Furthermore, the study explores how these design elements influence the safety of cyclist-vehicle interactions, including interaction effects between infrastructure and signal control.

Method

A 2 (traffic participant role) × 3 (stop line infrastructure) × 3 (traffic signal control) within-subject design is used. The experiment takes place in a high-fidelity cycling and vehicle simulator. Each scenario shows a signalized intersection with a right-turning vehicle and a straight-moving cyclist. Participants experience all scenarios from both perspectives. Infrastructure conditions include (a) a standard stop line, (b) an advanced stop line, and (c) a bike box. Signal control varies between (1) a simultaneous green, (2) a five-second early green for cyclists, and (3) a dedicated green phase. In total, 18 randomized scenarios are presented. The sample includes approximately N = 50 participants. Starting role and scenario order are randomized. Subjective measures include the IPQ (Igroup Presence Questionnaire; Schubert et al., 2001) and the SuSyCo (Subjective Safety & Comfort; Suing et al., 2026) questionnaire. A one-time questionnaire on traffic rules supports behavioural interpretation. Objective safety is assessed using SSMs such as minimum Time to Collision (TTCmin), Post-Encroachment Time

(PET), Delta-V, and jerk. These are derived from trajectory data and reflect temporal and dynamic interaction aspects. Data will be analysed using repeated-measures ANOVA.



(a) standard stop line (b) advanced stop-line (c) bike box

(1) simultaneous green (2) five-second early green (3) dedicated green

Figure 1: Infrastructure and traffic signal layouts

Results expected

Data collection is ongoing. Based on prior research, infrastructure and signal control providing spatial or temporal separation are expected to improve safety. Advanced stop lines and bike boxes should reduce conflicts compared to standard stop lines. Early and especially dedicated green phases are expected to decrease critical interactions, with dedicated phases eliminating conflicts entirely but potentially reducing traffic efficiency. Differences between user perspectives are also expected, with cyclists likely reporting greater increases in subjective safety.

Conclusion

By combining objective and subjective safety, this study contributes to a better understanding of cyclist-vehicle interactions. The findings support more consistent and evidence-based design guidelines while highlighting the need to balance safety and traffic flow.

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References

Johnsson C., Laureshyn A., De Ceunynck T. [2018]. In search of surrogate safety indicators for vulnerable road users: A review of surrogate safety indicators. Transport Reviews, Vol. 38, No. 6, pp. 765-785. https://doi.org/10.1080/01441647.2018.1442888

Schubert, T., Friedmann, F., Regenbrecht, H., 2001. The Experience of Presence: Factor Analytic Insights. Presence: Teleoperators and Virtual Environments 10, 266-281. https://doi.org/10.1162/105474601300343603

Suing M., Harkin, A.M., Pliquett, S., Bohmann, S., Huemer, A.K., Gehlert, T., Hantschel, S., Holte, H., Jürgensohn, T., Oehme, A., von Stülpnagel, R. [2026]. Subjektive Sicherheit und Fahrkomfort von Radfahrenden (SuSiKo): Handlungsleitfaden für die Radverkehrsplanung. Bundesanstalt für Straßen- und Verkehrswesen.

International Co-operation on Theories and Concepts in Traffic Safety

Prevalence of Rule Violations by and Against Cyclists: A Comparison of Self-Reported and Crash Data

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Introduction

Traffic rule violations involving cyclists can occur in two different directions: violations committed against cyclists by other road users (e.g., insufficient lateral clearance when overtaking, failure to yield at intersections), and violations committed by cyclists themselves (e.g., riding on sidewalks, disregarding traffic signals, or cycling in the wrong direction). Both types can contribute to conflicts and/or crashes, with potentially serious consequences for cyclists and other vulnerable road users such as pedestrians. Beyond their role in crash causation, however, traffic rule violations are also relevant because they contribute to negative attitudes between road user groups, even when they do not result in injury, and because they can signal where the traffic system is suboptimal, unclear, or failing to meet road users' needs. Understanding the relative prevalence of these violation types is essential for informing targeted road safety measures.

Research on cycling-related rule violations has expanded substantially since 2013, accompanied by a widening range of methodologies. This body of work has documented a core set of violations, including red light running, wrong-way cycling, failure to yield, and insufficient lateral clearance, that recur consistently across contexts and countries. However, crash statistics capture only police-recorded crashes in which a rule violation contributed to the event, not all of which involve injuries, while not all crashes serious enough to require hospital treatment are police-recorded, and may therefore not reflect which violations are most prevalent in everyday traffic or most disruptive to road users. This study addresses this gap by systematically examining a broader set of rule violations involving cyclists from two complementary perspectives, what road users find salient enough to report, and what appears in crash records, and by comparing how the two pictures align.

Aim

This study aims to determine which traffic rule violations involving cyclists, both as the affected party and as the violating party, are most salient in public violation reports and most strongly represented in crash data, and to assess the degree to which these two pictures converge or diverge. To enable this comparison, violations recorded in both data sources were mapped onto a harmonized classification scheme.

Method

Two complementary data sources were analyzed. First, self-reported violation data were collected via regelverstoesse.de, an online platform developed for this study that allowed anyone interested to submit georeferenced reports of observed or experienced traffic rule violations anywhere in Germany during summer 2025. A total of approximately 13,000 reports were collected. For each entry, reporters specified the violating and affected road user, the location of the event (e.g., roadway, cycle path, sidewalk, intersection), and the rule that was violated. Reporters also indicated their own role in the situation (victim, offender, or observer). The dataset was filtered to retain only entries in which cyclists were either the affected or the violating party.

Second, German federal police crash data for 2023 and 2024 were filtered to include crashes involving cyclists and pedal electric cycle (pedelec) riders as either the victim or the causative party, drawing on a total of approximately 114,000 recorded injury crashes. Crashes were stratified by injury severity (fatal and seriously injured versus all injuries) and aggregated by violation type, road user role, and crash type.

To allow direct comparison across data sources, violations from both datasets were mapped onto a harmonized classification scheme derived from the German federal crash cause coding system and adapted to accommodate the wider range of behaviors captured on regelverstoesse.de. Frequency distributions from both datasets were then analyzed separately and compared to assess convergence and divergence between perceived violation prevalence and crash-recorded violation involvement.

Results expected

Preliminary analyses confirm the presence of well-documented violations, red light running, wrong-way cycling, failure to yield, and close overtaking, across both datasets. Beyond this established set, initial comparisons reveal meaningful divergences. Among violations against cyclists, close overtaking and failure to yield are both frequently reported and prominent in crash data, while illegal stopping or parking on cycle infrastructure features heavily in reports but minimally in crashes. Among violations by cyclists, sidewalk riding dominates self-reported data yet plays a limited role in crash statistics. Turning errors by motorists at intersections are underrepresented in public reports relative to their share of crash causes.

Conclusion

This study provides a comparative perspective on traffic rule violations involving cyclists by combining self-reported and crash-based evidence. The results highlight behaviors that are frequently salient to road users but have received comparatively little research attention, as well as violations that are rare in public reports but strongly associated with crash involvement. This dual perspective supports more targeted interventions that address both demonstrably dangerous behaviors and the everyday conflict patterns that shape relations between road user groups.

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International Co-operation on Theories and Concepts in Traffic Safety

Why Do Road Users Break the Rules? Motivations Behind Cycling-Related Traffic Violations

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Introduction

A commonly held assumption is that traffic rule violations involving cyclists, whether committed by or against them, stem primarily from recklessness or ignorance of the rules. Yet research consistently shows that cyclists frequently perceive their own violations as a rational response to situational constraints rather than as willful non-compliance (Marshall et al., 2017). Both perspectives may be biased by self-serving attributions. However, the motivational and contextual factors underlying non-compliance have rarely been studied systematically across multiple reporter perspectives simultaneously. Initial evidence also suggests that motives differ by the type of violation committed, with some violations more closely tied to situational factors and others to comfort or attentional errors (von Stülpnagel et al., 2026). Understanding these divergences is essential for designing effective interventions that go beyond enforcement and education.

Aim

This study examines the motivational and contextual factors that road users attribute to traffic rule violations in cycling contexts, addressing how these attributions differ by the role of the reporter (offender, victim, or observer), road user group, and physical environment. These analyses contribute toward an empirically grounded partial model of the contextual and motivational conditions underlying cycling-related rule violations.

Method

Data were drawn from regelverstoesse.de, a publicly accessible crowdsourcing platform on which anyone interested could voluntarily submit georeferenced reports of traffic rule violations involving cyclists, drawing on 13,591 reports. Alongside specifying the violation type, location, and road user groups involved, reporters selected one or more reasons they attributed to the violation from a predefined set covering a broad motivational spectrum: lack of rule knowledge, inattention, convenience, habit, low perceived detection risk, non-acceptance of the rule or infrastructure design, perceived safety benefit, and perceived harmlessness. Reporters additionally indicated whether they were the offender, a victim, or an observer of the reported violation. A classification framework distinguishing person-centered motives (e.g., recklessness, convenience, rule non-acceptance) from situation-centered motives (e.g., infrastructure design, perceived safety, situational necessity) was applied, and attributed reasons were analyzed by violation type, road user group, reporter role, main transport mode of

the reporter, and infrastructural context. As the data are based on voluntary self-reports, they may be subject to selection and attribution biases.

Results expected

Preliminary analyses indicate a consistent divergence between self-attributed and other-attributed motives. Offenders, both cyclists reporting their own violations and motorists reporting their own violations toward cyclists, primarily cite situational factors such as safety concerns and contextual necessity, while victims and observers predominantly attribute the same behaviors to recklessness and routine. Convenience is a prominent motive across all reporter roles for both violation directions, though it is cited somewhat more often by offenders and observers than by victims. Motivational profiles further differ between violations by cyclists and violations against cyclists: harmlessness and rule non-acceptance feature more prominently among cyclist offenders, while infrastructure design is cited more frequently by motorist offenders reporting violations against cyclists than by cyclist offenders. Routine and recklessness are attributed at higher rates across all reporter roles in the context of violations against cyclists than in violations committed by cyclists.

The findings above are based on reporter role and road user group alone. Whether and how these motivational patterns are additionally shaped by the physical and infrastructural environment, including road type, speed limit, junction complexity, and cycling infrastructure design, will be examined in subsequent analyses.

Conclusion

The attributed reasons captured in the self-reported data offer systematic insight into the motivational and contextual factors underlying traffic rule non-compliance in cycling contexts. The pronounced divergence between self-attributed and other-attributed motives, and the differences in motivational profiles between violations by cyclists and violations against cyclists, suggests that purely punitive or educational approaches are unlikely to be sufficient when violations are frequently perceived by offenders as situationally justified. Whether these patterns are further shaped by the physical environment will be investigated in subsequent analyses, contributing toward a more empirically grounded understanding of when and why violations occur and providing a basis for developing more targeted, evidence-based approaches to reducing non-compliance.

Funding

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References

Marshall, W. E., Piatkowski, D., & Johnson, A. (2017). Scofflaw bicycling: Illegal but rational. Journal of Transport and Land Use, 10(1), 805–836. https://doi.org/10.5198/jtlu.2017.871

von Stülpnagel, R., Niemann, F., Nassereddine, H., Huemer, A., & Leonhardt, A. (2026). Why do cyclists violate traffic rules? Evidence for situationally and personally motivated violations, slips, and mistakes from a crowdsourcing project. Transportation Research Part F: Traffic Psychology and Behaviour, 117, 103470. https://doi.org/10.1016/j.trf.2025.103470

International Co-operation on Theories and
Concepts in Traffic Safety

Assessing the Potential of Small Open Vision-Language Models for Traffic Conflict Criticality Assessment: A Comparative Study of Unprotected Left-Turn Interactions with Oncoming Traffic

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Introduction

Traditional traffic safety analysis is predominantly based on surrogate safety measures (SSMs) derived from trajectory data, which offer interpretable indicators for criticality but rely on predefined formulations and inadequately capture complex and dynamic interactions among road users (Mahmud et al. 2017). Recent advances in vision-language models (VLMs) have enabled more holistic interpretation of traffic scenes by jointly integrating visual inputs with contextual language representations (Jain et al. 2024). While VLMs can semantically interpret traffic events, their ability to provide meaningful criticality assessments remains insufficiently understood (Wang et al. 2026). This study contributes to this gap by evaluating small open VLMs for traffic conflict criticality assessment in unprotected left-turn interactions with oncoming traffic at an urban intersection. These smaller models are of particular interest because their lower computational requirements make them suitable candidates for integration into local traffic analysis applications. Their classifications are compared with post-encroachment time (PET) values and expert-based criticality assessments, while the effects of model size and prompt formulation are also examined.

Research methodology

To achieve this, the study combines a conventional SSM-based analysis with a VLM-based scene assessment. First, trajectories are extracted from stationary video recordings at an urban intersection and assigned to predefined movement paths. This route assignment is used to isolate only the relevant interaction pairs, namely unprotected left-turning vehicles and temporally overlapping oncoming vehicles. For these interaction pairs, the PET is calculated as the time difference between the left-turning vehicle clearing the conflict point and the oncoming vehicle reaching the same point (Allen et al. 1978). All events with PET values below 3 s, in which the left-turning vehicle passes the conflict point first, are selected. For each selected event, image sequences from 5 s before to 4 s after the left-turning vehicle reaches the conflict point are extracted and sampled at 1 s intervals. The relevant road users are then automatically augmented by the software with bounding boxes and object IDs. The resulting image sequences are independently assessed for criticality by a human expert and by three Qwen3-VL models using the same prompting scheme. Qwen3-VL was selected because it is the Qwen3 model line specifically designed for image and video understanding and, as an openly available multimodal family with several size variants, enables a controlled comparison of scaling effects within a consistent architecture. The evaluated models were Qwen3-VL-2B-Instruct, Qwen3-VL-8B-Instruct, and Qwen3-VL-30B-A3B-Instruct. A structured prompt constrained the models to visually observable evidence and a concise JSON output, while the user prompt provided temporal image order, annotated object IDs, and PET as scenario-specific context. Since preliminary tests (Brusnicki et al. 2026) indicated that the wording of the prompts affect model

responses, the models evaluated each scenario using two alternative criticality formulations: 1) “critical” / “not critical” and 2) “criticality low” / “criticality high”.

Results

The analysis was conducted using the DLR Urban Traffic dataset (Schicktanz et al. 2025). From 32,249 trajectories, those relevant to unprotected left-turn interactions with oncoming traffic were selected. Among 550 left-turning and 3,214 oncoming traffic participants, 36 interactions with PET values below 3 s were identified. The human expert classified only the two scenarios with the lowest PET values as critical or, respectively, as high criticality; all remaining scenarios were assessed as not critical or low criticality. In both critical scenarios, the oncoming vehicle decelerated to mitigate the interaction. Model outputs differed substantially by model size and prompt formulation. All assessments are summarized in Table 1.

Table 1: Assessment of the scenarios

Assessment / Model	Critical	Not critical	Criticality high	Criticality low
Expert	2	34	2	34
Qwen3-VL-2B-Instruct	9	25	25	11
Qwen3-VL-8B-Instruct	0	36	1	35
Qwen3-VL-30B-A3B-Instruct	0	36	9	27

The 2B model showed limited understanding of the interaction scenarios, whereas the larger models captured basic object motion more reliably, indicating improved scene comprehension with increasing model size. But, even in the most critical scenario identified by the expert, characterized by a temporal gap of 1.45 s, the larger models did not classify the interaction as a near-miss or as critical.

Discussion and conclusion

This study compares three size variants of a single open VLM family rather than a broad cross-model benchmark. The findings should therefore be interpreted as evidence on scaling and prompt effects within Qwen3-VL model family, not as a general assessment of VLM capability. The results suggest that Qwen3-VL models with at least 8B parameters can capture the general context of multi-image traffic scenarios and describe observable motion, whereas the 2B model showed limited scene understanding and implausible criticality judgements. However, even the larger models were not able to assess interaction criticality in a way that was consistent with expert judgement. Thus, all three comparatively small open-weight VLMs evaluated here can support descriptive scene interpretation, but cannot yet replace human expert judgement in criticality assessment. Future work should explore alternative prompt formulations, richer input representations, and emerging traffic-specific multimodal models.

References

Allen, Brian L./Shin, B. Tom/Cooper, Peter J. (1978). ANALYSIS OF TRAFFIC CONFLICTS AND COLLISIONS. Transportation Research Record (HS-025 846). Available online at https://trid.trb.org/view/85806.

Brusnicki, Roberto/Piccinini, Mattia/Betz, Johannes (2026). How Well Do Vision-Language Models Understand Sequential Driving Scenes? A Sensitivity Study. Available online at https://arxiv.org/pdf/2604.06750.

Jain, Sandesh/Thapa, Surendrabikram/Chen, Kuan-Ting/Abbott, A. Lynn/Sarkar, Abhijit (2024). Semantic Understanding of Traffic Scenes with Large Vision Language Models. In: 2024 IEEE Intelligent Vehicles Symposium (IV). June 2-5, 2024. Jeju Island, Korea, 2024 IEEE Intelligent Vehicle Symposium (IV), Jeju Island, Korea, Republic of, 6/2/2024 - 6/5/2024. Piscataway, NJ, IEEE, 1580–1587.

Mahmud, S. SohelM./Ferreira, Luis/Hoque, Md. Shamsul/Tavassoli, Ahmad (2017). Application of proximal surrogate indicators for safety evaluation: A review of recent developments and research needs. IATSS Research 41 (4), 153–163. https://doi.org/10.1016/j.iatssr.2017.02.001.

Schicktanz, Clemens/Klitzke, Lars/Gimm, Kay/Rizzo, Giancarlo/Liesner, Karsten/Mosebach, Henning Hajo/Knake-Langhorst, Sascha (2025). The DLR Urban Traffic Dataset (DLR-UT): A Comprehensive Traffic Dataset from an Urban Research Intersection. In: IEEE IV 2025 - 36th IEEE Intelligent Vehicles Symposium. June 22-25, 2025, Grand Hotel Italia, Cluj-Napoca, Romania, 2025 IEEE Intelligent Vehicles Symposium (IV), Cluj-Napoca, Romania, 6/22/2025 - 6/25/2025. Piscataway, NJ, IEEE, 398–405.

Wang, C./Abdel-Aty, M./Easa, S. M./Zhai, S. (2026). Vision-Language and Generative Models in Traffic Video Safety Analysis: A Computational Framework and Research Agenda.

International Co-operation on Theories and Concepts in Traffic Safety

Beyond Compliance: Subjective Legitimacy of Traffic Rule Violations Involving Cyclists and Drivers

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Introduction

Cyclists are a vulnerable road user group, frequently affected by the rule violating behavior of drivers. However, most cyclists also commit traffic rule violations on a frequent basis. These infringements contribute to conflicts and crashes between these road user groups. Understanding potentially dangerous rule violations by cyclists and car drivers, and how these are perceived by other road users, is essential for improving road safety. For example, a rule violation that appears legitimate to one road user may be experienced as dangerous by another. In preparation for this study, cyclists' and car drivers' violations were analyzed using German federal police crash data and self-reported violations from regelverstoesse.de. The analysis identified five prevalent violation types for the current investigation. Three involved cyclists committing procedural errors at signalized intersections by using the sidewalk or crosswalk rather than the roadway: turning left incorrectly, turning right incorrectly, and crossing straight ahead incorrectly. The remaining two involved car drivers: failing to yield to oncoming cyclists when turning left at an unsignalized intersection, and overtaking cyclists without maintaining the legally required minimum lateral passing distance on a narrow road. These scenarios span cyclist- and driver-initiated violations and interactions frequently contributing to conflicts and collisions in everyday urban traffic.

Aim

The primary aim of this online survey study is to examine how observers judge rule-violating behavior in mixed road user interactions, with a particular focus on the subjective legitimacy attributed to each violation. Specifically, it investigates whether participants perceive the depicted violations as justified, understandable, or morally defensible. Secondary aims are to assess perceived risk and legal knowledge, test whether role identification moderates legitimacy judgments, and analyze associations with self-reported driving and cycling behavior.

Method

An online survey will be conducted with a representative German sample. Based on the five identified rule violations, virtual scenarios were developed in SILAB to simulate exemplary instances of each violation. Participants view randomized videos of the five rule violations from the perpetrators' perspective. After each video, participants rate the depicted behavior on several dimensions. Perceived risk is assessed by items on the behavior's danger, the probability that another road user would need to brake or swerve, and the overall accident risk. Rule compliance is assessed with a single item on consistency with traffic law. Role identification is

measured by asking participants with whom they most identify in the scenario (car driver, cyclist, pedestrian, someone else, or no one). Subjective legitimacy is assessed using a shortened adaptation of the legitimacy scale proposed by Varet et al. (2024), covering perceived proportionality, understandability of motivation, moral justifiability, and fairness. Participants then complete the Cycling Behavior Questionnaire (Useche et al., 2018) and the Driver Behavior Questionnaire (Parker et al., 1995) to capture self-reported violations, errors, and lapses for both modes, conditional on having used the respective mode in the past 12 months. General rule legitimacy is also assessed using a brief scale. Rule knowledge relevant to each scenario is tested through targeted multiple-choice questions covering legal requirements. The survey concludes with sociodemographic items and transport use frequency.

Expected Results

While results from the planned survey are not yet available, the study will evaluate how subjective legitimacy is attributed to rule violations across five different scenarios involving cyclists and car drivers. The psychometric structure of the adapted legitimacy scale will first be examined using confirmatory factor analysis. Multilevel regression models will then be estimated to account for the nesting of scenarios within participants and to examine associations between legitimacy judgments and predictors such as role identification, rule knowledge, and self-reported driving and cycling behavior.

Conclusions

This study provides a novel perspective on traffic rule violations in mixed road user interactions by focusing not merely on what violations occur, but on how they are morally and socially evaluated by the public. Understanding the subjective legitimacy of such violations is relevant for road safety intervention design: behaviors that are perceived as legitimate despite being illegal may require different countermeasures than those already viewed as unacceptable. The use of realistic, simulation-based video stimuli and a multi-dimensional assessment battery makes this study well-suited to capturing the complexity of how observers judge rule-violating behavior in everyday traffic situations.

Funding

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References

Parker, D., Reason, J. T., Manstead, A. S., & Stradling, S. G. (1995). Driving errors, driving violations and accident involvement. *Ergonomics*, *38*(5), 1036–1048. https://doi.org/10.1080/00140139508925170

Useche, S. A., Montoro, L., Tomas, J. M., & Cendales, B. (2018). Validation of the cycling behavior questionnaire: A tool for measuring cyclists' road behaviors. *Transportation Research Part F: Traffic Psychology and Behaviour*, *58*, 1021–1030. https://doi.org/10.1016/j.trf.2018.08.003

Varet, F., Pelé, M., Carnis, L., Piermattéo, A., Martinez, F., & Granié, M.-A. (2024). Toward a multidimensional model of legitimacy: Validation of the traffic rules perceived legitimacy scale. *Psychology, Public Policy, and Law*, *30*(2), 206–222. https://doi.org/10.1037/law0000416

International Co-operation on Theories and Concepts in Traffic Safety

Capturing Cyclists` Driving Errors – privacy-compliant methods, insights, and infrastructure approaches concerning AI

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Introduction

Despite improvements in overall road safety, cyclist fatalities have stagnated over the past decade, both in the EU (European Commission 2025) and in Germany, in contrast to a decrease in car driver fatalities (Destatis 2024a). Specific driving errors of cyclists are strongly associated with accident occurrence: incorrect road use and failure to yield together account for nearly a quarter of cyclist injury accidents in Germany (Destatis 2024b). As driving errors mark the starting point of a chain of events leading via traffic conflicts to accidents (Hydén 1987), recording them enables proactive safety analysis and targeted interventions. Yet, official statistics capture only coarse categories – missing finer-grained behaviors such as insufficient shoulder checks, failure to signal, or smartphone use – and no standardized or AI-driven method currently exists to systematically and privacy-compliantly capture them in real-world traffic.

Therefore, we analyze and evaluate existing methods and sensors for their capability to capture driving errors regarding their technological feasibility, level of detail, and regulatory compliance (i.e., European and German data protection regulatory regimes), providing insights into: (A) how we translate driving errors into technical language, (B) three methods for capturing driving errors (with AI), (C) the feasibility of infrastructural interventions via a bicycle simulator, and (D) an analysis of our methods regarding regulatory compliance.

Research Methodology

Based on a review of the literature and methods, three methods are examined to capture and detect driving errors: (1) Manual video observation – a trained experimenter records and encodes cyclists' riding behavior. (2) The bicycle's perspective – using sensors on an instrumented bicycle (e.g., Hall-Sensor, GNSS, Inertial Measurement Units (IMU)) and wearables by the cyclist (e.g., smartphones, smartwatches, headphones) with AI. (3) The car's and infrastructural perspective via a Roadside Unit (RSU) – using LiDAR and camera with AI.

For each method, driving errors were translated into technical language by operationalizing and decomposing them into single cycling behaviors, postures, and context information. We determine which sensors and metrics (e.g., surrogate safety measures, F1-Score) can be applied to capture and validate driving errors and their impact on accidents. A regulatory compliance assessment examines permissibility (i.e., data protection) for each method. Additionally, we analyze which infrastructure characteristics, such as the absence of cycling facilities, restricted

sight lines, or cobblestone, promote specific driving errors, and assess the effectiveness of infrastructure interventions using a bicycle simulator.

Results

Manual video observation (1) is the most informative method, enabling the capture of nearly all error types and providing rich annotations (e.g., scene context, interaction partners), which are essential as training data for AI development. Its main limitation is scalability: personnel requirements are high, and video recordings in public space, particularly of bypassers without explicit consent, can pose substantial data protection concerns. Due to inherent sensor uncertainties, **bicycle- or cyclist-mounted sensors (2)** need to be fused and processed by algorithms to detect cyclists' activities. With this, only cycling activities and their absence, not their corresponding driving error, can be inferred. Driving errors consist of (absent) activities within specific traffic situations and therefore need to be contextualized to be detected as such. Thus, context information from a digital twin and the cyclist's precise position are required to infer a driving error. The data protection concerns are similar to those in (1), with additional concerns arising from movement data and location data. **RSU- and car-based detection (3)** of driving errors shows great potential for specific traffic situations, but widespread implementation is limited by high costs, the limitations of these systems under various weather conditions, and data protection concerns fueled by the hardly possible anonymization without substantial loss of important AI training features.

Bicycle simulators allow controlled investigations of infrastructural interventions for selected driving errors in a privacy compliant manner, but show limited real-world validity for surfaces like cobblestones and maneuvers such as stopping or starting.

Detailed results are summarized in a table that compares for each driving error the three mentioned methods, their regulatory compliance assessments, and the feasibility of replicating the infrastructural interventions for them.

Discussion and conclusions

Our analysis reveals that AI-based methods (2 & 3) compared to manual video observation (1) provide a powerful, time-efficient tool for objective capturing and detecting driving errors. Thereby, they enable the identification of accident causes and thus contribute to evidence-based accident prevention. However, we found that none of these methods fully cover the capture and detection of all considered driving errors, regardless of context. Thus, a multi-method approach is recommended, in which the different methods complement each other according to the needs and application context, while accounting for each method's regulatory compliance requirements. Even though manual video observation is outperformed by AI-based methods, it remains indispensable until sufficient training data for AI-based methods are available to capture and detect driving errors, and for making evidence-based decisions on which driving errors should be prioritized. Considering the knowledge gained regarding the association of specific infrastructural characteristics and driving errors, the bicycle simulator appears promising for validating infrastructural interventions aimed at reducing these errors, even though its real-world validity remains limited. Finally, our findings provide a methodological base for AI-supported research on cyclists' driving errors and can be incorporated into traffic planning recommendations.

Sources:

Destatis (2024a): Durchschnittlich 8 Tote und 1 004 Verletzte pro Tag im Straßenverkehr im Jahr 2023. Pressemitteilung Nr. 261 vom 5. Juli 2024. Statistisches Bundesamt, Wiesbaden. https://www.destatis.de/DE/Presse/Pressemitteilungen/2024/07/PD24_261_46241.html

Destatis (2024b): Unfälle von Fahrradfahrern/-fahrerinnen 2023. Genesis-Online, Tab. 46241-0009. Statistisches Bundesamt. https://www-genesis.destatis.de/datenbank/online/statistic/46241/table/46241-0009

European Commission (2025): Facts & Figures: Cyclists. European Road Safety Observatory. Brussels, European Commission, Directorate General for Transport. https://road-safety.transport.ec.europa.eu/european-road-safety-observatory/data-and-analysis/facts-and-figures_en

Hydén, C. (1987): The development of a method for traffic safety evaluation: The Swedish Traffic Conflict Technique. Bulletin 70, Department of Traffic Planning and Engineering, Lund University.

International Co-operation on Theories and Concepts in Traffic Safety

Analysis of crashes using detailed exposure data: A Case Study of the city of Braunschweig

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Introduction

As cycling plays an increasingly important role in achieving sustainability goals, ensuring the safety of cyclists has become a critical concern. With increasing cyclist share, their involvement in crashes increases, at least as long as the car share is not significantly reduced.

This work aims to better understand the safety of cyclists by analysing crashes at urban intersections in the city of Braunschweig. The analysis integrates crash data with traffic exposure, intersection characteristics, and temporal effects within a unified framework. Two complementary modelling approaches are applied: a Negative Binomial Model to estimate annual crash frequencies, and a binomial logistic model to analyse monthly crash occurrences [1]. The study aims to quantify the effects of bicycle and motor-vehicle traffic volumes on crash risk, examine how risk varies across intersection types, and assess the influence of temporal factors.

Research methodology

This study investigates cyclist-motor vehicle crash risk at urban intersections in the city of Braunschweig, Germany. Multiple datasets were integrated to construct a spatially explicit analytical framework, including crash records, intersection data, traffic exposure, and weather information.

Crash data were obtained from the German Accident Atlas [2] database, covering the period from 2017 to 2023. The dataset includes information on accident location, type, and temporal attributes such as month, and is limited to accidents involving personal injury. For this analysis, only accidents involving cyclists were considered.

Intersection locations and traffic control information were derived from OpenStreetMap (OSM). Bicycle and motor-vehicle traffic exposure were represented using average daily traffic (ADT) values. Bicycle ADT values were based on modelled estimates calibrated using floating bicycle data, while motor-vehicle ADT values were extracted from a SUMO traffic simulation model [3]. Weather data, including temperature, precipitation, and sunshine duration, were obtained from the Deutscher Wetterdienst (DWD) [4] and aggregated at a monthly level.

Results

Figure 1a shows the yearly number of total and cyclist-involved crashes in Braunschweig between 2017 and 2023. Overall accident counts fluctuate moderately across the years, while cyclist-related crashes consistently account for a substantial share of total accidents. A noticeable decline is observed in 2020 and 2021, corresponding to reduced traffic volumes during the COVID-19 pandemic. This is followed by an increase in 2022, reflecting the return to normal mobility patterns.

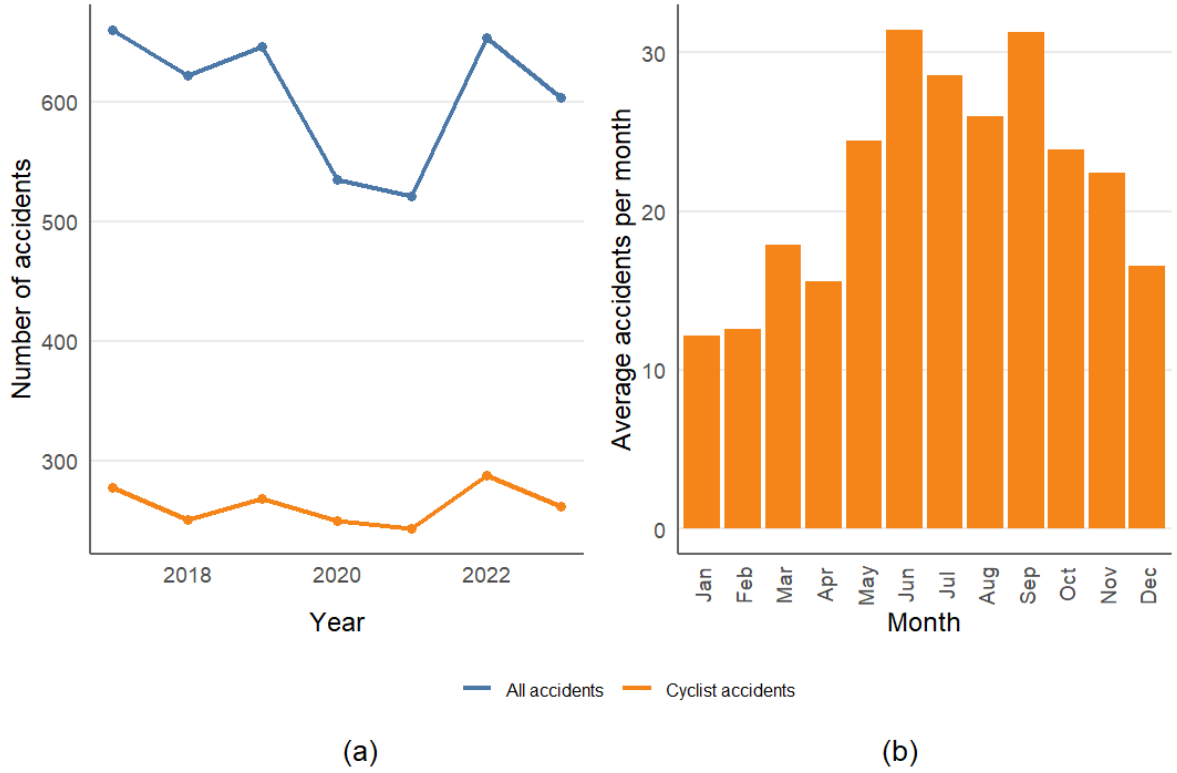


Figure 1 (a) Left: Yearly number of accidents in Braunschweig; (b) Right: monthly number of crashes.

Across the study period, cyclist crashes remain relatively stable without a clear decreasing trend. This indicates that general road safety improvements have not led to substantial reductions in cyclist-related accidents, highlighting the need for targeted safety analysis.

A clear seasonal pattern can be observed in the monthly distribution of cyclist crashes as seen in Figure 1(b), with lower crash numbers during winter months and higher values during spring and summer. This trend reflects seasonal variation in cycling activity during warmer months leading to more crashes

Crash frequency at intersections was modelled using a negative binomial regression model to account for overdispersion in the crash data. The model results are presented in Table 1.

Deviance Residuals:				
Min	1Q	Median	3Q	Max
-1.7304	-1.0402	-0.5803	0.1978	3.3291
Coefficients:				
	Estimate Std.	**Std.Error**	**Z value**	**Pr(>|z|)**
(Intercept)	-9.53287	1.14169	-8.35	< 2e-16 ***
log(Qcyc)	0.88854	0.14837	5.989	2.12e-09 ***
log(Qveh)	0.3286	0.06793	4.837	1.32e-06 ***
TypePrio	0.58276	0.26313	2.215	0.026779 *
TypeRA	0.86051	0.41886	2.054	0.039937 *
TypeTS	0.64721	0.16684	3.879	0.000105 ***

Table 2 Negative Binomial model summary; Qcyc, Qveh=average daily traffic of bicycle and motor-vehicle traffic, RA=roundabouts, TS=traffic signals, Prio=prioritized intersection

The results show that traffic exposure is the primary determinant of cyclist crash risk at urban intersections. Bicycle traffic has a stronger influence on crash frequency than motor-vehicle traffic. Intersection type also has significant effect on crash occurrence. Compared to the reference category, priority-controlled ($\beta = 0.58$) and signalised intersections ($\beta = 0.65$) are associated with higher crash frequencies, reflecting increased interaction complexity.

In addition to the NB model, a binomial logistic model was applied to examine the monthly crash occurrence. The results confirm that exposure variables remain the dominant predictors of crash likelihood, while weather variables show limited influence. These findings highlight the importance of incorporating exposure measures when analysing cyclist safety and developing targeted interventions.

Conclusions

From a practical perspective, these findings suggest that improving cyclist safety requires targeted interventions at high-exposure and high-complexity intersections. Measures such as improved intersection design, clearer separation between cyclists and motor vehicles, and enhanced visibility at conflict points may reduce crash risk. In addition, temporal patterns indicate that safety measures may be particularly effective when focused on periods of increased cycling activity.

Overall, this study demonstrates that cyclist crash risk is primarily driven by exposure, with intersection design and temporal variation further shaping risk levels. By integrating these elements within a unified modelling framework, the study provides a robust basis for understanding and improving cyclist safety at urban intersections.

References

[1] Lord, D. and Mannering, F. (2010) 'The Statistical Analysis of Crash-Frequency Data: A Review and Assessment of Methodological Alternatives', *Transportation Research Part A: Policy and Practice*, vol. 44, pp. 291–305.

[2] Statistical Administration of the German Federal Government and the Federal States, *German Accident Atlas*, (2024).

[3] Lopez, P. A., Behrisch, M., Bieker-Walz, L., Erdmann, J., Flötteröd, Y.-P., Hilbrich, R., Lücken, L., Rummel, J., Wagner, P. and Wießner, E. (2018) 'Microscopic Traffic Simulation using SUMO', *The 21st IEEE International Conference on Intelligent Transportation Systems,* IEEE.

[4] Index of /climate_environment/CDC/observations_germany/climate/. (n.d.). https://opendata.dwd.de/climate_environment/CDC/observations_germany/climate/

International Co-operation on Theories and
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Analyses of automatically-generated data on e-scooter behaviours to characterize the safety level of urban sites and estimate safety-related interventions

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Introduction

In recent years, both in Israel and worldwide, the use of micromobility vehicles - e-bicycles and e-scooters - was steadily growing. Such devices provide mobility solutions for individual users in dense urban environment, with associated mobility, environmental and health benefits. However, alongside the growth in the use, an increase in e-riders' injury in traffic accidents was observed. In Israel, the number of casualties in e-scooter accidents had a 23-fold rise in a decade, where 90% of the casualties were e-riders. Among the reasons cited for the high injury rates were dangerous e-rider behaviours and traffic violations, e.g. high speeds, not wearing helmets, riding on sidewalks. Among the shortcomings in addressing the issue were low enforcement and insufficient regulations.

To delve into e-scooter riders' behaviours in urban space and assist authorities in identifying and enforcing e-rider violations, a project was initiated, in collaboration between technology companies, the Ramat Gan city and the academy. In the project, infrastructure and sensors were deployed at selected sites in the city to record e-rider behaviours, identify traffic violations and send alerts to the authorities. The main technology used for data collection was provided by the A.D. Knight Company, with the sensors performing real-time automatic detection of e-riders based on detecting radio waves from connected devices. Currently, the system collects data on illegal e-scooters' riding in pedestrian zones, at four sites (pedestrian malls, walking paths).

In the study, statistical analyses were performed on the data collected in the system that were intended for two purposes: 1) quantitative characteristics of e-rider behaviours, with identification of time periods with higher concentrations of rider violations; 2) examination of the impact of a safety intervention - the presence of municipal inspectors in the field, who enforced e-rider violations, on rider behaviours.

Research Methodology

The first analysis was based on the system data reported in March–June 2025. To identify high-count hours at each site, a methodology of formal analysis was developed, including three steps. First, a model for all weekdays and hours together was estimated to test the significance of "weekday × hour" interaction. Second, mixed-effects models were fitted to identify subsets of

hours whose Least-square-means (LS-means) are not significantly different in pairwise comparisons; this way, groups of hours with highest and lowest offense counts were found. Each model included a random intercept for a week to account for within-week dependence among observations. LS-means were obtained using the LSMEANS statement in PROC GLIMMIX, with the LINES option and T grouping without multiplicity adjustment; multiplicity adjustments were over-conservative in this context, leading to most of the hours being grouped together thereby obscuring potentially meaningful differences and thus, were not applied. Third, the statistical significance of differences between the highest and lowest counts' groups, in the same weekday, were estimated, to ascertain the highest groups.

The second analysis followed the intervention that was in the form of inspectors' presence in the field to deter e-riders from using pedestrian areas, and occurred in selected hours on weekdays in September–October 2025. To examine the intervention's impact a "before-after" comparison of violation frequencies was planned but found inapplicable due to data irregularities. Hence, the analysis was performed for the "after" period, comparing violation frequencies during intervention hours ("treatment group") with frequencies during non-intervention hours ("control group"), while accounting for general trends in the effect of day type and time-of-day periods, at each site. For that, first, two "baseline" models were fitted: Model 1 that relied on "before" period data (July-August) during hours identified as "intervention hours" in the "after" period (September–October), and Model 2 that was based on days in the "after" period without inspectors' activity but during hours identified as "intervention hours". Second, "consequent" models were estimated: Model 3 based on the structure of Model 1; Model 4 based on the structure of Model 2, whereas each model used all days in the "after" period during "intervention hours". The latter comprised days with and without inspectors' activity, thus enabling estimation of differences in violation frequencies between the two conditions. The models were fitted using the PROC GLIMMIX procedure in SAS 9.4, using a negative binomial regression model with a logarithmic link function, and a random intercept for each day to account for possible dependence between observations. Predicted means of violation counts with confidence intervals were estimated by LSMEANS.

Results

Both analyses were conducted for two sites of the system: site 1 (Rambam) and site 2 (Merom Naveh). The first analysis was based on 16,917 violation records, in weeks 20-23. The hourly average of violations was 6.8 (± 6.0) at site 1 and 6.6 (± 6.5) at site 2, with maximum values between 37-41, indicating that both sites were characterized by a high frequency of violations. The initial model showed differences in the hourly profile of violation counts across different days of the week, necessitating separate models for each day. Hence, groups of hours with highest violation counts were identified for each day type; the differences in violation frequencies between groups with maximum and minimum violations were significant on all days of the week, at both sites. At site 1, the numbers of high-violation hours were large, of 14-17 hours, on Sundays, Tuesdays, Fridays, and Saturdays. At site 2, these numbers were large on all weekdays (14-19 hours per group), indicating that most of the day, or even all daylight hours, at this site, were characterized by high frequency of e-scooter violations.

The second analysis included 14,917 violation records. The model results showed that, at both sites, a decreasing trend was found in violation frequency during hours with intervention

activity compared to hours without activity – Table 1. The average decrease in hourly violation rate was 6%–10% at site 1 and 12%–13% at site 2. The lack of significance was expected given the limited number of intervention hours, per site (12-14) that were examined in the final models. Nevertheless, the observed decrease in odds ratios of the risk rates and reduction trends in violation counts indicated on the potential effectiveness of on-site enforcement.

Table 1. Effect of inspector presence on hourly violation frequency of e-scooter riders.

	Model 3			*Model 4*		
site	Mean effect (p-value)	Expected hourly number of violations with intervention [95% CI]	Expected hourly number of violations without intervention [95% CI]	Mean effect (p-value)	Expected hourly number of violations with intervention [95% CI]	Expected hourly number of violations without intervention [95% CI]
1	decrease 10% (p=0.573)	4.83 [3.12; 7.49]	5.39 [4.01; 7.25]	decrease 6.4% (p=0.843)	4.85 [2.11; 8.71]	5.18 [3.39; 7.35]
2	decrease 13.5% (p=0.455)	3.75 [2.29; 6.15]	4.34 [3.12; 6.04]	decrease 12.4% (p=0.405)	3.89 [2.53; 5.98]	4.44 [3.26; 6.04]

Conclusions

Based on automatically-generated data on e-scooter behaviours, this study developed statistical methods that enabled identification of hours with high concentrations of e-scooter violations, which may assist in planning of safety interventions, and examining the impact of a safety intervention on the frequency of e-riders' violations.

The analyses performed in the study can be applied repeatedly to monitor over-time trends in e-rider behaviours at the sites included in the surveillance, to evaluate the impacts of various safety interventions, or to compare safety levels between different sites in the city in terms of the extent of dangerous e-rider behaviours.

International Co-operation on Theories and
Concepts in Traffic Safety

Confident but vulnerable: Insights on young motorcyclists' decision-making and riding behaviour

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Introduction

Light motorcycles constitute a popular mode of transportation among young people in Norway, meeting the mobility needs of 16–17-year-olds who are not yet eligible to obtain a driver's licence for cars. However, the risk of being killed or seriously injured as a motorcyclist is much higher than for car drivers. In the last years, the crash risk among young car drivers has been decreasing in Norway, while the fatalities have been increasing among young motorcyclists. Previous studies have reported that the risk of serious injuries for young riders is higher than for older riders. Other risk factors identified by literature include being male, inexperienced, traffic violations and riding errors. Studies investigating car drivers found that those who perceive themselves as skilful, or perceive their own abilities more positively, tend to engage in more risky behaviours. It is possible that is also applies for motorcycle riders. Due to their high vulnerability and the growing number of young riders who are killed and seriously injured, it is necessary to address motorcycle safety among this group.

Riding behaviour is complex with multiple simultaneous subtasks. Most of the riders are young with little experience in traffic as a motorized road user. Thus, it may be helpful to investigate rider behaviour from different levels: their abilities in handling the motorcycle in different traffic situations, how they describe their behaviours, the risks they perceive and strategies they use to manage them (i.e. their behaviours at operational, tactical and strategic levels). Another interesting factor to explore is their self-assessment of their driving skills as it may provide valuable insights into their actual behaviour. The present study therefore aimed to explore the behavioural choices young riders do, and their self-assessment as a motorcycle rider.

Research methodology

Seventeen young male riders and one female were recruited, they were 16-18 years old. All held a licence for light motorcycles. This paper is a part of a larger project where the participants first rode their own motorcycles in real traffic while wearing an eye-tracker. On a separate day, semi-structured interviews were conducted to gain deeper insight into their decision-making process in different traffic situations, such as driving in curves and roundabouts, as well as their risk perceptions related to typical risky situations and how they saw themselves as riders. Here we report the results from the interviews.

Results

Preliminary findings indicate that young rides have limited capacity to interpret traffic-related risks and often report unsafe strategies at tactical levels in typical risky situations (e.g. curves and roundabouts). Although they frequently describe themselves as being careful riders, they are not always able to identify risk elements and alternative actions when questioned. At the same time, many report enjoying riding on curves because it allows them to feel in control of the motorcycle, something that gives them excitement. Several also state that they actively seek out roads with many curves to fulfil this desire. Speeding is reported by many as an important element of riding, and some note that speeding often occurs when riding together with friends.

The findings also show that young riders have high confidence in their own riding abilities. They often describe themselves as cautious and competent, while at the same time reporting behaviours that are unsafe (e.g. speeding). Interestingly, many report having less trust in other road users, yet believe that their own skills are sufficient to compensate for others road users' mistakes. Although the participants appear to have a good theoretical understanding of safe riding principles, they do not necessarily apply this knowledge in practice in real traffic situations. Adjustments to speed or position were often described as responses to emerging problems rather than as preventive measures taken early. All participants reported having experience some type of unpleasant or potentially hazardous situation while riding, which elicited emotional responses and behavioural adaptations such as having a more defensive driving style or developing a distrust towards other road users. Participants confirm that motorcycles are manly used as a mean of transportation, but they also have a strong social dimension attached since they say it is common to ride together with friends (both spontaneously and planned). Riding with friends also appears to elicit risk-taking behaviours such as speeding.

Discussion and conclusions

Young riders seem to have a good theoretical understanding of risk, motorcycle handling at an operational level, however this does not seem to be consistently translated into correctly and safe behaviours at higher levels. Targeting riders' attitudes, their perceived behavioural control and subjective norms may be therefore an effective way than solely increasing their knowledge about risky situations. Gaining a deeper understanding of motorcycle behaviour among young riders will contribute to the development of targeted traffic safety interventions and offer valuable input for regulatory authorities. The results from this study provide insight into young motorcyclists' behaviour that can contribute to this work.

International Co-operation on Theories and
Concepts in Traffic Safety

Recognizing Cyclists' Signals: What Automated Systems can learn from Human Perception

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Introduction

Cyclists primarily communicate upcoming maneuvers to other road users through hand signals [1], [2]. The reliable interpretation of these signals is therefore a critical factor for safe interactions in mixed traffic environments, since misinterpretations of cyclists' intentions can lead to hesitation, incorrect decisions, and potentially dangerous conflicts, particularly in complex situations such as intersections [3]. The perceptual processes underlying human judgments of hand signals have rarely been empirically characterized. Existing research has identified technical parameters related to signal execution, such as arm extension or gesture duration [4], [5]. However, prior studies often restrict observation perspectives and standardize the execution of hand signals, consequently limiting the ability to capture the variability of real-world signals of cyclists. As a result, the extent to which such parameters accurately reflect the perception of signals executed under natural traffic conditions remains unclear.

This limited understanding of how humans perceive cyclists' communication cues is a foundational problem for the development of AI models in automated driving systems. These systems are increasingly adopted in commercial cars operating in shared traffic spaces. Unlike human observers, they are not yet able to reliably detect and interpret cyclists' signaling behavior. Safe deployment of these systems requires the functionality to distinguish intentional turn signals from incidental movements, understanding their contextual meaning, and differentiating the natural variability in signal execution. Automated systems lack such a well-defined perceptual benchmark that specifies to what extent an arm movement should be considered a signal. Such a benchmark must be grounded in human perception.

This study addresses these gaps by investigating which perceptual and contextual parameters influence the recognition and interpretation of cyclists' hand signals by human observers in naturalistic traffic scenarios — distinguishing intentional turn signals from arm movements unrelated to turning intentions.

Research methodology

To empirically establish a human-perception-grounded benchmark for the purpose of training AI systems, a naturalistic video dataset is collected that captures cyclists' signaling behavior in realistic traffic situations. The recordings take place at a T-intersection and are captured from multiple observation perspectives corresponding to the viewpoints of other road users, such as oncoming, crossing, or following traffic. Participants ride bicycles from all approach directions,

either continuing straight or performing turning maneuvers. First, cyclists navigate the intersection without any instructions regarding signaling behavior, allowing the dataset to capture naturalistic variability in gesture execution. Second, cyclists are instructed to provide hand signals when indicating turning maneuvers. This approach allows the analysis of whether such instructions influence the presence, timing, or form of signaling behavior while still preserving ecological validity.

The resulting video material is subsequently presented to human observers in a computer-based eye-tracking experiment. For each scenario, participants indicate whether they recognize a hand signal and report their confidence in the interpretation, while their gaze is recorded during video playback. This enables the identification of specific features of hand signal execution that humans perceive when making these types of judgments. Moreover, we investigate whether differences in signal execution and characteristics of the cyclist or observer lead to systematic differences in signal recognizability, interpretation and recognition time. The temporal moment of signal recognition is operationalized using a Detection Response Task (DRT): participants press a key as soon as they recognize a hand signal. This provides a baseline measurement for signal recognition time in future AI applications. In a second DRT, participants indicate the moment at which they become confident that the cyclist intends to turn, independent of whether a hand signal has already been detected. Comparing these two moments allows us to examine whether turning intentions are often inferred from contextual cues, such as speed changes, lane position, or body posture, before an explicit hand signal is recognized.

Results & Discussion

The experiment enables the analysis of observers' detection accuracy, sensitivity and response patterns using signal detection theory, providing empirically grounded reference values for the development and evaluation of AI-based perception systems. By characterizing when and how human observers recognize cyclists' signals under realistic conditions, the study establishes a perceptual benchmark that can guide the design and validation of such systems. Moreover, the annotated video dataset, enriched with gaze data and behavioral annotations, will serve as a training resource for future AI-based signal recognition systems.

Sources

[1] C. M. Petersen and P. R. DeLucia, "Do drivers understand cyclists' communication cues?," *Accident Analysis & Prevention*, vol. 225, p. 108333, Feb. 2026.
[2] F. Westerhuis and D. De Waard, "Reading cyclist intentions: Can a lead cyclist's behaviour be predicted?," *Accident Analysis & Prevention*, vol. 105, pp. 146–155, Aug. 2017.
[3] H. Bi, X. Zhang, W. Zhu, H. Gao, and Z. Ye, "Why they take the risk to perform a direct left turn at intersections: A data-driven framework for cyclist violation modeling," *Accident Analysis & Prevention*, vol. 209, p. 107846, Jan. 2025.
[4] P. E. Hemeren, M. Johannesson, M. Lebram, F. Eriksson, K. Ekman, and P. Veto, "The use of visual cues to determine the intent of cyclists in traffic," in *2014 IEEE International Inter-Disciplinary Conference on Cognitive Methods in Situation Awareness and Decision Support (CogSIMA)*, pp. 47–51, Mar. 2014.
[5] R. Herpers, D. Scherfgen, S. Felsner, and T. Saitov, "Entwicklung eines Fahrradfahrsimulators zur Verkehrserziehung und zum Verkehrssicherheitstraining für verschiedene Altersklassen," University of Applied Sciences Bonn-Rhein-Sieg, Department of Computer Science, Sankt Augustin, Germany, Technical Report 03–2014, 2014.

International Co-operation on Theories and
Concepts in Traffic Safety

The role of microscopic traffic flow simulation in defining the scope of application for multi-purpose lanes (2-1 road): the case of the "MehrzweckSicher" project.

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Introduction

Promoting bicycle traffic through the development of a coherent cycling network contributes to achieving sustainable mobility goals. Due to spatial or financial constraints, the implementation of dedicated cycling infrastructure is not feasible everywhere. Multifunctional lanes (2-1 roads) can help fill these gaps, providing a low-cost and easy-to-implement solution, particularly for connections between small villages in rural areas. The traffic organization is modified by designating cycle lanes on the carriageway, which motor vehicle drivers may temporarily use exclusively to pass an oncoming vehicle. For this solution to fulfil its intended purpose, it needs to be thoroughly evaluated in terms of its effectiveness and safety.



Multi-purpose lanes. Source: AIT's own materials



A section of the network from a traffic flow simulation in SUMO

Microscopic traffic flow simulations are a valuable option to analyse different parameters of traffic situations of interest in real conditions without involving vulnerable road users. Using a replication of the real world fed with results of on-site data collection for the creation of base scenarios and modify these values for modifications of the scenario allows the test of different approaches to a research question. The options to modify and influence such microscopic traffic flow simulations range from simple changes in traffic load to changes in traffic behaviour of specific user groups.

The aim of the "MehrzweckSicher" project is to analyse the feasibility of implementing multifunctional lanes on narrow rural roads in Austria (2-1 roads) and to develop recommendations for their safe implementation.

Research methodology

To conduct the study, suitable test sections were selected in two Austrian municipalities. The research includes an assessment of road user behaviour measured via a mobile, video-based sensor system for the objective measurement and analysis of traffic safety (MOB-Mobility Observation Box), a bicycle with a distance-measuring system for overtaking distances as well as a questionnaire surveys. A traffic microsimulation was carried out using the Simulation of Urban Mobility (SUMO) programme developed by employees of the Institute of Transportation Systems at the German Aerospace Center (DLR).

To achieve the intended objective, it was necessary to create a traffic control model that would allow vehicles to move within a shared space, which went beyond the standard traffic models available in SUMO at the time the project was carried out. The new model defines the behaviour of road users required for a 2-1 cross-section road and regulates the interactions between them. Particular attention was paid to realistically modelling reactions to ensure the reliability of the results.

Microscopic traffic flow simulation networks are based on a link-node network representation, that gives boundaries on how traffic will flow through the network by defining speeds, curvature, inclines and crossings/merge areas. However, if reductions of lane width or oncoming traffic is needed, this representation often hits their boundaries in terms of influences on the traffic flow due to the internal representation as simple link without considering vehicle widths. SUMO is providing a slightly better approach by the usage of their sublane-model where an existing lane is divided into equal parts of smaller lanes to simulate more realistic behaviour of vehicles and their directional stability. This model also allows to simulate overtaking in the opposing lane, one of the hardest parts to implement in microscopic simulations. In this very project another speciality came into place, as the overtaking is now generated on reduced link width, meaning an overlapping representation of the specific link.

The microscopic traffic simulation supplements the collected data. The actual test sections have been modelled in a simulation software, which allows an in-depth analysis of various potential traffic and infrastructure scenarios. The baseline scenarios used real-world traffic data collected by the Mobility Observation Box, such as trajectories and average daily traffic. Thanks to this, it is possible to assess the model's sensitivity to changes in key parameters, such as speed limits, lane widths, proportion of lorries or traffic volumes. This approach allows the analysis of various possible scenarios. The analysis focuses on the output data obtained after conducting microscopic traffic simulation.

Results

The results of microscopic traffic simulation include data on travel times, time losses, speeds, queues, and conflicts between road users. Comparing the results obtained for different scenarios

provides information on the performance of multifunctional lanes under various road and traffic conditions. The expected outcome is the identification of threshold values that justify the feasibility of implementing multifunctional lanes while ensuring the safety of all road users. Of particular importance is determining the applicable ranges for key parameters, such as carriageway width, traffic volume, and traffic flow composition.

Discussion and conclusions

Defining the implementation framework for the 2-1 cross-section is crucial primarily for the safety of road users. Multifunctional lanes are easy to implement due to their low cost and ease of execution. Expanding bicycle infrastructure is important, but it must be justified and cannot come at the expense of increased safety risks even for few road users. A virtual environment enables the analysis of hazardous situations without endangering human life or health. Microscopic traffic flow simulation also reduces the costs of subsequent test sections, which would otherwise need to have varied parameters. The research results provide the basis for determining the potential for implementing this solution on a nationwide scale in each federal state, together with recommendations for changes to legal regulations and standards. Although the research is being conducted in Austria, the results can also be adapted in other countries striving to promote cycling.

The “MehrzweckSicher” project (“Accompanying study of multi-purpose lanes in rural areas with a reduced core lane”; Project No. FO999923385) is funded as an R&D service by the Climate and Energy Fund and implements the objectives of the Federal Ministry for Innovation, Mobility, and Infrastructure (BMIMI).

International Co-operation on Theories and Concepts in Traffic Safety

AI-Based Road Safety Management Platform for Network-Level Decision Support on Spain's Conventional Road Network

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Introduction

Effective road safety management at the network level requires the capability to identify latent risks, quantify them objectively across different user groups, and translate this information into investment strategies aligned with explicit cost–benefit objectives. Current practice within the Spanish General Directorate of Roads (Dirección General de Carreteras, DGC) remains largely reactive, relying on crash-record analysis, which limits the identification of underlying risk patterns and provides insufficient support for proactive investment planning. In this paper, conventional road network refers mainly to DGC-managed national interurban roads with single-carriageway, two-way configurations, as opposed to motorways or expressways with physically separated directions.

This extended abstract presents a road safety management platform currently under development for the DGC. The system leverages artificial intelligence (AI) and large-scale infrastructure data to support proactive safety governance across approximately 13,000 km of Spain's conventional road network. It integrates an AI-based safety model with a GIS environment to support risk assessment, diagnosis, scenario simulation, cost–benefit analysis, and long-term planning, in line with the principles of the Safe System and Vision Zero frameworks.

Research methodology

The proposed platform comprises three integrated components,

The **GIS-based management environment** (Component 1) provides interactive maps, diagnostic dashboards, scenario simulation, and cost–benefit-driven investment planning, enabling infrastructure managers to assess safety conditions and evaluate intervention strategies across the network.

The **data acquisition and processing layer** (Component 2) generates a detailed GIS-based road network model by capturing approximately 90 road infrastructure and operational variables (comprising more than 160 sub-variables) at 10-metre intervals along the road. These variables describe geometric design, the roadside environment, road signage, and traffic characteristics, including AADT and speed-related indicators such as posted speed limits and operating speed proxies. The layer combines video surveys with AI-based automated detection and classification of road assets, together with the reprocessing of multi-source cartographic layers, administrative datasets, and third-party data providers. This multi-source data fusion creates an unprecedented, continuously updatable Digital Twin of the Spanish conventional road network.

The **safety model** (Component 3) has, therefore, been conceived as a deductive–inductive framework specifically designed to overcome these data limitations.
The **deductive model** transforms the approximately 90 infrastructure variables (comprising more than 160 sub-variables) into a five-level inherent safety rating for each user group. This is achieved through a hierarchy of thematic categories whose weights are derived from the road safety literature and refined through expert knowledge. The model builds upon the adaptation of existing deductive methodologies to analyse the influence of infrastructure and operational variables, and their interactions, on the inherent safety of different road types and user groups. As a result, infrastructure risk can be quantified without requiring crash data for calibration.
The **inductive model (Machine learning model)** subsequently incorporates historical crash information while explicitly addressing the challenges posed by scarce and highly imbalanced datasets. Its AI workflow is structured around three complementary modelling strategies:

1. **Dimensionality reduction.** Instead of learning from all infrastructure variables, the model uses deductive safety-category scores plus selected operational variables, reducing dimensionality while preserving the information most relevant to crashes.
2. **Road segmentation.** Rather than using fixed-length segments with few crashes and zero-inflated targets, the network is divided into **homogeneous sections** reflecting infrastructure and operational changes, improving statistical relevance while preserving consistency.
3. **Transfer learning.** To address the imbalance between total and severe crashes, a neural network is first trained on the larger total-crash dataset and then fine-tuned for serious-injury and fatality models, enabling learning despite scarce positive observations.

Results

A functional prototype of the platform has been implemented using pilot data covering approximately 100 km of conventional roads, including six road sections selected to represent the diversity of infrastructure typologies and conditions across the Spanish conventional road network. The prototype integrates the GIS-based Safety Assessment module with the deductive safety model, generating five-level safety maps together with detailed diagnostics at both variable and thematic-category levels.
The complete AI framework has been designed and implemented at the architectural level. The kilometres captured to date do not yet represent a sufficient sample to yield robust results or firm conclusions. Infrastructure data acquisition is progressively extending beyond the pilot sections to cover the full network, and as this coverage grows, the inductive model will be trained and validated, enabling a comprehensive assessment of its predictive performance and its contribution to network-level road safety management.

Discussion and conclusions

The principal contribution of this work is not yet the predictive performance of a trained AI model, but the methodological framework that makes such a model feasible under severe data constraints. The proposed architecture addresses three main challenges faced by AI-based network-level road safety assessment: high-dimensional infrastructure data, sparse crash observations, and strong class imbalance. By combining expert-informed deductive modelling with homogeneous road segmentation and transfer learning, the framework establishes a robust and scalable basis for machine learning as network coverage progressively increases and additional crash observations become available.

International Co-operation on Theories and
Concepts in Traffic Safety

Pedestrian behavior at the crosswalk and their interaction with an automated vehicle: a full-scale experiment

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Introduction

Automated Vehicles (AVs) are a type of transportation that is gradually becoming more widespread in the mobility landscape. Vehicle automation is a process that develops in successive stages; in particular, the different levels of automation available are defined by SAE J3016, ranging from Level 0 (no automation) to Level 5 (full driving automation). The target of this study are vehicles at Level 3 and above, i.e., those equipped with "automated driving" that the vehicle can operate autonomously without human intervention.
The absence of a driver represents an aspect that requires careful attention when the vehicle interacts with a road user who is unable to communicate with it. In particular, the most critical interaction is with vulnerable road users such as pedestrians. Currently, pedestrians base their decision to cross the road primarily on the interaction they can establish with the driver inside the vehicle and on the qualitative evaluation of vehicle's dynamic parameters, such as distance and speed.
The present research, currently in progress and therefore not yet yielding results, aims to examine through field tests how the absence of a driver influences the parameters pedestrians take into account when deciding to cross the road. The purpose is to determine the optimal configuration of both the infrastructure and the vehicle to safely accommodate the next generation of automated vehicles, in terms of safe pedestrian-vehicle interaction, pedestrian behavior prediction capability and human-machine interface design.

Research Methodology

The research is based on both full-scale tests and simulation models with the main goal of analyzing the behavior of a pedestrian who must cross a one-way road with a single lane in front of a driverless automated vehicle. The crossing simulation is carried out using a section of road closed to traffic, protected on one side by New Jersey safety barriers and equipped with a pavement on the opposite side.
The vehicle is a golf car appropriately modified through the installation of systems that allow it to move without a driver on board. It can be controlled remotely via radio control, or it can follow a pre-set trajectory and speed profile. These characteristics do not make the vehicle actually automated according to SAE J3016 definitions, but they are useful for simulating its behavior in the absence of a vehicle with such capabilities. The methodology used is known as the "Wizard of Oz method", in which the automatic functionality of a device is simulated through human intervention to test the user's behavior interacting with it.
Specifically, the experiment requires the pedestrian to face three simulated crossing scenarios in front of the vehicle, which moves at a constant speed of 25 km/h (its maximum approved speed). At the start of each test, the pedestrian stands at a predetermined position with their

back to the vehicle, then is signaled to turn around and advance towards the road. The vehicle performs different braking maneuvers for each scenario: an emergency stop at maximum deceleration; a braking with three progressively increasing deceleration steps; an anticipatory braking with linearly increasing deceleration (constant jerk). For safety reasons and to protect the well-being of the volunteers participating in the experiment, they never actually cross the road in front of the vehicle. To record user behavior, each volunteer is equipped with an eye tracker, while cameras installed on the vehicle capture the area in front of it. Additional fixed cameras are installed around the test site to record all types of information useful to describe the phenomenon.
After completing the three scenarios, participants administered questionnaires assessing their perceived safety level, their pedestrian crossing habits, and their level of trust in interaction with automated vehicles. The responses to these questionnaires are essential for understanding how to adapt the infrastructure and the vehicle to users' needs.
The experiment is followed by the analysis of footage recorded by the cameras and eye trackers. The cameras are used to understand users' behavior as they prepare to cross the road, identifying characteristic features such as head and shoulder rotation and joint angles of the lower body. These measurements can be performed using algorithms appropriately trained on dedicated databases, exploiting the potential of artificial intelligence and machine learning. Similarly, eye tracker's recordings can be analyzed using suitable algorithms to classify and identify the elements on which the pedestrian focuses their gaze in the absence of a driver, who is the figure typically observed during road crossings.

Discussion and Conclusions

The experimental design aims to determine the behavior of users who must cross the road in front of a driverless vehicle. From the on-board camera recordings, it is expected to obtain distinct behavioral profiles for the three test scenarios, which will be useful for training systems capable of recognizing the intentions of vulnerable road users, to adapt the behavior of the automated vehicle accordingly. The use of the eye tracker will provide details on the elements observed by pedestrians, to determine the most effective method of communication between pedestrians and vehicles, and how a user-friendly external Human-Machine Interface can be implemented. The large amount of data obtained using this methodology provides the opportunity to introduce artificial intelligence and machine learning in road safety analysis, exploring their potential and limitations. The results obtained from this research can be used in future developments to determine how to design infrastructures with layouts that are functional for pedestrians, that is, to define guidelines for pedestrian crossings' configurations in which the interaction between vulnerable road users and automated vehicles is safe.

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International Co-operation on Theories and
Concepts in Traffic Safety

Can Able-Bodied Participants Serve as Proxies for Mobility Aid Users in Laboratory Studies of Inclined Walkways?

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Introduction

Laboratory studies on accessible infrastructure provide controlled conditions to examine how design parameters such as gradient and walkway length affect usability for people with limited mobility. However, recruiting mobility aid users for experimental studies is often challenging due to population heterogeneity, limited availability, and ethical constraints associated with physically demanding tasks, leading many studies to rely on able-bodied participants as a practical alternative (Kim et al., 2014). While this approach offers logistical advantages, it raises a critical methodological question: to what extent can able-bodied participants meaningfully represent the experiences of mobility aid users? The experience of navigating inclined walkways is shaped not only by the device but also by underlying physical conditions such as impaired balance, muscle weakness, chronic pain, and reduced endurance, that influence both strain and perceived risk in ways that healthy individuals cannot replicate.

Aim

This study examines whether able-bodied participants using mobility aids exhibit similar behavioral and perceptual responses to inclined walkways as mobility aid users and assesses the extent to which they can serve as a valid proxy in controlled laboratory settings.

Method

A laboratory experiment was conducted using a modular ramp system with six longitudinal gradients (5%, 6%, 7%, 8.3%, 9%, and 10%). Able-bodied participants (n = 16; 6 women, 10 men; aged 26-56) completed ascents and descents using a manual wheelchair and either forearm crutches or a wheeled walkers and were compared with mobility aid users (n = 81; 89 observation series) completing the same tasks with their own devices. Behavioral measures included travel time, rest breaks, and observable difficulties. After each run, participants rated perceived exertion, anxiety, and physical discomfort using the Borg CR-10 scale, as well as perceived difficulty and acceptability (Lenker et al., 2016).

Results

Both groups showed increasing exertion, anxiety, physical discomfort, and perceived difficulty, as well as declining acceptance, with increasing gradient. While able-bodied participants captured this overall directional pattern, they consistently reported substantially lower levels of strain and less variability across all subjective measures. For the manual wheelchair, both groups exhibited similar patterns, with ascent more demanding than descent; however, able-bodied participants reported markedly lower exertion and discomfort. At steeper gradients,

mobility aid users reported exertion between “moderate” and “a lot”, whereas able-bodied participants remained in the "little to moderate" range even at 10%. Larger discrepancies emerged for forearm crutches and the wheeled walker. Able-bodied participants reported low and stable strain across gradients when using crutches, while actual users showed substantially higher and more variable responses, particularly at steeper gradients where balance problems were frequently observed. For the wheeled walker, able-bodied participants reported almost no exertion, anxiety, or discomfort across all conditions, while wheeled walker users with mobility impairments experienced some of the most critical conditions in the study, with descent posing the greatest challenge and anxiety and discomfort increasing notably above 6%. Pain, exhaustion, and difficulty ratings followed the same pattern: rarely reported by able-bodied participants but present across device types from 5-6% onwards in actual users, with the wheeled walker among the most challenging situations observed despite able-bodied participants reporting no difficulty with it.

Discussion and Conclusion

The results show that while able-bodied participants capture the general directional trend of increasing difficulty with gradient, they systematically underestimate the magnitude of physical and psychological strain experienced by actual mobility aid users, particularly for the wheeled walker and forearm crutches, where the underlying reasons for device use (balance impairment, weakness, pain) fundamentally shape the experience of inclined walkways in ways that healthy participants cannot replicate. Beyond differences in magnitude, able-bodied participants also failed to report entire dimensions of difficulty that were prominent among actual users, most notably balance problems and loss of control, concerns that arise from the specific physical vulnerabilities that necessitate mobility aid use in the first place, and that would be invisible to any study design relying on simulated impairment. The finding that able-bodied participants reported almost no difficulty with the wheeled walker, despite it being one of the most challenging devices for actual users, illustrates this limit most starkly. These findings suggest that able-bodied simulation may be useful for pilot testing or exploratory work but cannot substitute empirical data from mobility aid users when evaluating the usability and safety of inclined walkways, and support the continued inclusion of mobility aid users in experimental accessibility research.

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References

Kim, C. S., Lee, D., Kwon, S., & Chung, M. K. (2014). Effects of ramp slope, ramp height and users’ pushing force on performance, muscular activity and subjective ratings during wheelchair driving on a ramp. International Journal of Industrial Ergonomics, 44(5), 636–646. https://doi.org/10.1016/j.ergon.2014.07.001

Lenker, J. A., Damle, U., D’Souza, C., Paquet, V., Mashtare, T., & Steinfeld, E. (2016). Usability evaluation of access ramps in transit buses: Preliminary findings. Journal of Public Transportation, 19(2), 109–127. https://doi.org/10.5038/2375-0901.19.2.7

International Co-operation on Theories and Concepts in Traffic Safety

How Accessible Are Inclined Walkways? Evidence from Mobility Aid Users' Experiences and Field Observations

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Introduction

Inclined walkways are a common feature of the built environment and are often unavoidable in urban settings. For mobility aid users, however, they can present substantial challenges to safe and independent movement, affecting everyday mobility and participation. These challenges are not determined by gradient alone, but arise from the interaction of slope, surface conditions, cross-slope, and available support infrastructure. In practice, such conditions can lead to increased physical effort, reduced stability, and difficulties in maintaining control, particularly during descent. They may also influence route choice and result in the avoidance of certain walkways altogether. Despite their relevance, empirical evidence on how inclined walkways are experienced and navigated in real-world settings remains limited, with existing knowledge largely derived from controlled studies or normative guidelines.

Aim

This study aims to examine how mobility aid users experience and navigate inclined walkways in naturalistic urban settings, and how gradient and walkway length relate to usability, safety, and perceived accessibility.

Method

Two complementary approaches were used. First, online focus groups were conducted with ten mobility aid users (six women, four men; aged 30-70s) using a range of mobility aids, including manual and powered wheelchairs, wheeled walkers, walking sticks, and forearm crutches. Participants reflected on their experiences navigating inclined walkways and identified conditions they found most challenging or limiting.

Second, field observations were conducted on 25 inclined public walkways in Munich covering gradients from 1.3% to 10.4% and lengths from 6 m to 170.4 m, selected through spatial analysis combining street network data with terrain elevation models and pedestrian traffic estimates. Over 66.5 hours between January and May 2025, 384 mobility aid users were observed (155 men, 229 women; 210 ascents, 174 descents) across device types including wheeled walkers, walking sticks, forearm crutches, manual wheelchairs, and motorized devices. For each traversal, rest breaks, visible signs of physical exhaustion, observable difficulties (e.g., loss of balance or uncontrolled movement), and travel time were recorded. Rest breaks, exhaustion, observable difficulties, and travel time were recorded for each traversal. Twenty individuals were additionally interviewed using standardized scales for perceived difficulty, acceptability, exertion, anxiety, and discomfort (Borg CR-10) (Lenker et al., 2016), as well as

self-reported physical, psychological, and environmental challenges. A further 468 able-bodied pedestrians were observed as a reference group.

Results

Focus group participants confirmed that gradient and path length affect navigability but emphasized that these factors rarely operate in isolation. Cross-slopes required simultaneous forward and lateral effort, sometimes forcing detours; hazardous surfaces increased fall risk; handrails were widely desired for both ascent and descent; and unpredictability of unfamiliar routes contributed to avoidance behavior.

Field observations confirmed increasing difficulty with steeper gradients, particularly for non-motorized aid users. Of 384 traversals, 35 individuals took at least one break (44 total), with frequency and duration increasing above 6% and among older users. Visible exhaustion (22 cases) and acute difficulties such as balance problems and uncontrolled movement (7 cases) were recorded, though exhaustion is likely underestimated. Non-motorized aid users were consistently slower than even the oldest able-bodied pedestrians, with the gap widening at steeper gradients, and descent posed distinct challenges particularly for wheeled walkers and walking stick users. Post-traversal interviews revealed a mismatch between rated and observed difficulty, with eight of 20 interviewees reporting avoidance of paths they had just used. A self-selection effect at steeper sites suggests more affected individuals may already be absent from observation.

Discussion and Conclusion

The findings show that the usability of inclined walkways cannot be understood from gradient and length alone, as users' experiences are shaped by a combination of geometric and environmental factors. Surface quality, cross-slope, and handrail availability influence navigability in ways that gradient alone does not capture and should be considered alongside steepness in any evaluation of accessibility. Field observations indicate that difficulty increases progressively with gradient, with a noticeable change around 6%, particularly for users of non-motorized aids. At the same time, descent presents distinct safety challenges, especially for wheeled walkers and walking stick users. The reduced presence of mobility aid users at steeper sites further suggests a self-selection effect, indicating that those most affected may avoid such walkways altogether. Overall, the findings support a more comprehensive and user-centered approach to accessibility assessment that reflects the diversity of mobility aid users and the combined influence of geometric and environmental conditions.

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References

Lenker, J. A., Damle, U., D'Souza, C., Paquet, V., Mashtare, T., & Steinfeld, E. (2016). Usability evaluation of access ramps in transit buses: Preliminary findings. Journal of Public Transportation, 19(2), 109–127. https://doi.org/10.5038/2375-0901.19.2.7

International Co-operation on Theories and Concepts in Traffic Safety

How Steep Is Too Steep? Experimental Evidence on the Usability of Inclined Walkways for Mobility Aid Users

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Introduction

Public walkways with longitudinal gradients pose challenges for people with limited mobility, yet the standards governing their design vary considerably across countries. In Germany, DIN 18040-3, the central standard for accessible public circulation areas, discourages gradients above 6% and limits walkways between 3% and 6% to a maximum of 10 m between intermediate landings (Deutsches Institut für Normung, 2014). International frameworks permit gradients of up to 8.3%, with maximum lengths adjusted to the gradient. As European standards move toward harmonization, whether international specifications can be incorporated into German regulations without compromising usability and safety for mobility aid users remains an open empirical question.

Aim

This study aims to systematically examine how longitudinal gradients affect the ability of mobility aid users to traverse inclined walkways, and how increasing gradient influences perceived exertion, anxiety, physical discomfort, difficulty, and acceptance.

Method

Controlled experiments were conducted using a modular ramp system to simulate inclined walkways across six gradient conditions (5%, 6%, 7%, 8.3%, 9%, and 10%), with the highest gradients included to test the upper boundary of manageability. To control for fatigue effects, gradient order was counterbalanced across groups, and two independent ramps were used alternately. A total of 81 participants (41 women, 40 men; aged 27-97) using manual and powered wheelchairs, wheeled walkers, walking sticks, forearm crutches, and electric mobility scooters completed ascents and descents under all conditions; six participants used two different mobility aids, yielding 89 observations. Behavioral measures included traversal duration, rest breaks, and observable difficulties. After each run, participants rated perceived exertion, anxiety, and physical discomfort (Borg CR-10), as well as perceived difficulty and acceptability (Lenker et al., 2016), followed by a structured survey and group discussion.

Results

Most participants successfully completed the full ramp lengths at all gradient conditions without interruption: 98.3% at gradients up to 6% and 99.1% at gradients up to 8.3%. At 8.3%, 95.3% managed the full ramp on ascent and 97.6% on descent without stopping. The most vulnerable groups were manual wheelchair users on ascent, for whom the need for rest increased above

6%, and wheeled walker users on descent. Perceived exertion, anxiety, physical discomfort, and difficulty increased with gradient, while acceptance declined. A marked shift occurred between 6% and 7%, with the proportion reporting at least moderate exertion rising from approximately 37% to 52%, accompanied by pronounced increases in perceived difficulty and anxiety. The proportion rating walkways as at least somewhat unacceptable rose from around 10% at gradients up to 6% to 22% at 8.3% and 25% at 9-10%, while avoidance intentions rose from under 5% to approximately 15% at 10%. At gradients of 9% and above, over 40% of wheeled walker users reported at least moderate anxiety on both ascent and descent.

Mixed linear models were fitted to traversal speeds identified as the strongest predictor of speed reduction ($\beta = -0.041$ m/s per percentage point), with device type moderating this effect. Manual wheelchair users showed the steepest speed decline with increasing gradient, while walking stick and wheeled walker users showed considerably smaller effects, and powered device users were largely unaffected. A multilevel confirmatory factor analysis (MCFA) of the subjective measures identified two distinct latent dimensions, physical strain and psychological strain, both increasing with gradient and varying by device type. The sharpest increase in both dimensions occurred between 6% and 7%. Wheeled walker users showed the highest baseline psychological strain, while manual wheelchair users exhibited the strongest gradient-related increase in physical strain. Evidence of fatigue accumulation suggests that strain may be underestimated under real-world conditions.

Discussion and Conclusion

Most mobility aid users can traverse inclined walkways across the tested gradient range; however, physical and psychological strain, perceived difficulty, and walkway avoidance increase substantially with gradient. A marked deterioration occurs between 6% and 7%, while the greatest strain is observed at gradients of 9% and above, particularly for wheeled walker users. Longer and flatter walkways were generally perceived as more acceptable than shorter and steeper alternatives, especially among manual wheelchair users, whereas wheeled walker users identified steep descents as the primary challenge. These findings provide an empirical basis for evaluating permissible gradients in accessibility standards. The study further highlights the value of combining behavioral indicators, repeated subjective ratings, and multilevel modeling, representing one of the most comprehensive experimental investigations of gradient usability across multiple mobility aid types to date.

Acknowledgements

This report is based on parts of the research project carried out at the request of and with funding of the Federal Ministry for Digital and Transport, represented by the Federal Highway Research Institute, under research project No. FE77.0607/2022. The authors are solely responsible for the content.

References

Deutsches Institut für Normung. (2014). DIN 18040-3. Barrierefreies Bauen - Planungsgrundlagen - Teil 3: Öffentlicher Verkehrs- und Freiraum, Ausgabe 2014.

Lenker, J. A., Damle, U., D'Souza, C., Paquet, V., Mashtare, T., & Steinfeld, E. (2016). Usability evaluation of access ramps in transit buses: Preliminary findings. Journal of Public Transportation, 19(2), 109–127. https://doi.org/10.5038/2375-0901.19.2.7

International Co-operation on Theories and Concepts in Traffic Safety

Behavioural Effects of a Bicycle-Mounted Collision Warning Device at a Simulated Intersection with Limited Sight Distance

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Keywords: *Smart warning; bicycle simulator; cyclists' safety; gaze behaviour; kinematic behavior; critical event*

Introduction

Cyclists face critical safety challenges when interacting with vehicles in urban environments, particularly at intersections. Non-signalized intersections can be hazardous due to visibility issues and limited sight distance. C-ITS technology and bicycle-mounted collision warning devices can enhance rider situational awareness by detecting approaching vehicles and providing timely alerts. These systems have the potential to mitigate vehicle–bicycle conflicts by reducing surprise encounters and supporting earlier evasive responses. Although the number of these technological solutions is increasing, the evaluations of bicycle-mounted collision warning devices are still limited.

Therefore, the aim of this study is to investigate the impact of a bicycle-mounted audiovisual warning device on cyclists' behaviour and safety at non-signalised intersections with limited visibility.

Research methodology

A controlled virtual experiment was implemented using a multi-sensor bicycle simulator. The intersection object of the study is a T-intersection located on Santa Sofia Street within the Cittadella University Campus in Catania. In the simulation, subjects cycled along the major approach, while sight distance toward the right minor leg was restricted by a wall. A vehicle approached from the minor leg and executed a left-turn manoeuvre across the intersection.

Cyclists experienced five scenarios: intersection with no vehicle, critical and non-critical intersection scenarios with and without the warning device (Table 1).

Table 1. Scenario Configurations and Descriptions

Scenario #	Scenario groups	Scenarios	Description
1	No WS	Baseline	No vehicle
2 Critical for collision	No WS	D = 10 m	Based on the bicycle's distance (D), the vehicle's movement is triggered.
3 Available stopping distance	No WS	D = 15 m	
4 Critical for collision, but with warning	With WS	D = 10 m	Based on the bicycle's distance (D), the vehicle's movement is triggered. An audiovisual warning is provided.
5 Not Critical for collision, warning	With WS	D = 15 m	

The experiment was conducted in Italy and Hungary to enable cross-country comparison. 12 participants (7 males, mean age = 23.1 ± 1.8 years; 5 females, mean age = 25.2 ± 6.7 years) were recruited at the University of Catania, and 19 participants (18 males, mean age = 21.4 ± 2.3 years; 1 female, 24 years) participated at the University of Győr.

Across five scenarios, cyclists' kinematic responses, including braking duration, mean and peak deceleration, approaching speed, reaction time to the vehicle and/or warning, and maximum and minimum speeds, visual behavior (First Visual Orientation Latency, FVOL), and post-encroachment time (PET) were analyzed, and usability was assessed using the System Usability Scale (SUS).

Preliminary results

Catania scenarios were characterised by higher approach speeds and shorter PET values compared to those in Győr. In both countries, warnings were associated with earlier braking onset. While braking frequency increased under warning conditions in Győr, it remained consistently high in Catania irrespective of warning presence. An ART ANOVA revealed a pronounced country effect on PET, with a large effect size indicating substantial differences between Catania and Győr ($F = 45.24$, $p < 0.001$, $\eta^2p = 0.342$). A significant effect of the warning system was also observed, corresponding to a moderate-to-large effect size ($F = 16.54$, $p < 0.001$, $\eta^2p = 0.169$), indicating increased PET when warnings were provided. The Country × Warning interaction was negligible and not significant ($F = 0.26$, $p = 0.61$, $\eta^2p = 0.003$), suggesting that the effect of the warning system was comparable across locations. Post-hoc analyses supported this pattern, showing significant increases in PET under warning conditions in both Catania ($p = 0.002$) and Győr ($p = 0.009$).

In the Hungarian group, warnings were associated with longer FVOL in both critical and non-critical scenarios, indicating delayed visual orientation following warning onset. In contrast, Italian participants showed markedly earlier visual orientation under warning conditions in critical scenarios, while in non-critical scenarios warnings were associated with slightly longer FVOL. Across all conditions, correlations between FVOL and other gaze metrics were weak ($|r| \leq 0.27$), indicating that variation in gaze latency was not driven by low-level eye-movement characteristics but reflected differences in visual conflict-resolution strategies.

The warning system achieved a mean SUS score of 84.0 (SD = 11.4; range = 57.5–100). According to established SUS benchmarks, this score corresponds to excellent perceived usability, indicating that participants generally found the system easy to use and well-integrated.

Conclusion

This study demonstrates that a bicycle-mounted audiovisual warning device can positively influence cyclist–vehicle interactions at non-signalized intersections by modulating visual and kinematic behavior, rather than simply accelerating responses. The warning was associated with earlier braking and increased PET, indicating improved safety margins, while gaze behavior revealed scenario-dependent visual strategies rather than uniform reductions in visual latency. High SUS scores further suggest that the warning system is not only behaviorally effective but also perceived as usable and acceptable by cyclists, supporting its potential for real-world application.

International Co-operation on Theories and
Concepts in Traffic Safety

Trust and perceived safety in shared automated vehicles: User experiences from a public transport pilot in Oslo

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Introduction

Vehicle automation is increasingly entering road transport through pilot services that combine automated driving with shared and on-demand mobility. Shared automated vehicles (SAVs) may contribute to more flexible, efficient and accessible transport systems, but deployment depends not only on technical capability. While road safety is often assessed through crashes, injuries and system performance, passengers also experience safety psychologically, through trust, perceived control, predictability, and the extent to which automated systems feel understandable and reliable in use. Public acceptance is therefore central, particularly when automated services are introduced into ordinary traffic and existing public transport networks.

Despite growing research on SAV acceptance, relatively little is known about how passengers experience such vehicles as part of public transport. This is partly because few services have moved beyond hypothetical scenarios, low-speed shuttle pilots, or controlled demonstrations. The present study examines early users of an on-demand SAV service integrated into Oslo's public transport network. The service operated in ordinary mixed traffic, at speeds up to 60 km/h, between designated pick-up and drop-off points. During the study period, the vehicles operated at SAE Level 2, with a professional safety driver present and responsible for supervision and intervention. The overall research question is: How do test users experience and evaluate a SAV service operating in real traffic? The aim is to provide insight into how passengers interpret SAVs as both a transport technology and an everyday public transport service, with attention to trust, perceived safety, utility, and social comfort.

Research methodology

We performed in-depth semi-structured interviews with 12 SAV test users. Participants ranged in age from 22 to 75, included seven men and five women, and represented diverse mobility backgrounds and levels of technology familiarity. Interviews were conducted digitally and covered ride experience, trust in the automated system, utility perceptions, and social dynamics of sharing.

The transcripts from the interviews were analysed in NVivo 14 using reflexive thematic analysis informed by a hybrid approach: inductively derived codes from participants' own language were interpreted and grouped into themes using the SAVA framework (Shared Automated Vehicle Acceptance), which structures acceptance around trust, utility, and social comfort, and Social Practice Theory (SPT).

Results
Four overarching themes emerged: everyday mobility contexts, utility, trust, and social comfort.

Everyday mobility contexts shaped how participants interpreted the SAV by anchoring it in existing travel routines, expectations, and practical constraints. Experiences were evaluated in relation to familiar modes and local knowledge, with the service being more positively received when it aligned with established patterns of movement and less so when it disrupted them.

Utility captured how participants assessed the service's practical value in everyday travel. Evaluations depended on travel flow, routing, waiting times, and integration with existing transport options. Variability in these factors, such as unpredictable wait times or routes that conflicted with participants' mental maps, introduced uncertainty and reduced confidence in the service.

Trust reflected how participants made sense of the automated driving system and its safety. Safety was constructed through multiple interacting elements, including the presence of the safety driver, the visibility and interpretability of system behaviour, and trust in the service provider and regulatory context. The findings suggest that trust is developed dynamically during the ride, with specific events and explanations shaping how the system was understood and evaluated.

Social comfort addressed the experience of sharing space with others and the expectations associated with it. Although most participants had limited direct experience with co-riding, they expressed clear concerns about proximity, vulnerability, and uncertainty regarding social norms. These concerns were often framed in terms of personal safety, indicating that perceptions of safety extended beyond the vehicle and its driving performance to include the social environment of the service.

Discussion and conclusions
The findings suggest that passengers' evaluations of the SAV were shaped by the alignment between automated driving, service design and everyday mobility practices. Trust and perceived safety were not formed solely through impressions of the vehicle's driving performance, but through the broader service encounter: visible supervision, understandable system behaviour, predictable routing, reliable access points and recognizable public transport responsibility. In this context, perceived safety becomes part of how passengers judge the service as safe and trustworthy in ordinary traffic, rather than a separate assessment of automation.

This has implications for the gradual introduction of automated vehicles in public transport. As services move beyond demonstration pilots, perceived safety, and appropriate trust will depend on making SAVs practically useful and socially intelligible in ordinary traffic. Clear information about route logic, pick-up and drop-off points, sharing conditions, and available customer support may help passengers understand when and how to rely on the service. The study therefore points to future road safety as not only a matter of vehicle automation, but also of service implementation, communication, and integration into everyday transport systems.

International Co-operation on Theories and
Concepts in Traffic Safety

Gender differences in speed behaviour on horizontal curves in micromobility infrastructure

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Introduction

Micromobility is increasingly recognized as a consolidated mode of transport in urban areas. Despite the growing number of micromobility users, gender disparities persist in the use of these transport modes, with women being less likely to use bicycles and scooters. Previous research has also identified differences in travel behaviour between men and women, particularly in terms of perceived risk, infrastructure preferences, and operational behaviour.

In this context, the geometric design of cycling infrastructure plays a key role in ensuring user safety and comfort. However, research on its influence on micromobility behaviour remains limited, particularly from a gender perspective. Incorporating this perspective in the design process from the outset may improve perceived safety and, consequently, increase the use of micromobility among underrepresented groups. Therefore, this study aims to analyse the influence of geometric design on users' operational behaviour, with a particular focus on gender differences in speed as an indicator of riding behaviour.

Research Methodology

A test track was built to study the influence of geometric design on micromobility users' behaviour. The closed circuit simulates a two-way bike lane 200 m long and 2.20 m wide, marked solely by road markings. It consists of eight simple curves between tangents, all of them with a radius of 5 m and deflection angles of 30°, 45°, 60°, 75°, 90°, and 105°.

For data collection, volunteers were recruited to represent micromobility users of different ages, genders, and levels of experience. The sample included 27 bicycle users (10 women) and 24 e-scooter users (8 women). The trials consisted of riding along the test track under free-flow conditions, with no specific riding instructions, in order to capture natural behaviour. Data collection was performed using a video recording system. The video data were processed through an initial filtering stage to remove noise, followed by digital image processing techniques to extract instantaneous speeds at five points of interest: PC (Point of Curvature), MP (Midpoint), PT (Point of Tangency), and two intermediate points located between PC–MP and MP–PT. All recordings were conducted in accordance with regulations on anonymization and data protection.

From this, a global descriptive analysis was conducted to assess gender-based differences independently of the deflection angle and vehicle type.

Results

For the analysis, the speed at the point of curvature (PC) is selected, since here is where users define their approach strategy suggesting a convergence in speed at curve entry likely driven by geometric constraints. Despite this, mean speeds differ across all curves, with women consistently riding at lower speeds and men exhibiting higher variability, although these differences do not vary systematically with the deflection angle.

Analysing the influence of the deflection angle three distinct patterns are revealed. The largest differences occur in intermediate curves (45°, 60°, and 75°), where speeds differ by approximately 3 km/h, reaching up to 4.5 km/h at 45°, with higher variability in men (SD up to 4 km/h) compared to women (3.3 km/h), suggesting that less restrictive geometric conditions allow for more diverse riding strategies. In contrast, smooth curves (30°) show smaller differences, although higher speeds are observed for both groups due to lower geometric constraints. Finally, in the most demanding curves (90° and 105°), differences remain but are reduced—particularly at 90° (2.17 km/h)—along with lower variability for both groups, indicating that geometric constraints increasingly dominate over individual riding behaviour.

When analyzing mean speeds across all curve points by gender and vehicle type, results show consistent differences between groups. Women exhibit similar mean speeds for both bicycles (16.2 km/h) and e-scooters (16.3 km/h), with relatively moderate variability (SD = 2.6 and 3.0 km/h, respectively). In contrast, men present higher mean speeds in both cases, reaching 19.5 km/h for bicycles and 19.3 km/h for e-scooters, along with greater variability (SD = 3.8 and 3.6 km/h, respectively). These findings indicate that while vehicle type has limited influence on women's speeds, men tend to ride slightly faster on bicycles and show more dispersed behaviour as well.

Discussion and Conclusions

Notably, these findings highlight differences in user behaviour between genders, which should be considered in the geometric design process. Integrating this perspective can support the development of safer, more inclusive, and user-focused micromobility infrastructure. Mainly considerations are listed as follow:

- Women consistently exhibit lower speeds than men, although both genders follow similar patterns in response to changes in deflection angle.
- Speed variability differs by gender, with men exhibiting greater dispersion across deflection angles.
- Women show consistent speeds across vehicles, while men ride slightly faster on bicycles.

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International Co-operation on Theories and Concepts in Traffic Safety

Trajectory analysis of micromobility users in horizontal curves

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Introduction

Micromobility infrastructure must meet minimum geometric design requirements to ensure safe and comfortable operation. However, its adaptation to existing urban layout has resulted in a wide variety of geometric configurations, some of which leading safety issues. In this context, geometric features such as curve radius, deflection angle, and lane width play a critical role in influencing riders' speed, stability, and trajectory, which are key indicators of operational behaviour and infrastructure safety. Factors such as user anticipation and curve predictability further affect riding dynamics and the likelihood of falls or conflicts.

Despite their importance, quantitative evidence on micromobility user behaviour in curved sections remains limited, particularly regarding trajectory under different geometric configurations. This lack of data constrains the development of evidence-based design guidelines for safer micromobility infrastructure. In this context, the present study aims to characterize the operational behaviour of micromobility users based on their trajectories, with the objective of developing design recommendations to improve safety and comfort in micromobility infrastructure.

Research methodology

An experimental test track was built to evaluate different curve geometries. The closed circuit is 200 m long and comprise simple curves with similar radius of 5 m and deflection angles ranging from 30° to 105°. The cross-section consists of a 2.20 m bidirectional bicycle lane, defined by road markings. The trials consisted of riding along the test track under free-flow conditions for both turning directions (right and left), with 27 participants involved. No specific instructions were provided to ensure natural riding behaviour. Trajectories were recorded using overhead cameras positioned 6 m above each curve midpoint, providing a bird's-eye view of the user passing manoeuvre, and were subsequently processed through automated image analysis in compliance with data protection regulations.

User trajectories were mapped at five points of observation: PC (Point of Curvature), MP (Midpoint), PT (Point of Tangency), Intermediate Point 1 (midpoint between PC and MP) and Intermediate Point 2 (midpoint between MP and PT). Lateral position was defined with respect to the centreline, assigning positive values to positions within the lane corresponding to the direction of travel, while negative values indicate intrusion into the opposing traffic lane. The cross-

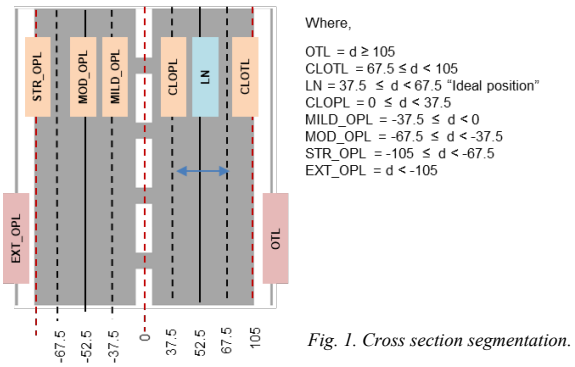


Fig. 1. Cross section segmentation.

section was segmented based on the ideal riding position (lane centre) and an operational width of 75 cm (see Fig. 1). Lateral positioning was then examined through spatial distribution patterns across the segmented cross-section.

Results

The analysis of lateral position distributions reveals a consistent behavioural pattern along the central portion of the curve (INT1–MP–INT2), where a clear differentiation between turning directions is observed. During right turns, users predominantly occupy CLOP and LN categories, indicating trajectories close to the centreline and, in some cases, encroaching into the opposing lane. In contrast, left turns are mainly associated with CLOP and OPL-related categories, reflecting a systematic shift towards the inner side of the curve.

The deflection angle primarily influences the dispersion and stability of lateral position distributions, while the direction of displacement remains governed by turning direction. Low angles (e.g., 30°) show dispersed and weakly structured patterns, indicating limited geometric constraint. As the angle increases to intermediate values (45°–75°), distributions become progressively more structured, with clearer separation between left and right turns—particularly in the central section of the curve (INT1, MP, INT2). This effect is most evident around 60°–75°, where trajectories appear more stable and consistent. At higher deflection angles (90°–105°), distributions become more pronounced, with users occupying more extreme lateral positions. Despite this intensification, the underlying behavioural pattern remains unchanged. However, variability increases again at the entry (PC) and exit (PT), reflecting the need for transitional adjustment before and after riding sharper curves.

Discussion and conclusions

Overall, the results highlight a consistent and structured lateral positioning behaviour that can be directly translated into geometric design recommendations for cycling infrastructure, particularly through targeted widening and improved edge configurations in curves, ultimately contributing to safer and more efficient cyclist movements. Notably, the findings show that:

- Turning direction governs lateral positioning, while deflection angle modulates distribution stability and intensity.
- Trajectories stabilize in the central portion of the curve (INT1–MP–INT2), with greater dispersion at entry (PC) and exit (PT).
- In the central portion, users' position is nearer the cross-sectional center (OPL) rather than within their lane (LN).

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International Co-operation on Theories and
Concepts in Traffic Safety

Perceived safety of edge elements in micromobility infrastructure

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Introduction

Micromobility users generally prefer riding on segregated bicycle lanes, physically protected from motorized traffic, in urban areas. However, the selection and design of edge elements are rarely justified in design guidelines, particularly regarding their specifications and configuration. In these documents, the choice of edge elements is often based on adjacent traffic conditions rather than on user perception of safety and comfort, although both aspects should be considered.

Edge elements should not only provide protection from motorized traffic, but also ensure that their geometry and materials do not increase injury risk in case of falls or collisions, while remaining sufficiently continuous to prevent vehicle intrusion. In addition to the type of element, its position within the cross-section and the spacing between elements are key design variables, as they affect the effective width of the lane. Despite this complexity, most existing studies focus primarily on external environmental factors, such as traffic conditions, when evaluating perceived safety, rather than isolating the effect of the edge element itself and the operational conditions within the lane.

For these reasons, this study aims to assess user preferences and perceived safety of different edge elements through controlled surveys and experimental trials, isolating the effect of the element geometry and configuration from external factors. To achieve this goal, a pre-post experiment was carried out, to obtain the perceived safety of three types of edge elements, before and after a ridding experience.

Research methodology

Data collection was conducted through experimental trials on a test track specifically designed to evaluate micromobility infrastructure conditions. The track, where a set of edge elements was installed, consisted of four simple curves with the following geometries: radii of 10 m (deflection angles of 90° and 30°) and 5 m (deflection angles of 60° and 75°), providing variability in operating conditions. The cross-section width was 2.20 m, defined solely by road markings.

Six scenarios were evaluated using three types of edge elements: (i) discontinuous mountable curbs, (ii) rubber curved lane separators, and (iii) delineator posts. Spacing was fixed at 1.5 m for horizontal elements (i and ii) and 3 m for vertical elements (iii). Two lateral separation distances from the bike lane were tested: 10 cm and 30 cm from the road marking, consistent with Spanish design recommendations for bike lanes on road with one adjacent motorized traffic lane and for two or more lanes, respectively. A total of 24 volunteers participated in the study, primarily using bicycles. Perceived safety was assessed through surveys conducted

before and after riding. The survey consisted of a 4-point Likert scale question assessing perceived safety for each edge element, ranging from 1 (very unsafe) to 4 (very safe). In addition, a ranking question was included to establish user preferences regarding the type of edge elements they would prefer to encounter in micromobility infrastructure.

Results

Prior to the trials, delineator posts received the highest perceived safety ratings (mean = 3.21), followed by discontinuous mountable curbs (2.63), and rubber curved lane separators (2.13). In terms of distribution, 83% of users rated rubber curved separators as "unsafe", indicating a strong initial perception of low safety. Discontinuous curbs showed a more balanced perception, with approximately 45% rating them as unsafe and 45% as safe. Delineator posts were clearly better perceived, with 62.5% rating them as safe and 29.2% as very safe.

After performing the trials, mean values showed a significant improvement for rubber curved separators (+0.46), while discontinuous curbs and delineator posts remained largely stable (+0.04). This result suggests that initial perceptions of certain edge elements may be influenced by unfamiliarity rather than their actual performance. In particular, rubber curved separators appear to be initially underestimated, as direct experience leads to a substantial positive shift in perceived safety.

This improvement is also reflected in the distribution of responses. After riding, rubber curved separators show a clear shift towards higher safety ratings, with 37.5% and 16.7% of users considering them "safe" and "very safe," respectively. Discontinuous curbs exhibit a moderate shift, remaining as an intermediate solution, while delineator posts consolidate their positive evaluation, with 50% of users rating them as very safe. Ranking results remain consistent in terms of element preference; however, across all elements, users clearly prefer configurations with greater lateral separation (30 cm).

Discussion and conclusions

Overall, these findings reinforce the need for a user-centered approach to micromobility infrastructure design, integrating both perceptual and objective criteria. For instance, the current results, can be consider as a first approaching:

- User perception of edge elements varies before and after riding experience, indicating a clear influence of familiarity on perceived safety.
- Vertical edge elements are consistently perceived as safer than horizontal elements.
- Across all element types, users show a clear preference for configurations with greater lateral separation.

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Cycling Safety in One-Way Streets: Insights from OSM and Crash Data

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Introduction

Legal contraflow cycling in one-way streets is a well-established way of promoting active travel, but its effect on road safety is still being discussed (Alrutz et al., 2001). While recent studies have successfully used machine learning and open datasets to predict accident hotspots and cyclist crash risks (e.g. Auzzas et al., 2025; Elsayed et al., 2026), the specific impact of regulatory signage has not been sufficiently researched. To this end, the study combines open-source geospatial OpenStreetMap (OSM) data with two different accident datasets. This study aims to assess cycling accidents as spatial patterns and in terms of compliance with traffic regulations. Subsequently, spatial 'pain points' are identified where legalised contraflow cycling requires measures beyond standard regulatory signage.

Research methodology

The methodology of this study is based on a comparative analysis of two primary data sources: the publicly accessible German Accident Atlas (2026) covering the years 2018-2024 and police reported data with cycling accidents for the State of Berlin in the years 2001-2024. To facilitate a robust spatial assessment, both datasets were integrated in the OSM road network to be capable of correlating them with specific infrastructural attributes. Within the OSM dataset, street segments were filtered to distinguish between one-way streets that are permitted for contraflow cycling and those where it remained prohibited. For the legal contraflow segments, further categorisations were made on the various traffic signs and combinations of signs present. Within the police accident dataset, the cyclists' direction of travel at the time of the collision was determined by employing vector geometry to align the recorded accident angle with the road’s azimuth. This calculation was essential for distinguishing between legal and illegal contraflow movements. For the spatial analysis, a 15m buffer was used to define intersection areas; accidents outside this radius were classified as 'open road'. Furthermore, to mitigate the 'historical blur' inherent in OSM signage data over a long period, the dataset was validated against the Berlin Open Data (2014), which contains digitised data such as street objects, traffic signs, and traffic areas derived from a mobile mapping survey. Finally, an ongoing evaluation of an exploratory machine learning approach aims to assess its potential in identifying recurring infrastructural 'pain points' where specific road designs correlate with increased safety risks for cyclists, with the final results yet to be determined.

Results

The evaluation of the German Accident Atlas identified 165 accidents with bicycle involvement on open road segments with legal contraflow and 4,016 accidents where it was prohibited. When filtering for specific sign combinations (e.g., 220 (one-way) + 1000-32 (contraflow cycling permitted)), the number of attributable accidents drops drastically to around 100,

reflecting the sparsity of detailed OSM signage tags. When normalized by time and distance, the accident rate in the German Accident Atlas for legal contraflow is approximately 0.23 accidents/km/year, compared to 0.25 accidents/km/year in restricted one-way streets. In comparison, the detailed Berlin police accident dataset recorded a significantly higher density: In legal contraflow segments, the rate is approximately 0.81 accidents/km/year (2,036 total incidents on the open road), while restricted segments show a rate of 0.94 accidents/km/year (35,566 total incidents). This normalization confirms that the police dataset captures nearly four times as many incidents per year as the Accident Atlas, highlighting a substantial 'dark figure' in open data sources. The police data reveals that in restricted one-way streets, illegal contraflow movements account for roughly 4% of accidents. On the 'open road', a high frequency of accidents involves crossing movements (house entrances or supermarket driveways). Furthermore, 'dooring' remains a dominant conflict pattern on the open road, with 1,385 recorded cases in legalized contraflow streets within the police dataset.

Discussion

In summary, while legalised contraflow cycling is statistically safer per kilometre and per year than restricted one-way streets, specific junctions and mid-block sections remain high-risk areas. The fact that the normalized accident rate is lower for legalized contraflow (0.81 vs. 0.94) supports the general safety of this regulation. The fact that sole regulatory signage cannot prevent collisions at these locations highlights the urgent need for measures such as physical infrastructure improvements, enhanced visibility at intersections, or advanced pavement markings. This opens up an intriguing avenue for future research, which is the use of cognitive methods such as eye tracking to explore whether motorists overlook specific signs due to sensory overload or distraction. In conclusion, contraflow cycling can pose safety risks if complex locations are managed solely with regulatory signage instead of physical interventions. However, the proposed methodology offers great potential to mitigate this: integrating these datasets with future AI-driven analysis will provide urban planners with a proactive tool to detect specific 'pain points' before accidents happen.

References

Alrutz, D., Angenendt, W., Draeger, W. and Gündel, D. (2001). Verkehrssicherheit in Einbahnstraßen mit gegengerichtetem Radverkehr. Wirtschaftsverl. NW.

Auzzas, A., Capra, G. F., & Ganga, A. (2025). Assessing the Impact of Infrastructure and Social Environment Predictors on Road Accidents in Switzerland Using Machine Learning Algorithms and Open Large-Scale Dataset. Urban Science, 9(9), 343. https://doi.org/10.3390/urbansci9090343

Berlin Open Data (2014). Senatsverwaltung für Stadtentwicklung und Umwelt Berlin. Straßenbefahrung 2014 (WMS) [Data set].
https://daten.berlin.de/datensaetze/strassenbefahrung-2014-wms-d4c0abae

Elsayed, A., Abdel-Rahim, A., & Prescott, L. (2026). From Prediction to Explanation: Explainable Machine Learning for Motor Vehicle–Involved Pedestrian and Cyclist Crash Risk. Infrastructures, 11(3), 77. https://doi.org/10.3390/infrastructures11030077

German Accident Atlas (2026). Statistisches Bundesamt (Destatis): German Accident Atlas, web map application [Online; accessed 16 April 2026]. https://unfallatlas.statistikportal.de/

OpenStreetMap contributors. (2026). OpenStreetMap data for Braunschweig, Germany [Online; accessed: 21 April 2026]

International Co-operation on Theories and Concepts in Traffic Safety

An evaluation study of the safety effects of an advanced training course for motorcycle riders

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Introduction: Motorcycle riders are a highly vulnerable group of road users. In Israel, the number of motorcyclists who died or were severely injured in road accidents has increased steadily over the past decade. Training drivers and riders to better anticipate forthcoming traffic hazards is mentioned in the literature as having the potential to reduce crash risk among trained drivers. Yet, only a few studies have tested the safety effects of such programs on rider safety, and their findings have shown mixed results. In 2022, the Israel National Road Safety Authority (NRSA), in collaboration with the Ministry of Transport and Road Safety, launched a pilot program focused on providing motorcyclists with strategic riding skills to enhance their capabilities to anticipate and avoid potential traffic hazards. These included cognitive skills to identify and analyze hazards as well as maneuvering and operational skills to support such processes and allowing their implementation. The program also includes interventions aimed at motivating riders to adopt proactive riding habits (such as planning ahead, taking responsibility for their ride, and adopting self-reflection to their toolbox), as such measures are associated in the literature with sustainable driver safety. The training combines both practical and theoretical learning components and includes sterile and on-road practices. The safety effects of this program were assessed in an evaluation study led by the NRSA Research Department.

Aim: The main objective of the present study was to examine the effects of the training on rider hazard perception capabilities, locus of control, risk perceptions and riding behaviors and habits.

Methodology: Data was collected through an online survey in three phases: before the training (T0), at the end of the training (T1) and three months afterward (T2). The survey was administered over 20 training cycles. The questionnaire consists of several subjects, including subjective hazard perception scale, the ability to anticipate and avoid potential hazards in hypothetical scenarios, self-assessment of proficiency in controlling and maneuvering a motorcycle, collision risk perception, a locus of control scale, and risky riding behaviors. The questionnaires at the 'before' and 'after' periods were similar, except for questions regarding the training that were included after its completion. Motorcyclists who filled out a registration form were randomly assigned to one of three study conditions: three learning sessions (Experimental 1), four learning sessions (Experimental 2), and control condition (riders who didn't receive the current training). The two experimental groups differed in that the second one also practiced riding on winding interurban roads. The program was open to voluntary participation by riders who had not received training in the 5 years prior to it. Overall, 326 participants completed at least T0 and T1 questionnaires (165 in experimental conditions and

161 in control). Mean changes in outcome measures were compared between study groups using two-way repeated measures ANOVA with *post hoc* tests.

Results: Results showed significant improvements in key outcomes among trained participants when compared to the control group: subjective hazard perception score ($p<0.01$), ability to anticipate and avoid potential hazards ($p<0.001$), self-assessment of controlling and maneuvering skills ($p<0.01$) and internal locus of control ($p<0.05$). These effects were maintained three months later and even strengthened across some of the measures. Whereas changes in the frequency of reported risky riding behaviors and self-estimation of one's likelihood of being involved in motorcycle collision, were not significant, despite being in the hypothesized direction. Additionally, it was found that approximately 90% of the trainees expressed highly positive attitudes towards the contribution of the course to motorcyclist safety.

Discussion and Conclusions: The study adds to the existing literature by demonstrating that a training course focused on developing hazard anticipation and avoidance abilities can have a positive contribution to the safety of motorcycle riders. The marked increase in internal locus of control after the course supports the idea that the training affects the mindset of the riders by encouraging them to adopt a proactive approach to riding. Importantly, the analysis of in-depth interviews conducted with a sample of training participants supports the possibility that the course did not lead to overconfidence among participants.

Keywords: advanced rider training; hazard perception; risky riding behaviours.

Note: A previous version of this abstract was accepted for presentation at the ICTCT 2023 conference. However, due to the circumstances in Israel at that time, the author was unable to attend and present the work.

International Co-operation on Theories and
Concepts in Traffic Safety

COVID-19 effects on road safety and driving behaviours

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Introduction

This study examines through a survey the impact of the COVID-19 pandemic on changes in risky driving behaviours and road safety in Québec across three key periods: Fall 2019 (before), Fall 2020 (during), and Fall 2023 (after restrictions were lifted). While previous studies have shed light on the pandemic's effects on road safety outcomes such as crashes, important gaps remain. Most published research focuses on the early months of the pandemic, providing only a short-term snapshot of changes in traffic volume, crashes, and risky driving behaviours.
The main research question guiding this study is: how did the COVID-19 pandemic influence driving behaviours, attitudes toward risky driving, and self-reported safety outcomes in Québec across these three periods, and to what extent did these changes persist in 2023, after most restrictions had been lifted? Three specific objectives guide the analyses: 1) to quantify changes in mobility and risky behaviours across Fall 2019, Fall 2020, and Fall 2023; 2) to identify distinct driver profiles and their evolution across these periods; and 3) to determine which socio-demographic and attitudinal factors predict risky profiles and near-misses/crashes.

Research methodology

This study employs an online survey, composed of self-reported information on demographics, travel frequencies and mobility patterns, risky driving behaviours along with attitudinal questions and respondent experiences of crashes/near-misses for the three periods. The target population consisted of Québec residents aged 22 and above (so that they were of legal driving age in 2019), including both drivers and non-drivers. After data cleaning, the analytical approach used descriptive analyses to document changes across periods, along with statistical analyses. Clustering analysis was then used to identify driving profiles, while multinomial logit (MNL) models and binary logistic regressions were used to examine near-miss/crash outcomes.

Results

Mobility and travel patterns shifted in 2020 and only partly returned to pre-COVID levels by 2023. There was a clear shift in ownership toward SUVs from 2019 to 2023, which is significant for road safety as larger vehicles increase injury severity. Risky driving behaviours decreased during the pandemic, then became more frequent again by 2023, particularly minor speeding (1-10 km/h above the limit) and technology-related distractions. Minor speeding is the most common risky behaviour. Its prevalence dipped slightly in 2020 and then rose in 2023 above 2019 levels. Texting while driving and looking at screens, talking hands-free on a phone while driving and driving while fatigued all increased in 2023 compared with 2019.

The number of self-reported near-misses and crashes decreased in 2020 then rose again by 2023, especially near-misses. The number of respondents involved in at least one crash fell by 25% in 2020 then increased by 5% in 2023 compared to 2019. The number of respondents with at least one near-miss decreased by 24% in 2020then increased by 35% in 2023 compared to 2019.

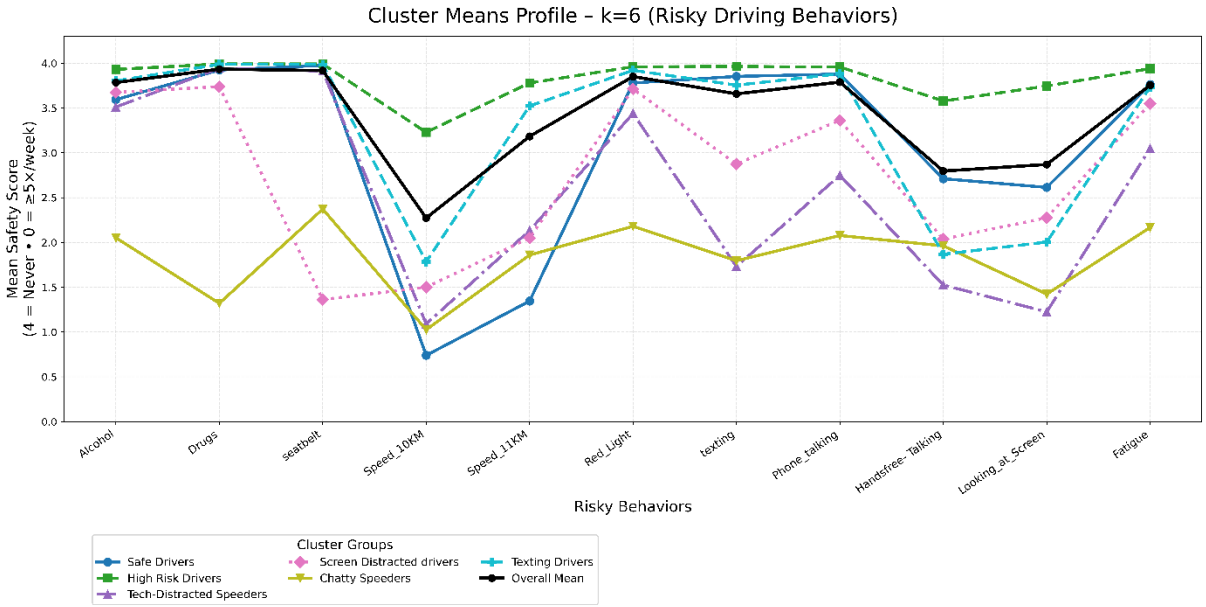


Figure 1. Mean scores for the eleven risky driving behaviors across the clusters. Higher values indicate lower frequency of risky behavior (safer behavior).

Six behaviour-based clusters were identified across all periods (*Figure 1*): Safe Drivers, High-Risk Drivers, Tech-Distracted Speeders, Screen-Distracted Drivers, Chatty Speeders, and Texting Drivers. Safe Drivers have the cleanest driving records and the lowest crash and near-miss frequencies in all three years. The MNL results show that all five unsafe clusters show higher near-miss odds than Safe Drivers in 2019, 2020 and 2023, and higher crash odds in most years. Gender is a consistent and strong differentiator: men are less likely to be Safe Drivers. Young adults are more likely to belong to High-Risk Drivers and Texting Drivers. Acceptability of risky driving behaviour is the strongest attitudinal and most consistent risky behaviour predictor. General risk-taking personality shows weaker and less consistent relationships than acceptability of risky driving.

Discussion and conclusions

A novel aspect of this study is the detailed profiling of distracted driving behaviours in combination with traditional risky behaviours. This combination can be deadly and law enforcement and education campaigns typically target these behaviours separately. Overall, the observed “safer 2020” and “riskier 2023” pattern is consistent with Canadian evidence that changes in exposure during the pandemic coincided with shifts in risky driving. However, our data are based on self-reported behaviours and attitudes which were collected through an online survey, and participants in 2023 were asked to recall their behaviours from 2019 and 2020, which may introduce recall errors.

International Co-operation on Theories and Concepts in Traffic Safety

The Effect of Alcohol Impairment on Visual Attention During Critical Events in Road Safety

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Introduction
Road safety is a critical public health issue, with human behavior accounting for over 90% of road accidents. Alcohol impairment is a significant risk factor, contributing to around 8.5% of crashes and nearly 10% of drivers resulting in positive testing roadside checks, even when not involved in an accident. This number could be underestimated due to limited test campaigns. Understanding the effects of low-to-moderate alcohol consumption on driving behavior is essential, especially as many jurisdictions permit alcohol levels up to 0.5 g/l. While the impact of alcohol on psychomotor and cognitive functions is well established, the specific influence of legally permissible alcohol levels on attention, perception, workload, and reaction times remain underexplored. This gap hinders the development of targeted interventions to mitigate alcohol-related risks. This study aims to fill this gap by using a high-fidelity driving simulator, complemented by physiological and behavioral tools like eye-tracking systems. The objective is to examine how alcohol consumption affects drivers' ability to perceive and respond to critical events, particularly pedestrian detection during unexpected crossing. While previous research has focused on reaction times and motor skills, less is known about alcohol's impact on visual attention. The study compares gaze patterns of drivers under the influence of alcohol and sober to understand how alcohol affects hazard perception, including the timing of detection, intensity and duration of gaze engagement, visual attention stability, and the likelihood of maintaining focus on the hazard. These insights could help in improving road safety measures and reducing road deaths.
Research methodology
Data from a total of 146 driving simulations were recorded, including both driving after alcohol consumption and without any alcohol assumption. Participants wore eye-tracking devices to monitor their gaze during the test, which involved an illegal pedestrian crossing at a traffic light. Eye-tracking data were continuously collected throughout the simulation to capture participants' gaze behavior, focusing on their interaction with the pedestrian. The data were analyzed to obtained information about:

- time-to-first-fixation (TFF): the time elapsed before the participant’s first fixation on the pedestrian, since he/she becomes visible in the field of view;
- fixations information: the number of times and the total time spent fixating on the pedestrian;
- gaze dispersion: the spread of gaze points across the visual scene, indicating how focused or scattered the attention was.

Pedestrian boxes were manually annotated to define Areas of Interest (AOIs) that tracked driver-pedestrian interaction. AI and machine learning were used to enhance data processing efficiency. AI algorithms automatically detected and extracted frames from the simulation

video, identifying key moments when the pedestrian appeared and when the driver's gaze was directed toward him/her. Supervised machine learning models classified gaze patterns based on features like TFF, fixation duration, and gaze dispersion, helping to identify differences in alcohol impairment versus sober behavior. An AI-driven model also predicted impairment status based on gaze characteristics, offering insights into how alcohol consumption affects driving performance. The analysis of the alcohol's impact on visual attention was evaluated by means of the following indices:

- TFF: the time to fixate the first time on the pedestrian, indicating the driver's response speed to the hazard;
- dwell time: the total time spent looking at the pedestrian, indicating sustained attention;
- gaze on pedestrian ratio: the proportion of time the driver's gaze was focused on the pedestrian;
- saccadic movements: the frequency and amplitude of eye movements, which indicate how effectively the driver scans the scene for relevant stimuli;
- gaze dispersion and entropy: the variability in gaze points, assessing stability and focus of attention.

By combining traditional eye-tracking metrics with AI and machine learning, this study provides a deeper understanding of how alcohol affects visual attention and driving behavior during critical events.

Results

In the impaired condition, participants showed a significant delay in detecting the pedestrian, with time to first fixation greater than 2 seconds. In contrast, sober participants exhibited faster detection times, with TFF averaging around 0.68 seconds, indicating quicker responses.

The delay recorded for impaired drivers was accompanied by low engagement, with an average dwell time of about 0.25 seconds and only one or two brief fixations on the pedestrian. The gaze-on-pedestrian ratio was low, ranging from 3.9% to 8.2%, suggesting that the attention was often diverted away from the hazard. High gaze dispersion and entropy values indicated a disorganized scanning strategy and reduced focus on the pedestrian. Few times, the gaze failed to engage with the pedestrian entirely, resulting in a zero gaze-on-pedestrian ratio and no meaningful fixation.

Sober drivers showed instead more consistent engagement, with higher dwell times (1.5s) and more fixations, reflecting sustained attention on the pedestrian. The gaze-on-pedestrian ratio was much higher (over 35%), indicating a stronger focus on the hazard. They also demonstrated low gaze dispersion and entropy, signifying a more structured and focused scanning pattern, in contrast to the impaired group's disorganized strategy.

Discussions and conclusion

The findings reveal that even low alcohol consumption significantly affects visual attention during critical driving events. Specifically, impaired drivers show delayed hazard detection, reduced attention to the pedestrian, and a less focused visual scanning strategy. These deficits can increase the risk of accidents, as delayed detection and poor engagement reduce the time available for corrective actions. In contrast, sober participants exhibited faster detection and more sustained engagement with the pedestrian, reflecting a more efficient visual attention allocation.

Further research is needed to estimate the precise reaction times, as well as to develop interventions aimed at improving visual scanning patterns in drivers with alcohol consumption within the legal limits.

International Co-operation on Theories and Concepts in Traffic Safety

Know What You Ask – Evaluating LLM-Assisted Decision Support for Road Safety Practitioners

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Introduction

The rapid integration of Large Language Models (LLMs) into professional workflows has raised questions regarding their applicability in practical work. In the domain of road safety engineering, where design decisions directly impact human lives, the accuracy and depth of technical guidance are key quality criteria when trying to find answers for such questions. For an overview, see [10]. This paper summarizes a conversational experiment designed to test an LLM's ability to assist a practitioner in evaluating the safety impact of coloured bicycle crossings at roundabouts. The dialog touched the tension between subjective safety (perceived comfort) and objective safety (accident rates), the overall quality and methodology of the studies (correlation vs. causality, statistical flaws, statistical significance, bias in data, regression to the mean - RTM), and exposure modelling (safety in numbers - SiN).

Research Methodology

The experiment was a dialog in English between a hypothetic practitioner and the LLM. It contained the following prompts:

#	Prompt	Expected Result
1	I have a question regarding road safety. I need to know if coloring the crossing lane of bicyclists at a roundabout would increase or decrease the traffic safety. I need to know the relevant studies and their outcome.	[1-8]
2	I have heard of a study by Bondzio that mentions the matter of coloured bicycle crossings.	[2, 3]
3	Which of all those Studies uses a correct model to consider the link between traffic flow and accident count?	[1, 4-8]
4	Are your findings justified by before/after investigations or by ensemble studies?	Ensemble: [1-4, 6, 8] Before/After: [5, 7]
5	A proper before/after study should model regression to the mean. Which of the studies you mentioned is a proper study in that sense?	[5, 7]
6	A proper ensemble study should differentiate correlation and causality, discuss statistical significance, account for bias in data and do correct	[1, 4, 6, 8]

	exposure modelling (SiN). Which of the ensemble studies you mentioned is a proper study in that sense?	

The evaluation criteria were:

a. Is the LLM able to identify the literature [1-8] that contains substantial findings on the matter?
b. Is the LLM able to identify statistical flaws (significance, bias in data, regression to the mean), differentiate study designs (before/after, ensemble)?
c. Is the LLM able to identify which studies do proper nonlinear modelling of the link between traffic flow and crash count?
d. Can the LLM point the interviewer to the tradeoff between objective versus subjective safety?
e. When reviewing the answers from the LLM: Is the difference between causality and correlation clear?
f. Beyond benchmarking the LLM against expected results: Does the LLM reveal valuable aspects of the matter, that the authors of this study did not expect?

Results

The "interview" evaluated in this study was carried out on Google search AI (Gemini 3.1 Pro [12]). However, similar findings were observed with Claude Sonnet 4.6 [13], GPT-5.2 [14] and Sonar [15]. The interaction yielded the following findings regarding the LLM's performance.

1. **Omission of core literature:**
    a) None of the literature [1-8] has been identified directly by the LLM after prompt 1.
    b) Instead, other literature that did not contain findings on the specific matter was found (e.g. [9]). However, prompt 2 revealed, that at least [3] was accessible for the LLM.
    c) More literature seems to have been accounted for in the answer for prompt 1 as the answers to the subsequent prompts suggest.
2. **Failure in exposure modeling and hallucination:** Prompt 3 revealed, that the LLM was aware of [4-7]. However, it wrongly hallucinated, that [3] modeled the link between exposure and accident rate correctly, while [4-7] did not. The opposite is true.
3. **Identification of methodology:** The response to prompt 4 correctly stated that [9] is a before-and-after study. This is not surprising, because its abstract emphasizes this fact. It also correctly identified that [3-5] are cross-sectional studies.
4. **Methodological rigor:**
    a) On prompt 5 the LLM erroneously hallucinated that [9] corrected for RTM.
    b) The LLM hallucinated on prompt 6 that [2] would have used a Negative Binomial Distribution and that it accounted for SiN. When checking within the study, this statement turned out to be wrong. The authors of [2] solely calculated crash rates per unit average daily traffic (AADT).

   c) On prompt 6, the LLM stated that [2] would have accounted for statistical significance, which is true.
   d) However, on prompt 6, as well, the LLM hallucinated that [2] would have found out that red marked crossings correlate with larger crash numbers and that this finding was statistically significant. The truth is, that the sample size in [2] was too small to state that larger numbers of crashes per AADT for colored crossings were not statistically significant. Only the confidence intervals of the crash rates in mixed traffic and roundabouts with separated crossings *with and without* color were significant.
5. **Correlation and Causality:** It is known from literature [3, 6-8] that colored crossings between the bicycle lane and the vehicle lane, when applied to a leg of a roundabout, correlate with larger bicycle crash numbers. But this may be just a correlation and no causality in case the red paint is applied as a treatment for crash hotspots. The LLM was not able to identify this flaw, although literature mentions this issue.
6. The LLM, although citing another study, correctly pointed out, that the red color could give a wrong sense of safety to the bicyclist. This is known from literature [6, 8] and correctly points towards the possible tradeoff between **subjective and objective** safety.
7. The "LLM interview" was perceived by the interviewer like a **brain storming** session, because the LLM, although failing to give the expected results, pointed to issues beyond the benchmark. It emphasized the importance of the separation between the lane and the crossing in addition to the color of the lane and it mentioned studies that had analyzed yield rates depending on the color of the crossing.

A frequent hallucination was attributing publications to wrong authors that were active in a similar field. For instance, reference [8] was credited with the wrong authors: Leich, A., Bondzio, L., & Maier, R. (2022). Traffic Safety at German Roundabouts—A Replication Study. Safety, 8(3), 50. https://doi.org/10.3390/safety8030050

Conclusion

This abstract presented a benchmark approach to determine the ability of specific LLM's to achieve the level of functionality needed to be applied by transport planners.
This experiment demonstrates that while LLMs can serve as a rapid brainstorming tool, but they turn out to be currently unreliable for this specific engineering task. A state-of-the-art LLM hallucinates methodological rigor and falsely attributes advanced statistical techniques such as non-linear safety performance functions and regression to the mean corrections to literature. This can pose a significant risk to practitioners. Further studies should employ a faithfulness evaluator such as Ragas [11] for detecting hallucination and hyperparameter tuning, proper prompting and LLM design in general to avoid those issues.

References

[1] Aumann, P., Pratt, K., Papamiltiades, A., 2017. Bicycle Safety at Roundabouts. volume AP-R542-17 of Research Report. Austroads Ltd, Sydney, Australia.
[2] Bondzio, L., Ortlepp, J., Scheit, M., Voß, H., Weinert, R., 2012. Verkehrssicherheit innerörtlicher Kreisverkehre. Unfallforschung der Versicherer.
[3] Bondzio, L., Scheit, M., Berghaus, B., Bissantz, N., Bakaba, J.E., Ortlepp, J., 2017. Sicherung von bevorrechtigten umlaufenden Radwegen an innerörtlichen Kreisverkehren. Gesamtverband der Deutschen Versicherungswirtschaft eV, Unfallforschung der Versicherer.
[4] Daniels, S., Brijs, T., Nuyts, E., Wets, G., 2009. Explaining variation in safety performance of roundabouts. Accident Analysis & Prevention 42, 393–402. doi:10.1016/j.aap.2009.08.019.
[5] Daniels, S., Nuyts, E., Wets, G., 2008. The effects of roundabouts on traffic safety for bicyclists: An observational study. Accident Analysis & Prevention 40, 518 – 526. doi:10.1016/j.aap.2007.07.016.
[6] Jensen, S., Buch, T., 2015. Two-way cycle crossings at non-signalized intersections and roundabouts, in: 4TH International Cycling Safety Conference. Hannover, Germany. Paper presented at 4th International Cycling Safety Conference.
[7] Jensen, S.U., 2017. Safe roundabouts for cyclists. Accident Analysis & Prevention 105, 30 – 37. doi:10.1016/j.aap.2016.09.005
[8] Leich, A., Fuchs, J., Srinivas, G., Niemeijer, J., Wagner, P., 2022. Traffic safety at German roundabouts—a replication study. Safety 8, 50. doi:10. 3390/safety8030050.
[9] Jensen, S. U., Rosenkilde, C., & Jensen, N. (2007). Road safety and perceived risk of cycle facilities in Copenhagen. *Presentation to AGM of European Cyclists Federation*, 1-9.
[10] Karim, M. M., Shi, Y., Zhang, S., Wang, B., Nasri, M., & Wang, Y. (2025). Large language models and their applications in roadway safety and mobility enhancement: A comprehensive review. *Artificial Intelligence for Transportation*, *1*, 100004.
[11] Es, S., James, J., Anke, L. E., & Schockaert, S. (2024, March). Ragas: Automated evaluation of retrieval augmented generation. In *Proceedings of the 18th conference of the European chapter of the association for computational linguistics: system demonstrations* (pp. 150-158).
[12] Gemini 3.1 Pro: Google DeepMind's multimodal large language model. https://deepmind.google/models/gemini/pro/ (2026)
[13] Claude Sonnet 4.6: Anthropic's multimodal large language model. https://www.anthropic.com/news/claude-sonnet-4-6 (2026)
[14] GPT-5.2: OpenAI's multimodal large language model. https://openai.com/index/introducing-gpt-5-2/ (2025)
[15] Sonar : Perplexity AI's retrieval-augmented large language model. https://www.perplexity.ai/hub/blog/meet-new-sonar (2025)

International Co-operation on Theories and Concepts in Traffic Safety

Professional Learning and Identity Construction Among Heavy-Vehicle Driving Teacher Students

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Introduction
Globally, the road transport sector is facing a critical shortage of professional drivers, with at least 3.6 million unfilled positions reported in 2024, a figure expected to increase further. This shortage is compounded by an ageing workforce and difficulties in recruiting younger drivers. At the same time, international and European reports highlight a growing need for formalised professional competence in transport, particularly related to safety, sustainability and technological development. In Norway, the estimated annual demand until 2030 is at least 2,500 freight drivers and 1,000–2,000 passenger transport drivers. In response to these challenges, and due to limited educational capacity, Nord University was commissioned in 2023 to develop a new two-year higher education programme for driving teachers for heavy-vehicles. The aim is to strengthen access to professional driver education while maintaining high levels of road safety.

Research aims and objectives
Driving teachers play a crucial role in shaping both driving competence and road safety culture. Despite their importance, research on the education and professional development of driving teachers for heavy-vehicle classes remains limited. This study seeks to address this gap by exploring the following overarching question: "*How do heavy-vehicle driving teacher students experience their teaching and learning processes throughout a two-year university-level education programme?*". To guide the investigation, the study addresses the following research question: How do driving teacher students draw upon their previous professional driving experience in their learning processes, and how do these experiences contribute to the development of their professional identity as future driving teachers?

Research Methodology
The project is theoretically informed by learning theory, peer learning and the theory of practice architectures, which provide an analytical lens for examining how experiential knowledge is recontextualised in driving teacher education. This study follows a cohort of 18 volunteer participants from a class of 21 heavy-vehicle driving teacher students throughout a two-year, full-time university degree programme. The 120 ECTS programme consists of campus-based teaching, online learning, workplace placements, and independent study. These students do not have prior driving teacher education in any other vehicle categories, as they constitute the first cohort to be admitted directly to education for heavy-vehicle classes at Nord University. The study adopts a qualitative research design to develop in-depth knowledge of professional learning and identity construction among driving teacher students in heavy- vehicle classes. The empirical material is generated through complementary data sources. Video recordings of group processes are used to capture peer learning, interaction and collective reflection, particularly how professional driving experience is integrated into

learning situations. Semi-structured individual interviews explore students' perspectives on their learning processes, professional identity development and understanding of the teacher role. Group interviews are conducted to stimulate dialogical reflection and shared meaning-making. Background information is collected through a short questionnaire. The participant group consists of strategically selected students with broad and varied professional driving experience. The data are analysed using thematic analysis, allowing patterns and themes across data sources to be identified and interpreted. The research project has been approved by SIKT, the Norwegian Agency for Shared Services in Education and Research.

Results

As data collection is ongoing, results presented in this extended abstract are preliminary and based on early phases of analysis. Initial findings indicate that students actively draw on their prior professional experience as heavy-vehicle drivers when engaging in teaching activities. This experience serves both as a resource and a point of reflection as students transition from drivers to teachers. Peer learning emerges as particularly important, with students learning from each other's diverse backgrounds, types of transport and work contexts. Early analyses also suggest that students view the teacher role as involving not only technical competence but also responsibility for shaping attitudes, safety awareness and professional judgement among future drivers. The process of identity construction appears dynamic, where students negotiate their self-understanding between being experienced drivers and becoming pedagogically competent teachers.

Discussion and conclusions

The preliminary findings highlight the central role of experiential knowledge in the professional learning of driving teacher students for heavy-vehicles. The transition from practitioner to educator requires reflection on established practices and the development of new pedagogical competencies. Peer learning environments appear to function as important arenas for this transition, allowing students to articulate, challenge and refine their professional perspectives. Framing teacher education within the theory of practice architectures makes it possible to understand these learning processes as shaped by what participants say, do, and how they relate to one another, as well as by the cultural-, material-, and social arrangements within the programme that may enable or constrain learning.
The study contributes new empirical knowledge to a field where research is limited and dominated by a focus on learner drivers rather than teachers. By focusing on driving teacher students in heavy-vehicle classes, the project provides insights relevant for the development of driving teacher education, road safety policy and professional driver training. In the long term, strengthening the competence and professional identity of driving teachers may contribute to improved road safety, more sustainable transport practices and enhanced recruitment to the transport sector. These insights are directly relevant for the design of driver and teacher education aimed at improving road traffic safety in professional transport.
Preliminary findings suggest that experiential knowledge and peer learning may support teaching quality and safety culture, with potential implications for the competencies of future heavy-vehicle drivers.
Further research: observations will be carried out in classroom settings and in-vehicle teaching to examine how experiential knowledge is enacted in pedagogical practice.

International Co-operation on Theories and
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Age-Related Differences in Road Crash Characteristics: Evidence from Slovenia

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Population ageing is increasingly influencing traffic safety patterns: while young drivers continue to represent one of the highest-risk groups due to inexperience and risk-taking behaviour, older drivers increase their risk due to lower physical and cognitive skills. Understanding the differences in crash involvement between these two vulnerable groups is essential for the development of effective and targeted road safety measures.

The aim of this study is to analyse and compare road crash characteristics of older (65+) and young (18–21) car drivers, in order to identify differences and leading patterns that affect crash occurrence and severity.

The analysis is based on the national road crash dataset of the Slovenian Police. The data included in the analysis are related to passenger car drivers belonging to the two mentioned age groups, that were involved in road crashes in the last five-year period (from 2021 to 2025) and contains information on crash severity, crash type, time of occurrence (month, day of the week and hour), environmental conditions, and driver responsibility. The research is carried out in two steps. First, a comparative analysis is conducted using descriptive statistics to examine differences between the two age groups. The focus is on identifying general patterns and distributions across selected variables. In the second step, a simple modelling approach is used to explore how selected factors relate to crash outcomes. The intention is not to develop a fully predictive model, but rather to check whether differences between the two age groups can also be observed when variables are analysed together.

Initial findings indicate that there are noticeable differences between younger and older drivers across several variables. Younger drivers appear more frequently in crashes that occur during nighttime and weekends, which may be linked to higher exposure and different driving conditions. Older drivers, on the other hand, are more often involved in crashes in situations that require more complex decision-making, such as intersections. The modelling step is expected to provide additional insight into these patterns by showing how different factors are related to crash outcomes within each group.

The comparison suggests that crash involvement differs between younger and older drivers, indicating that age-related factors influence both driving behaviour and crash risk. Younger

drivers may be more affected by situational and behavioural factors, while older drivers may face challenges related to perception and decision-making. The study, besides providing an initial overview of age-specific crash patterns, also acknowledges the limitations of police-based data, particularly the lack of detailed behavioural information. The results of this study will be further developed and may contribute to future research on traffic safety and driver behaviour.

International Co-operation on Theories and
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Acceptance of Road Safety Measures Across Citizens, Professionals, and Politicians

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Introduction

Despite substantial improvements in traffic safety, progress in Sweden has stagnated over the past decade, and current fatality and injury levels remain far from the national interim targets for 2030.

There is a range of available measures with strong scientific evidence that could substantially reduce fatalities and serious injuries, but are not currently implemented or are implemented only to a limited extent. One explanation for this gap between evidence and practice is that certain traffic safety measures are perceived as controversial, unpopular, or lacking in public and political support.

This can be illustrated by the reduction of speed limits on rural roads. Despite well-documented safety effects, speed limit reductions have often met strong resistance. In Sweden, several reductions of speed limits from 90 to 80 km/h had to be reversed, and the measure was not implemented as originally planned due to public opposition, even though evaluations demonstrated its effectiveness (Vadeby & Forsman, 2018, 2023). This example highlights how acceptance can be critical for how technically effective traffic safety measures are realised in practice.

Previous research shows that high acceptance and support for policy measures are closely linked to perceived legitimacy, which in turn leads to the possibilities of implementing them (Grelle & Hofmann, 2024). Technically well-justified measures can be perceived as legitimate or illegitimate depending on people's values, perceptions of justice and social norms, which makes the question of acceptance central to the practical implementation of Vision Zero.

Traffic safety policy operates within a complex transport system characterised by multiple and sometimes competing objectives, including accessibility, environmental impact, public health, and safety. In addition, the responsibility for the transport system is distributed across several actor groups: political decision-makers, professionals who plan and implement measures, and citizens who are affected by and expected to comply with interventions. Acceptance among these groups is therefore critical for successful implementation.

This study aims to examine the acceptance of road safety measures among key actor groups: citizens, transport professionals, and political decision-makers. And to identify factors that might facilitate or hinder implementation in practice.

Research methodology

The study takes a quantitative survey design targeting three key actor groups involved in traffic safety policy and implementation: citizens. professionals working within transportation, and political decision-makers at local, regional, and national levels. Three tailored versions of an online questionnaire were developed to capture both shared and group-specific perspectives on traffic safety and traffic safety measures.

The survey measures general attitudes towards traffic safety, as well as acceptance levels for specific traffic safety measures. Particular attention is given to three topical and potentially controversial measures: speed limit reductions on rural roads, speed limit reductions in urban areas, and a potential mandatory bicycle helmet law. These measures were selected because they involve trade-offs between safety, accessibility, and personal freedom. Acceptance is examined in relation to factors highlighted in previous research, including perceived effectiveness, distributive and procedural justice, trust in institutions, perceived paternalism, and impacts on everyday mobility.

Data collection is ongoing at the time of writing. The planned analyses include descriptive statistics, comparisons between actor groups, and multivariate models to explore factors associated with acceptance across measures and groups.

Results

As data collection is ongoing, this abstract focuses on the study´s problem formulation and study design. The final results are expected to provide insights into how acceptance of traffic safety measures varies between citizens, transport professionals, and politicians, and how these differences are related to perceptions of effectiveness, fairness, legitimacy, and responsibility. Depending on the stage of analysis, preliminary or final results will be presented at the conference.

Discussion

Understanding acceptance and legitimacy is essential for addressing the implementation gap in traffic safety policy. By examining acceptance across multiple actor groups simultaneously, this study contributes to a more nuanced understanding of the conditions under which evidence-based road safety measures can be successfully implemented. The findings are expected to be relevant for both research and practice on traffic safety policy, highlighting the importance of addressing social acceptability alongside technical effectiveness in mature contexts where further progress often depends on controversial measures.

References

Grelle, S., & Hofmann, W. (2024). When and Why Do People Accept Public-Policy Interventions? An Integrative Public-Policy-Acceptance Framework. *Perspectives on Psychological Science*, *19*(1), 258–279. https://doi.org/10.1177/17456916231180580

Vadeby, A., & Forsman, Å. (2018). Traffic safety effects of new speed limits in Sweden. *Accident Analysis & Prevention*, *114*, 34–39. https://doi.org/10.1016/j.aap.2017.02.003

Vadeby, A., & Forsman, Å. (2023). *Hastighetsgränser på statliga tvåfältsvägar: Plottrighet, trafiksäkerhet och målkonflikter* (No. 1176; VTI Rapport). VTI.

International Co-operation on Theories and Concepts in Traffic Safety

Comparative Analysis of Adaptive Cruise Control Performance Across Vehicle Brands

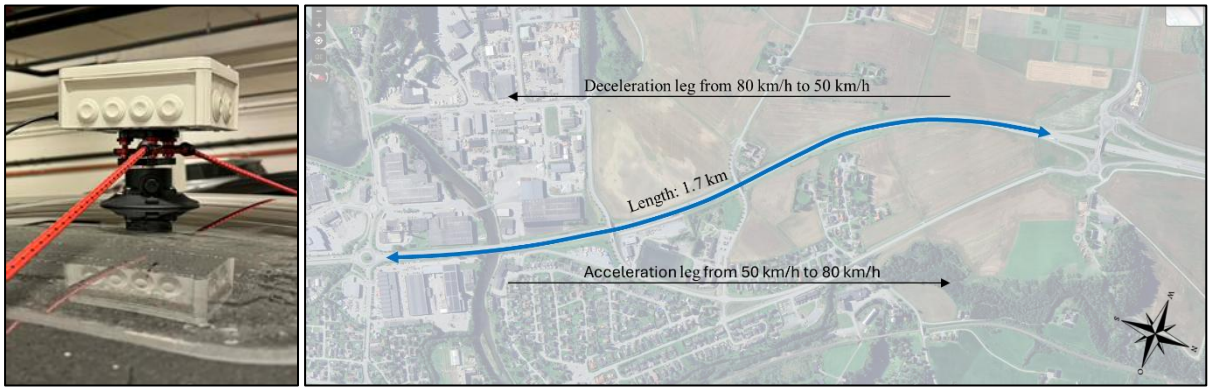
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Introduction: Adaptive Cruise Control (ACC) has become a central component of Advanced Driver Assistance Systems (ADAS), with the potential to improve driver comfort, safety, and traffic flow. Despite their widespread adoption in modern vehicles, ACC functionality varies significantly across manufacturers, leading to differences in system behaviour. Understanding these differences is important for evaluating their implications for traffic safety and user experience. Previous studies have shown that ACC behaviour depends on system settings and responds similarly to human drivers (Raju et al., 2022), while also exhibiting complex dynamic effects such as oscillation amplification and stability issues in traffic flow (Li et al., 2021). More recent research further highlights variability in following distances across commercial ACC systems (Mohammed and Horváth, 2024).
This study further explores this research field by presenting a comparative analysis of ACC performance across nine vehicle brands based on field experiments, focusing on key behavioural metrics including speed adaptation, acceleration and deceleration patterns, response time, and following distance.
The study investigates the following research questions: (1) What following gaps are maintained by ACC systems across different vehicle brands, and how are these influenced by the ACC settings (e.g., low, medium, and high gap)? (2) How do speed differences, acceleration and deceleration behaviours, and response times vary across vehicle brands?

Method: The study employs a quantitative experimental design based on real-world field tests, in which nine passenger cars from different brands were driven in a car-following scenario behind a lead vehicle following predefined speed profiles (Figure 1b). High-frequency Inertial-GNSS sensors (Figure 1a) mounted on both vehicles were used to collect synchronized data on speed, distance, acceleration, and deceleration (Table 1). The analysis focused on steady-state conditions as well as dynamic transitions during acceleration and deceleration phases, allowing for the evaluation of response times and control behaviour across different ACC systems.

Table 1- Overview of the experimental parameters

Parameter	***Description***	***Levels***
Independent		
Speed	50, 60, 70, 80 km/h	4
ACC distance settings	Low, Medium and High	3 to 5
Acceleration	50-60, 60-70, 70-80 km/h	3
Deceleration	80-70, 70-60, 60-50 km/h	3
Car Brand	Nine different car brands	9
Dependent		
Distance/Time gap	Clerance (from back bumper to front bumper)	-
Acceleration rate	Average acceleration rate	-
Deceleration rate	Average deceleration rate	-
Response Time	Delay time	-
Speed Difference	Detected speed difference between both cars	-



(a) (b)

Figure 1 - (a) Detail of the GNSS sensor mounted on the car rooftop and (b) overview of the road section adopted for the tests

Results: The preliminary results indicate clear and systematic differences in how Adaptive Cruise Control (ACC) systems behave across different vehicle brands. For all tested vehicles, the following distance increased consistently with both higher speed and higher distance settings, confirming that ACC systems scale distance proportionally with driving conditions. However, significant variation was observed between vehicles even when similar settings were used. For instance, at 50 km/h and the lowest distance setting, following distances ranged approximately from 16.5 m to 24.7 m, while at 80 km/h the variation remained substantial, ranging from about 25.7 m to over 32 m. These discrepancies suggest that distance settings are not standardized across manufacturers. Additionally, the data reveal asymmetries in system response: vehicles generally adapted faster and more smoothly during acceleration phases, whereas deceleration caused delayed responses and temporary reductions in following distance. This often resulted in oscillations before the system stabilized. Some vehicles also exhibited longer stabilization times, further contributing to variability in measured distances. Despite minor measurement uncertainties and occasional sensor errors, the overall pattern is robust: ACC systems differ notably in both distance control and dynamic response, which may have implications for consistency, user expectations, and potentially traffic safety.

Discussion and Conclusions These preliminary findings highlight the lack of standardisation in ACC behaviour across manufacturers and suggest that differences in system design may influence real-world safety margins and driver expectations. Further research is needed to assess how these differences affect mixed traffic environments and driver interaction with ADAS.

References

[1] Li, T., Chen, D., Zhou, H., Laval, J., & Xie, Y. (2021). Car-following behavior characteristics of adaptive cruise control vehicles based on empirical experiments. *Transportation research part B: methodological*, *147*, 67-91.

[2] Raju, N., Schakel, W., Reddy, N., Dong, Y., & Farah, H. (2022). Car-following properties of a commercial adaptive cruise control system: A pilot field test. *Transportation research record*, *2676*(7), 128-143.

[3] Mohammed, D., & Horváth, B. (2024). Comparative analysis of following distances in different adaptive cruise control systems at steady speeds. *World Electric Vehicle Journal*, *15*(3), 116.

International Co-operation on Theories and Concepts in Traffic Safety

Accounting for temporal variations of driving speed

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Introduction

Temporal variability is a fundamental characteristic of road traffic, and its treatment is well established for traffic volumes through the use of adjustment factors to estimate Annual Average Daily Traffic. In contrast, driving speed is commonly assumed to be temporally stable, or directly comparable across periods, provided that road geometry and other conditions remain unchanged. This assumption persists although it is known that speed is influenced by weather and seasonal conditions, trip purpose and traffic composition. However, the majority of this research has focused on short-term operational effects or forecasting, rather than on the implications for evaluation practice (Romanowska and Budzyński, 2022).

This lack of knowledge is critical in the context of speed impact studies, for example, evaluations of effectiveness of traffic calming measures. For a before-after study, a comparison group is recommended to control for any confounding differences, including the seasonal variations of traffic volume, weather, etc. However, a review by Ambros et al. (2023) noted that most studies do not use a comparison group; thus, seasonal variations are erroneously attributed to the studied traffic calming measure impacts. In addition, the magnitude of such temporal variations is unknown: e.g., in a sample of Spanish urban roads, the speed differences across months were between –7% and +6% compared to the annual mean; in a sample of Italian rural roads, the differences across seasons were up to 15% (Ambros et al., 2022, 2024).

This study aims to quantify temporal variations in driving speed and to propose adjustment factors ("monthly speed ratios") that enable the estimation of an Annual Average Speed for evaluation purposes. This concept may improve the internal validity and comparability of speed-based evaluations.

Data and methods

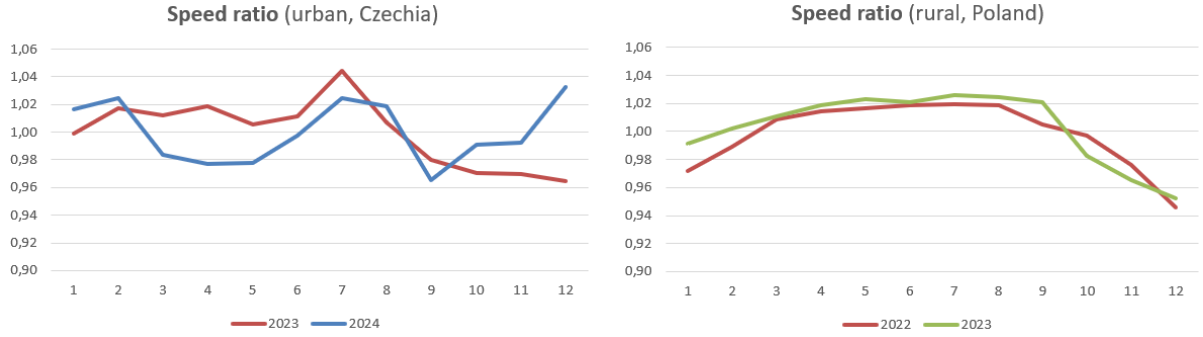
Several international samples of speed and volume data were collected. The samples covered at least two years, avoiding the years 2020 and 2021 with the most intense Covid-19 lockdowns. The data were split into road categories and individual months. The two research questions were:

(1) What is the monthly pattern of driving speed? This task was addressed by deriving the speed ratios, i.e., the proportions of average monthly speeds to the average annual speed.

(2) Is this pattern stable over years? The task used statistical testing of the differences between the respective months in the first and the second year.

Results

Example of preliminary results is shown; the graphs present speed ratios for samples of urban roads in Czechia, and rural roads in Poland in two years. The patterns are different across the datasets. Although the range of ratios is quite small (below 10%), it may still be influential, since traffic calming effectiveness is typically around 20% (Ambros and Kieć, 2025).



Discussion and conclusions

The results are expected to provide insight into temporal variations of driving speed. If there is a recurrent pattern, it will allow deriving the ratios to estimate adjusted speed, which will be useful for before-after speed evaluations.

References

Ambros, J., Elgner, J., Vyskočilová, L., Zůvala, R. (2022). *Connected Vehicle Data Analysis*. CDV – Transport Research Centre, Brno.
Ambros, J., Tomešová, L., Jurewicz, C., Valentová, V. (2023). A review of the best practice in traffic calming evaluation. *Accident Analysis and Prevention*, Vol. 189, No. 107073.
Ambros, J., Elgner, J., Usami, D. S., Sauchuk, A., Carroccia R., Dadáková, K. (2024). Investigation of floating car data characteristics and their implications for speed impact studies. In *36th ICTCT Conference*, the Hague.
Ambros, J., Kieć, M. (2025). Are the speed-crash models applicable for low speeds? *European Transport Research Review*, Vol. 17, No. 59.
Romanowska, A., Budzyński, M. (2022). Investigating the impact of weather conditions and time of day on traffic flow characteristics. *Weather, Climate, and Society*, Vol. 14, pp. 823–833.

International Co-operation on Theories and Concepts in Traffic Safety

Disentangling the relationship between driving speed, road infrastructure and traffic safety

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Introduction

Driving speed is a major risk factor. This holds especially on the macro level, as described by the Power Model which defines the relationship between the changes in speed and the changes in the traffic safety outcomes. The model, as well as its later variants, was mainly based on the national speed limit interventions, and has been validated internationally (OECD, 2018).

However, on other levels, the speed-safety relationship is less clear. Several aspects play a role:

- *The speed-safety relationship is highly scale-dependent.* At vehicle level, higher speed increases both crash likelihood and severity. But at segment or network levels, aggregate relationships are dominated by infrastructure, exposure, and land-use context, generating conflicting results, which leads to an ecological fallacy: relationships observed at aggregate scales cannot be directly inferred from individual-level mechanisms (Elvik, 2025).
- *Speed is not an exogenous variable* but responds to roadway design and other local conditions (Fitzpatrick et al., 2003). Safer roads, such as motorways, support higher operating speeds while simultaneously reducing crash likelihood. Conversely, complex urban environments with low design speeds may experience higher crash frequencies due to conflict density rather than speed itself. When not controlling for these factors, spurious relationships may emerge.
- *Speed is also tightly coupled with traffic flow.* Congested conditions are characterized by low speeds but high interaction rates, leading to frequent minor crashes. Free-flow conditions allow higher speeds but reduce conflict opportunities. Moreover, crash risk is frequently more sensitive to speed variance than mean speed, as large deviations from the prevailing flow increase interaction risk (Aarts and van Schagen, 2006). Studies relying solely on average speeds may therefore obscure the mechanisms driving crash occurrence.

As a consequence, empirical findings on the speed-safety relationship at meso- and network-levels remain contradictory, not necessarily because the relationship itself is unstable, but because speed is simultaneously a causal factor, a behavioural response, and a proxy for infrastructure and traffic conditions. Failure to explicitly separate analysis scales, speed metrics, and contextual determinants has led to inconsistent and sometimes misleading conclusions.

This study aims to disentangle the respective roles of road infrastructure, traffic exposure, and multiple speed metrics in explaining crash frequency on Czech primary road network, explicitly accounting for scale effects and temporal aggregation.

Data and methods

In addition to routinely used crash and traffic volume data, we collected and adapted three datasets:

- Driving speed metrics from floating car data (FCD) aggregated in TMC segments.
- Road geometry and infrastructure data (e.g., lane width, property access, roadside) linked to network-wide road safety assessment (NWA) segments (Ambros et al., 2026).
- Weather data: temperature, precipitation, wind speed, temperature, air pressure, etc.

After unifying the TMC and NWA segments, data were assigned and aggregated into temporal units (hours, days, weeks, months, years). Multilevel (mixed) generalized linear modelling was used to develop crash prediction models, reflecting the varying temporal scales.

Results, discussion and conclusions

A key methodological contribution of this study lies in the harmonisation of FCD-based speed data and network-wide infrastructure indicators, enabling simultaneous modelling across multiple temporal resolutions, which has been rarely feasible in previous speed-safety studies.

The results are expected to demonstrate how the apparent effect of speed on crash frequency changes across temporal scales and infrastructure contexts, and to identify conditions under which speed acts primarily as a causal risk factor versus a proxy for road design and traffic flow. The findings will be useful for further decisions related to speed management or other traffic safety interventions.

References

Aarts, L., van Schagen, I. (2006). Driving speed and the risk of road crashes: A review. *Accident Analysis and Prevention*, Vol. 38, pp. 215–224.
Ambros, J., Vyskočilová, L., Sedoník, J., Elgner, J., Andrášik, R., Valentová, V., Havránek, P., Caudr, M. (2026). Network-Wide Road Safety Assessment in Czechia. In *Transport Research Arena 2026*, Budapest.
Fitzpatrick, K., Carlson, P., Brewer, M. A., Wooldridge, M. D., Miaou, S.-P. (2003). *Design Speed, Operating Speed, and Posted Speed Practices*. NCHRP Report 504. TRB, Washington.
Elvik, R. (2025). Simpson's paradox: A collection of examples from road safety studies and emergency medicine. *Transportation Research Interdisciplinary Perspectives*, Vol. 31, No. 101471.
OECD (2018). *Speed and Crash Risk*. OECD, Paris.

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Pedestrian Falls and Collisions: Preliminary Findings from a Norwegian Injury Registration Study

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Introduction

Data from Oslo Emergency Clinic shows nearly 60 times more pedestrian accidents in the streets than officially registered, mostly due to the large number of pedestrian falls. Pedestrian injuries are often underrepresented in official road safety statistics because many incidents, particularly falls, are excluded from standard traffic accident definitions. As a result, pedestrian falls receive limited attention in transport safety research despite constituting a substantial share of pedestrian injuries. This introduces a systematic bias in the understanding of pedestrian safety and may influence which preventive measures are prioritised.

At the same time, many countries aim to increase walking as a mode of transport for environmental and public health reasons. Improved knowledge about pedestrian accidents is therefore important for developing safer walking environments.

This study aims to investigate:

1. What characterises pedestrian falls and collisions
2. Where do these accidents occur
3. Which factors injured pedestrians perceive as contributing to the accident

Research methodology

The study is based on data from the Norwegian CyWalk project, an ongoing injury registration project collecting data from hospitals and emergency clinics across Norway between 2024 and 2027. Injured pedestrians, cyclists and e-scooter riders self-report accident information through a web-based questionnaire. Participants provide information about accident circumstances, contributing factors and infrastructure conditions, and identify the accident location using maps and street-view tools.

This presentation focuses on pedestrian injuries registered up to May 2026. Preliminary analyses include approximately 1,700 pedestrian accidents. The analyses examine accident

types, contributing factors and accident locations based on self-reported data from injured pedestrians.

Results

Preliminary findings show that 89% of pedestrian injuries were single accidents, while only 9% involved collisions with another road user. Most single accidents occur in traffic environments, although some also occur in parks, nature areas and private property. The age and gender distribution show that the age group 55–65 is the largest group in single accidents, and not the oldest ones. In collisions the age group 25–35 is the largest. 64 % of all the injured pedestrians are women.

The most common contributing factor in single accidents was slipping on snow and ice, often combined with additional environmental factors such as slopes, gravel, uneven surfaces, curbs or poor visibility. Participants frequently described unexpected slippery surfaces or hidden hazards as contributing to the accident.

Collisions most often involved e-scooter riders, motor vehicles and cyclists . Car collisions frequently occurred at unsignalised crossings, while collisions involving cyclists and e-scooter riders more often occurred on pavements and shared walking-cycling facilities. Injured pedestrians often described the other road user as inattentive or travelling at high speed.

The data also demonstrates how detailed self-reported injury registration can identify specific accident mechanisms and locations that may not appear in official statistics. Examples of registrations on maps, with street view and free text will be included in the presentation.

Discussion and conclusions

The findings demonstrate that pedestrian falls constitute a major but often overlooked road safety issue. Excluding falls from official traffic safety frameworks risk underestimating the importance of infrastructure maintenance, winter operations and pedestrian environment design in injury prevention.

The study further illustrates the value of detailed injury registration systems that combine medical recruitment with self-reported information about accident circumstances and locations. Such data can contribute to identifying accident hotspots, recurring risk factors and infrastructure-related safety problems.

Improving pedestrian safety requires attention not only to collisions with vehicles, but also to environmental conditions that contribute to falls. This is particularly important in cities aiming to promote walking as a safe and attractive mode of transport.

Keywords: pedestrian safety, falls, collisions, walking, injury registration

International Co-operation on Theories and Concepts in Traffic Safety

Perceived Traffic Safety in Urban Areas: Implications for Low- and Middle-Income Countries

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Background
Traffic safety policies traditionally rely on reductions in recorded crashes and injuries. However, road users' behaviour is also shaped by how safe traffic environments are perceived to be. If walking, cycling, or using public transport is experienced as dangerous, people adapt by avoiding these modes or choosing routes that increase exposure to risk. This behavioural mechanism is highly relevant for low- and middle-income countries (LMICs), where mixed traffic, limited separation between road users, and uneven enforcement are common. Evidence from cities with differing levels of regulation and infrastructure quality can therefore provide insights into how perceived safety interacts with traffic safety outcomes.

Aim
The aim of this study is to identify which urban design and contextual factors are most strongly associated with perceived traffic safety across transport modes, independent of recorded accident rates.

Method
Survey data from more than 8,500 respondents in ten cities were analysed, collected within the EU Horizon 2020 AMIGOS project. The sample includes cities from Western and Northern Europe, two cities in Turkey, and one city in the Middle East, providing variation in traffic conditions, regulatory environments, and infrastructure quality. Respondents reported perceived safety when walking, cycling, and using public transport. These data were linked to contextual indicators including traffic volume, dedicated pedestrian and cycling infrastructure, lighting, street layout, urban greenery, and official accident statistics. Multilevel regression models were used to assess the influence of individual-level factors (gender, age) and city-level characteristics on perceived safety.

Results
Perceived traffic safety varied markedly between cities, even where accident statistics were comparable. Physical separation from motor traffic, adequate lighting, and clear street layouts were more strongly associated with perceived safety than recorded crash rates. Women and older adults consistently reported lower perceived safety, particularly for walking and cycling. Cities with more heterogeneous traffic environments showed larger gaps between objective safety indicators and subjective safety perceptions.

Conclusions

• Perceived traffic safety cannot be inferred from crash data alone.

• Design features that visibly reduce interaction with motor traffic are central to how safe environments are experienced.

• Women and older adults face persistent safety deficits, with implications for exposure and risk.

• For LMIC cities, addressing perceived safety through robust and visible design measures may be a critical complement to conventional traffic safety policies focused on injury reduction.

International Co-operation on Theories and Concepts in Traffic Safety

Spatial Distribution of Traffic Accidents Across Modal Interactions in Zagreb, Croatia

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Introduction

Multimodal transport networks integrate different transport modes within a single origin–destination journey, aiming to enhance efficiency and sustainability, especially in urban environments [1]. The interaction of different transport modes in shared traffic environments introduces additional complexity and represents a significant challenge for traffic safety [2]. As urban transport systems become increasingly multimodal, understanding how these interactions influence traffic accidents becomes essential. Empirical evidence on the spatial distribution of traffic accidents across specific modal interactions within urban networks remains limited. In urban environments such as Zagreb, where different transport modes operate within a dense traffic network, these interactions play a key role in traffic safety. This extended abstract examines how traffic accidents are distributed across modal interactions in the City of Zagreb. It aims to identify dominant modal interactions, focusing on bicycles, buses, trams, and passenger cars, and to examine their spatial distribution.

Research methodology

The analysis is based on traffic accident data from the Ministry of the Interior for the City of Zagreb in 2025, covering incidents within the administrative boundaries of the City of Zagreb. The study focuses on multimodal interactions, particularly accidents involving at least two transport modes, such as tram, bus, bicycle, and passenger car, while including single-vehicle accidents to provide additional context. Accident locations were georeferenced and analysed using QGIS, an open-source geographic information system. Modal interactions were defined based on combinations of transport modes involved in each recorded accident, and accidents involving multiple vehicles were decomposed into pairwise modal interactions to enable consistent classification. Spatial analysis was performed to examine the distribution of accidents across modal interactions within the urban transport network. The results may be affected by minor inaccuracies in the geolocation data obtained from official records.

Results

The results highlight key patterns of traffic accidents in relation to interactions between selected transport modes in the City of Zagreb. Figure 1 indicates that the most frequent multi-vehicle interactions occur between bicycles and passenger cars (26.7%), followed by bus–passenger car (14.5%) and passenger car–tram (11.0%) combinations. These findings highlight the dominant role of passenger cars in multimodal traffic conflicts, particularly in interactions with vulnerable road users and public transport modes. Additionally, 136 single-vehicle accidents were recorded, most of which involved bicycles, suggesting a high vulnerability of this transport mode.

Figure 1. Distribution of traffic accidents by vehicle type combinations in the City of Zagreb

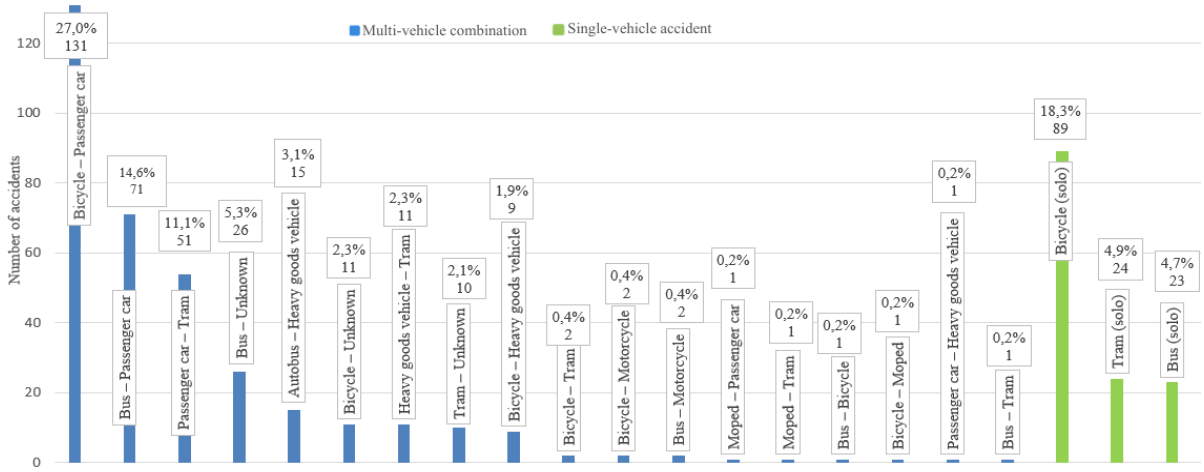


Figure 2 illustrates the spatial distribution of 480 recorded traffic accidents across the districts of the City of Zagreb. The highest number of accidents was recorded in Trešnjevka (14.2%), followed by Centar (12.9%) and Trnje (11.0%), indicating a concentration of accidents in central and highly urbanized areas. In contrast, peripheral districts such as Sesvete and Susedgrad recorded significantly fewer accidents. This concentration reflects higher traffic intensity and a greater density of interactions between different transport modes in central urban areas.

Figure 2. Distribution of traffic accidents across municipal districts of the City of Zagreb

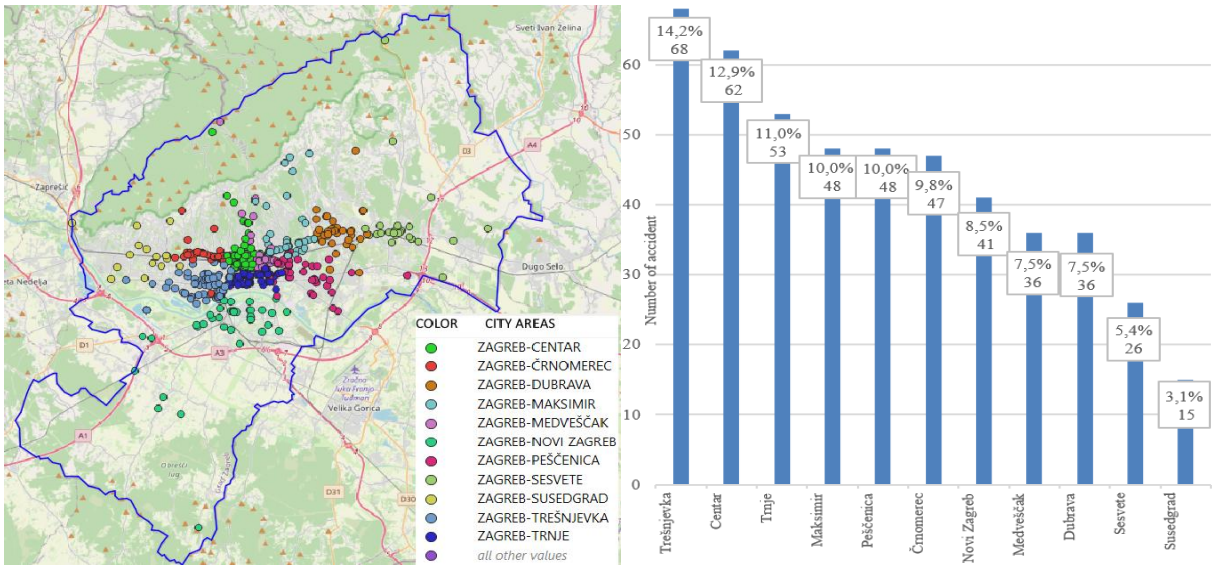
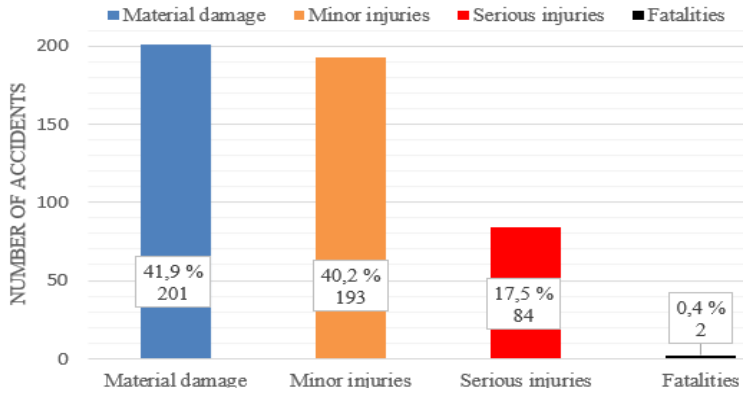


Figure 3 presents the distribution of 480 recorded traffic accidents by severity. Most accidents resulted in material damage (41.9%) or minor injuries (40.2%), while serious injuries accounted for 17.5% of cases. Fatal accidents were rare, with only 0.4% of recorded incidents. Although most accidents are of low severity, a noticeable share still results in serious injuries, which shows that multimodal interactions can lead to serious outcomes.

Figure 3. Distribution of traffic accidents by type of consequence in the City of Zagreb



Discussion and conclusions

The findings indicate that traffic accident patterns in the City of Zagreb are largely shaped by interactions between passenger cars and other transport modes, particularly bicycles, buses, and trams. The concentration of these interactions in central and highly urbanized areas suggests that dense multimodal traffic environments are associated with a higher occurrence of accidents involving different transport users. Although most accidents result in material damage or minor injuries, the presence of serious outcomes indicates that multimodal interactions remain a relevant safety concern, especially for vulnerable road users such as cyclists. These findings should be interpreted with caution, as they reflect absolute frequencies rather than relative risk levels. Areas with higher traffic volumes are expected to exhibit a greater number of accidents, meaning that the observed spatial patterns do not necessarily indicate higher safety risk. In this context, areas with fewer total accidents may still exhibit a higher proportion of multimodal interactions, indicating potentially greater safety concerns. These findings highlight the role of interactions between transport modes in urban traffic safety, particularly in high-density areas. It also provides empirical insight into the spatial distribution and interaction structure of traffic accidents within a multimodal urban network. Future research should incorporate exposure-based indicators, such as traffic volumes by district, to better assess the relative risk associated with specific modal interactions.

References

[1] O. Altintasi and O. S. Kirtiloglu, “Data-driven urban mobility planning: A GIS-based spatial modeling approach for shared mobility hub placement,” *Sustain. Cities Soc.*, vol. 140, Apr. 2026, doi: 10.1016/j.scs.2026.107261.

[2] M. R. Rahman, N. Poudel, and P. A. Singleton, “Multimodal traffic safety concerns in a university population,” *Transp. Res. Part F Traffic Psychol. Behav.*, vol. 80, pp. 424–435, Jul. 2021, doi: 10.1016/j.trf.2021.05.013.

[3] Ministry of the Interior of the Republic of Croatia (MUP), Traffic accident database for the City of Zagreb, 2025, unpublished data.

International Co-operation on Theories and
Concepts in Traffic Safety

Drivers' Trust in Proactive V2I Warning Systems at Complex Urban Intersections: A Driving Simulator Study

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Introduction

At urban intersections with limited visibility, drivers are often required to perform abrupt evasive manoeuvres, as visibility constraints prevent timely risk perception. In these situations, conventional driver assistance systems, including Emergency Braking Assistance Systems (EBAS), may exhibit operational limitations. Similarly, approaches based solely on traffic signs or on reactive strategies may be inconsistent with the dynamic evolution of the traffic scenario, thereby reducing their effectiveness. Within this context, Vehicle-to-Everything (V2X) communication in the framework of Cooperative Intelligent Transport Systems (C-ITS) represents a promising solution, providing early warnings before hazardous situations become directly observable to the driver. However, the effectiveness of such systems depends not only on technological performance, but also on how drivers interpret the information and develop trust in the system. Research focusing on trust formation in response to proactive warnings remains limited. Driving simulators are a well-established tool for studying the human-machine interface (HMI) and trust in the system, enabling controlled, repeatable analyses and overcoming limitations related to data availability and safety.
Considering these aspects, this study aims to investigate drivers' confidence in a C-ITS-based proactive safety system, with particular focus on the timing of the braking message. The aim is to assess whether and how the driver considers a predictive warning credible and useful, and how this information influences driving behaviour, also in the context of differences between EU countries. To develop the analysis, a simulated urban scenario was implemented, participants performed the driving tasks, and behavioural data on approach and braking at the intersection were collected under different warning conditions.

Research Methodology

Two fixed-base driving simulators have been adopted: one at NORD University (Norway) and one at the University of Catania (Italy), both using the same software (SCANeR Studio® ver. 2025.2) and hardware. Participants were recruited to ensure comparable samples of drivers across the two countries in terms of age, gender, driving experience, and familiarity with driving simulators or immersive virtual environments.
The two samples of participants in Norway and Italy drove through the same scenarios, composed of different intersections equipped with the C-ITS Emergency warning system in an urban environment. Within the road network, intersections with limited visibility were reconstructed to replicate critical conflict conditions Figure 1.



Figure 1. Warning message displayed at a limited-visibility intersection

A cyclist crossing was simulated by varying two experimental variables: (a) the status of the assistance system and (b) the distance of the vehicle from the conflict area at the time of the cyclist's crossing. The warning was issued only when the system is active, and a potential risk is detected. No message was provided otherwise. The possible combinations define the set of experimental configurations analysed in the study, reported in Table 1.

Event	System status	Warning	Bicycle distance
1	ON	YES	Close (20 m)
2	ON	YES	Medium (40 m)
3	ON	NO	Far
4	OFF	NO	Bicycle in close (20 m)
5	OFF	NO	Nearby bicycle (40 m)
6	OFF	NO	Distant bicycle

Table 1. Events list

Each participant was randomly exposed to different sequences of events to limit the learning effect in the data analysis. For each test, behavioural data were collected, including speed profiles, braking onset, and braking modulation, to assess the influence of warning conditions and experimental variables on driver behaviour.

Results

At the time of submitting this abstract, data collection is still ongoing, with plans to complete the results before the conference. However, some preliminary results can be presented.
Trust in the warning system will be influenced by the consistency between the message received and the subsequent evolution of the conflict scenario. Warnings provided in the presence of an actual risk and with a time anticipation perceived as appropriate should be considered credible and useful, thereby increasing confidence in the system. Based on the collected behaviour indicators, driver responses will be compared across warning and no-warning conditions and Countries. The presence of a proactive warning message should prompt a change in driving strategies before the direct perception of risk. Compared to conditions without warning, drivers could adopt more cautious behaviour near the intersection, reduce speed earlier and modulate decelerations more gradually.

Discussion & conclusions

The expected results support the design of V2I systems by defining appropriate warning timing to ensure usefulness and user acceptance, while providing behavioural insights to improve and deploy C-ITS applications.

International Co-operation on Theories and
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RoadBehave: Monitoring Multi-User Riding Behavior

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Introduction

Monitoring safety behavior among road users is important for improving urban traffic safety. Computer vision enables continuous large-scale traffic observation and can support the identification of unsafe or risky road-user behaviors that are difficult to capture through manual observation alone. One example is multi-user riding, where two individuals share a vehicle designed for a single rider, such as an e-scooter. Such events are relatively rare in long-duration traffic recordings and are therefore difficult to analyze manually at scale. At the same time, these behaviors are safety relevant because vulnerable road users are highly exposed to injury risk, particularly when protective equipment such as helmets is not used. In this work, we present RoadBehave, a weakly supervised framework for detecting and analyzing multi-user riding events in urban traffic videos. The proposed method focuses on two-person scooters and bicycles carrying child passengers. Rather than replacing human operators, the framework aims to support scalable behavioral monitoring by automatically extracting candidate rare events from large traffic-video collections.

Methodology

The proposed framework combines object detection, tracking, and temporal voting for weakly supervised detection of multi-user riding events in urban traffic videos. Each video frame is first processed using a customized YOLO-based detector trained for vulnerable road-user analysis. The detector identifies several traffic-related categories, including people, heads, bicycles, scooters, helmets, and a united-object category representing a rider together with the associated vehicle. Instead of training a dedicated multi-rider classifier, the framework infers multi-user riding events by combining relationships between these detected object classes over time. To improve temporal consistency, detected objects are tracked across frames using ByteTrack [1]. Tracking helps reduce instability caused by temporary occlusions, partial visibility, and crowded traffic scenes. Multi-user riding candidates are identified by analyzing the number of detected people associated with each tracked vehicle over time. Rather than relying on a single frame, the framework applies a soft-voting strategy across consecutive frames to reduce transient detection errors. The detector is intentionally configured to prioritize recall, allowing the system to capture most potential multi-user riding cases even at the cost of additional false positives. Candidate events are subsequently reviewed to remove obvious false detections before behavioral analysis. Experiments were conducted on more than four hours of urban traffic video from the Berlin Scooter Dataset [2]. The dataset contains both daytime and nighttime recordings and was annotated using CVAT [3]. Since the original annotations were designed for general road-user detection rather than explicit multi-user riding analysis, multi-user riding events were inferred during post-processing using object relationships, tracking consistency, and lightweight human verification.

Results

We evaluated the proposed multi-user riding detection pipeline on test videos of the Berlin scooter dataset. The detector output was post-processed using temporal tracking and a soft-

voting decision rule. To study the effect of the voting threshold, we repeated the experiment across 14 different voting-threshold configurations. The average multi-user detection accuracy ranged from approximately 30% to 60%. Here, multi-user riding refers to cases where more than one person, typically two individuals, shared the same bicycle or scooter. The results suggest that temporal voting improves detection robustness, although false positives still occurred in cases involving partial occlusions, overlapping riders, and edge-of-frame detections. Examples of detected multi-user bicycle and scooter cases are presented in Fig. 1. Three main categories of shared riding behavior were observed: normal bicycles, cargo bicycles carrying children, and multi-user scooters. For bicycle-based multi-user riding, all verified multi-user bike cases involved an adult carrying a child passenger, suggesting that shared bicycle riding in the dataset was mainly associated with child transport rather than recreational peer riding. Helmet-use behavior differed strongly between adults and children. In the verified adult–child bicycle cases, child passengers showed very high helmet usage. Child helmet usage reached 100%, while a more conservative interpretation treating invisible cases inside the cargo bike as no helmet yielded approximately 75%. In contrast, adult helmet use while carrying a child was substantially lower than child helmet use, although still higher than the observed helmet use among regular single bicycle riders, remaining approximately within the 12.5%-16.7% range. This suggests that adults may perceive helmet use as particularly important for children even when they do not wear helmets themselves. For regular multi-user scooters, no helmet use was reported after excluding the motor-scooter case. This contrasts strongly with the bicycle child-passenger cases and suggests a different safety behavior pattern, where scooter co-riding appears to be associated with higher risk acceptance and almost no observed protective equipment use.

Discussion and conclusions

Overall, the results show that the proposed weakly supervised pipeline can extract rare multi-user riding events from traffic video. Beyond event detection, the framework also supports the creation of verified datasets of uncommon traffic behaviors that are difficult to collect manually at scale. Automatic pre-selection combined with lightweight human verification can substantially reduce annotation effort while enabling behavioral analysis of rare but safety-relevant situations. The findings further suggest that multi-user riding behavior differs across vehicle types. Adult-child bicycle riding appeared primarily associated with child transport and relatively high child helmet use, whereas multi-user scooter riding showed almost no observed helmet use. These results demonstrate the potential of weakly supervised traffic-video analysis for studying underrepresented vulnerable-road-user behaviors in urban environments.

[1] Zhang, Yifu, et al. "Bytetrack: Multi-object tracking by associating every detection box." *European conference on computer vision*. Cham: Springer Nature Switzerland, 2022.

[2] F. W. Siebert, M. Ringhand, F. Englert, M. Hoff Knecht, T. Edwards, and M. Rotting, “Braking bad – ergonomic design and implications for the safe use of shared e-scooters,” Safety Science, vol. 140, p. 105294, 2021.

[3] B. Sekachev, M. Zhiltsov, N. Manovich, A. Zankevich, A. Zhavoronkov, D. Kalinin, B. Hoff, S. Ardi, T. Truong, C. Gao et al., “CVAT: Computer Vision Annotation Tool,”



Figure 1: Examples of detected multi-user scooter and bicycle riding

International Co-operation on Theories and Concepts in Traffic Safety

Nighttime visibility of pedestrian crossings: field evaluation of road marking materials and glass beads

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Introduction

Road markings are key elements of road safety, supporting traffic guidance. Pedestrian crossings are critical conflict zones between drivers and pedestrians, where drivers must detect the crossing and pedestrian in time to yield. Safety therefore depends on visibility of both the pedestrians and the pedestrian crossings. Visibility of road markings is achieved through colour contrast against the roadway surface; at night, visibility and contrast are enhanced by retroreflection – the phenomenon of reflecting light from vehicle's headlights back toward the driver, which is possible because of a layer of glass beads embedded in the paint layer of road markings. The selection of glass beads, particularly their refractive index (RI), influence the retroreflection; in combination with the material used for the paint layer it also determines durability of road markings. The aim of this study was to investigate how the choice of glass beads and structure of road markings affect the visibility of 'zebra' pedestrian crossings in both dry and wet conditions and how it changes with traffic exposure.

Research methodology

The study was conducted in the field, at four pedestrian crossings marked with flat and structured lines with commonly utilised materials and application technologies, without a full testing matrix. For flat lines were used thermoplastic (hot applied plastic) road marking made with hydrocarbon- and rosin-based binders, for randomly structured marking was used cold plastic material. Three types of glass beads were evaluated: 'standard' 0.2–0.8 mm (RI 1.5) that are most frequently used worldwide, 'large' 0.4–1.4 mm (RI 1.5) that should facilitate moisture drainage, and 'premium' 0.3–1.0 mm (RI 1.65) that ought to furnish higher retroreflection in both dry and wet conditions.

Coefficient of retroreflected luminance under dry (R_L) and wet (RW) conditions was used as surrogate measure for visibility. Performance was monitored over nine months (approximately 0.9 million vehicle passes per lane) to check the extent of deterioration under normal usage. Visibility distance was additionally evaluated from the driver's perspective using frame-by-frame analysis of dashboard camera recordings.

Results

The initially measured results were consistent with professional experience and prior literature reports: the refractive index of glass beads significantly affected R_L: >500 mcd/m²/lx was measured with glass beads characterised by RI 1.65 and <450 mcd/m²/lx when those with RI 1.5 were used. RW >100 mcd/m²/lx was measured with the 'premium' and the 'large' glass

beads and with structured road markings; the 'standard' glass beads in flat lines furnished RW <50 mcd/m²/lx.
After nine months, meaningful differences between the evaluated road marking systems were measured. On average, 69% (range: 36–97%) of the initial R_L was retained, indicating sustained but decreasing visibility under traffic exposure. In all cases, systems with 'premium' glass beads showed higher R_L retention compared to those with 'standard' glass beads; lowest R_L was measured with 'large' glass beads. Higher R_L was also measured in thermoplastic with rosin-based binders than for hydrocarbon-based systems.
To assess the reasons for dissimilar performance, samples were collected for analysis under microscope in laboratory. Observation revealed that in rosin-based thermoplastic only a few glass beads were extracted from the film, while those with hydrocarbon-based binder were almost devoid of glass beads. Unexpectedly, R_L of structured cold plastic was quite low; it was traced to significant dirt contamination.
After traffic exposure, RW values were significantly lower than R_L, with RW >35 mcd/m²/lx measured in the structured and in flat lines only when the 'premium' glass beads (RI 1.65) were used. The 'large' glass beads (RI 1.5), which initially improved wet performance due to their size facilitating moisture drainage, did not maintain their properties; microscope analysis revealed their extraction from the film and physical damage caused by tyres of passing vehicles.
From driver's perspective, visibility distances in daytime were circa 50 m, without significant differences between materials. Because some of the pedestrian crossings were externally illuminated, nighttime visibility under dry conditions was not affected by glass beads and was circa 140 m. Differences appeared only under wet nighttime conditions, where the structured 'zebra' stripes and flat lines reflectorised with 'premium' glass beads (RI 1.65) were visible from the distances >120 m and other markings from circa 90 m. These differences could be attributed to the dissimilar RW. The increased visibility distances at night as compared to daytime could be assumed to be a result of retroreflection, which enhanced the contrast.

Discussion and conclusions

Evaluation of road markings used for 'zebra' stripes pedestrian crossings showed meaningful differences between materials. Performance was influenced by binder type, marking structure, and glass beads choice. Refractive index of glass beads meaningfully affected nighttime visibility and retroreflection. The use of 'premium' glass beads (RI 1.65) lead to the best overall results, while 'standard' beads (RI 1.5) provided lower performance. The use of 'large' beads (RI 1.5) furnished initially good wet night visibility, but it was not maintained under traffic.
Thermoplastic road markings with rosin-based binders showed higher retention of R_L and RW than hydrocarbon-based systems, which was attributed to the differences in glass beads adhesion. Structured road markings were providing good visibility under wet nighttime conditions due to their design for moisture drainage, even though their R_L remained lower than with flat markings because of dirt accumulation. Visibility distances under wet night conditions were highest with materials providing RW >35 mcd/m²/lx. The differences between flat and structured road markings can be attributed primarily to the presence or absence of the structure and not the material type.
Based on these results, the use of 'premium' glass beads with refractive index 1.65 and structured road markings appears to be a better choice than selection of flat lines and glass beads with RI 1.5. For flat lines, thermoplastic with rosin-based binders represent a suitable choice because of good glass beads adhesion. Proper selection and maintenance of road markings are

essential for ensuring road safety through sustained visibility for drivers and support of driver assistance systems.

International Co-operation on Theories and Concepts in Traffic Safety

Systematic Review of speed evaluation and monitoring methods for road safety: a decade of research

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Introduction

Speed is universally recognized as a primary determinant of road safety, directly influencing both the probability of crash occurrence and the severity of resulting injuries. According to the World Health Organization, speed contributes to approximately one-third of fatal road crashes globally. Over the past decade, the landscape of speed monitoring has undergone a significant transformation. Traditional infrastructure-based measurements, such as radar guns and loop detectors, are increasingly being supplemented, and in some cases replaced, by advanced vehicle-based data and analytical frameworks. This shift is driven by the rise of Intelligent Transportation Systems (ITS) and the exponential growth of data science. In this context, Artificial Intelligence (AI) and Machine Learning (ML) techniques are increasingly playing a fundamental role. A central finding of this systematic review is the burgeoning role of AI and ML in modern road safety research. The transition from purely descriptive statistics to predictive and prescriptive analytics is largely powered by AI. Researchers are now leveraging AI to explore non-linear relationships and complex interactions within high-dimensional datasets that traditional regression models often fail to capture. Machine learning algorithms are being integrated into hybrid modelling frameworks to enhance predictive performance regarding speed behavior and crash risk. For instance, AI techniques are frequently applied to:

- *Predictive Speed Modelling*: Estimating operating speeds and consistency across complex road geometries where traditional models lack flexibility.
- *Surrogate Safety Measures (SSMs)*: Using computer vision and AI-based video analytics to identify near-miss events and traffic conflicts, providing a proactive safety assessment without waiting for actual crash data to accumulate.
- *Driver Behavior Analysis*: Classifying driving styles (e.g., aggressive vs. conservative) and predicting reactions to real-time interventions, such as Variable Speed Limits (VSL), using algorithms like Random Forests.
- *Automated Data Processing*: Managing and extracting meaningful speed profiles from massive streams of Floating Car Data (FCD) and smartphone sensing.

The integration of AI represents a shift in "epistemological orientation," prioritizing predictive accuracy and the ability to handle the "noise" inherent in real-world traffic data.

Methodology

This study follows a rigorous systematic approach based on the JBI Manual for Evidence Synthesis. A massive search was conducted across Web of Science and Scopus for the period 2015–2024, focusing on keywords related to speed, evaluation, and road safety.

The initial pool of 738 documents was refined through a multi-step screening process:

- *Consolidation*: Removal of duplicates and standardization using the Bibliometrix R-package.

- *Impact Filtering*: Exclusion of studies with low scientific visibility (fewer than one citation per year) to ensure the consideration of the most influencing papers.
- *Thematic Screening*: Manual review of titles and abstracts to exclude irrelevant topics like rail safety, autonomous vehicle hardware, or pedestrian-only studies.

A final dataset of 223 documents was retained for bibliometric and qualitative analysis.

Results

The analysis reveals a steady growth in scientific interest, peaking in 2020. The research is highly interdisciplinary, spanning engineering, psychology, and data science. Accident Analysis and Prevention emerges as the leading journal in the field, followed by Traffic Injury Prevention and Applied Sciences. Geographically, China leads in publication volume, followed by the USA and Australia.

A qualitative classification of the literature identified several key "methodological families":

- *Crash-based models*: Linking speed indicators to frequency and severity.
- *Geometric-focused studies*: Analyzing behavior on horizontal curves and at intersections.
- *Data acquisition techniques*: Comparing traditional sensors with FCD and driving simulators.
- *Analytical frameworks*: Categorizing studies into traditional statistical, Bayesian, and AI-driven approaches.

The review emphasizes that the choice of methodology depends on the specific safety objective.

- *Floating Car Data (FCD)*: Provides unprecedented network-level coverage but requires a deep cleaning to account for sampling biases. This screening and adjustment process is most time addressed by AI.
- *Driving Simulators*: Allow for controlled behavioral experiments, but face challenges regarding ecological validity.
- *Bayesian Frameworks*: Offer robust handling of uncertainty and small sample sizes, though they require significant statistical expertise.

The "transversal perspective" adopted in this review clarifies that no single method is sufficient. The most effective road safety strategies now involve an integrated approach, combining high-resolution data (like GPS trajectories) with advanced AI modelling to proactively identify hazards related to speed before crashes occur.

Conclusions and Discussion

This systematic review confirms that speed remains a central, albeit complex, risk factor. The field is moving away from static, point-based observations toward dynamic, network-wide monitoring. The increasing availability of high-resolution data and AI-driven analytical tools offers significant opportunities for road authorities to implement "Safe System" approaches.

However, the review also notes a "long tail" in research impact: while many studies apply AI, only a few influential contributions drive the methodological frontier. Future research must focus on the transparency and interpretability of AI models, the so-called "black box" problem, to ensure that data-driven insights can be effectively translated into actionable safety policies and infrastructure design. In conclusion, the synergy between innovative data sources and artificial intelligence is redefining how we understand and manage vehicle speed, providing the foundation for a more proactive and data-informed era of traffic safety.

International Co-operation on Theories and
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Behavioural Responses to a Light Rail Crossing Warning System: Qualitative Insights from Helsinki

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Introduction

Understanding how infrastructure interventions influence active mobility behaviour is crucial for developing safer, more inclusive urban environments. This is particularly relevant at tram and light-rail crossings, where collisions with unprotected road users can have severe outcomes, yet official crash statistics may underestimate the problem due to underreporting for low-severity incidents. Tram-specific risks also differ by mode: pedestrians face elevated injury risk near tracks and at stops/intersections, while cyclists are vulnerable to single-bicycle falls when tyres become trapped in rails. Risky behaviour can also be reinforced by low perceived tram collision risk and an ambiguous crossing design. Against this backdrop, behavioural observations provide important complementary safety evidence base by helping to infer the accident development process from near-misses, delayed detection, waiting/decision behaviour, and compliance patterns.

This study evaluates the responses of vulnerable road users (VRU), including pedestrians and cyclists, to a real-time light-and-audio warning system at an unsignalized light-rail crossing in Helsinki, Finland. The case site is part of the Line 15, a light-rail corridor where trams have legal priority over pedestrians and cyclists at crossings, unlike most conventional tram crossings in Helsinki. Additionally, the study area's intersection geometry creates a blind spot between tram drivers and VRUs.

Methodology

To assess behavioural changes associated with the warning system, a before-and-after video observation study was conducted at the light-rail crossing. Video data were collected during morning and evening peak hours before installation, in August–September 2024, and after installation, in August–September 2025. RUBA (Road User Behaviour Analysis) software was used to identify and register timestamps for each tram arrival at the intersection. Subsequently, each timestamp was reviewed manually to identify observable interactions between trams and VRUs, including pedestrians and cyclists. The analysis focused on qualitative behavioural indicators. The same observation procedure and classification criteria were applied to the before and after periods to support comparability between the two observation phases.

Tram-VRU interactions were classified into five categories: (1) potentially safety-critical interactions, such as situations in which VRUs crossed the intersection as a tram quickly approached; (2) situations in which VRUs waited for an extended period before the tram entered the intersection; (3) occasions in which VRUs waited significantly after the tram had cleared the intersection; (4) cases in which VRUs became aware of an approaching tram only at a late

stage; and (5) interactions that were otherwise safe, but in which the VRU did not comply with crossing regulations.

Results

The results indicate a clear improvement in VRU awareness regarding approaching trams. After installation of the warning system, situations in which pedestrians or cyclists appeared to become aware of an approaching tram only at a late stage were reduced to very few observed cases, suggesting a marked improvement in hazard awareness at the crossing. Likewise, a substantial reduction in potentially safety-critical interactions was observed after the installation of the warning system. In parallel, observed violations of the priority rules at the crossing decreased, suggesting improved compliance with tram right-of-way.

Qualitative analysis identified three dominant behavioural patterns: heightened caution with early stopping, partial compliance through moderate deceleration, and non-compliance. A recurrent observation was that pedestrians and cyclists remained waiting within the intersection for extended periods after tram passage, suggesting misinterpretation of the warning system as a conventional signalised crossing, similar to a level crossing. Contextual factors such as low visibility, unexpected tram movements, and complex multimodal interactions further influenced behaviour and occasionally generated ambiguity.

Discussion and conclusions

Overall, the findings highlight both the potential and limitations of technology-driven interventions. The warning system appeared to improve hazard awareness and regulatory compliance at an unsignalized tram crossing. However, its effectiveness was mediated by user interpretation and contextual conditions. In particular, the observed tendency of some pedestrians and cyclists to continue waiting after the tram had cleared the intersection suggests that the warning signal may, in some cases, be interpreted as a traffic control device rather than as a hazard warning. This indicates that, while such systems can improve safety, they can also produce secondary inefficiencies or ambiguity in user behaviour.

These results underscore the need for integrated safety strategies that combine active mobility intervention systems with appropriate infrastructure design, education, and enforcement. This is especially important in locations where regulatory norms differ from common user expectations. The observations provide qualitative evidence on context-specific behavioural responses and can inform the development of theoretical frameworks and policy measures that better reflect the complexities of urban mobility. Incorporating these insights may support more effective and socially equitable scaling of similar interventions at the city level, both from modelling and policy-making perspectives.

International Co-operation on Theories and Concepts in Traffic Safety

A Conflict-Based Diagnostic Framework for Signalized Intersections Integrating Conflict Characteristics and Signal Phases

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- Introduction

Road safety assessment at signalized intersections has traditionally relied on crash data. However, crashes are relatively rare events, often underreported, and inherently retrospective, limiting their effectiveness for proactive safety analysis. Despite these limitations, crash-based studies have enabled the identification of several key crash risk mechanisms and associated risk factors at signalized intersections, including inadequate change and clearance intervals, permissive turning conflicts, and insufficient pedestrian priority (Chandler et al., 2013; Mcgee et al., 2011; Ogden et al., 1994). To overcome the limitations of crash-based approaches, researchers have increasingly adopted proactive safety assessment methods based on traffic conflicts, where near-miss interactions are interpreted as indicators of unsafe conditions (Gettman & Head, 2003; Hyden, 1987). In this context, surrogate safety measures (SSMs), such as Time-to-Collision (TTC) and Post-Encroachment Time (PET), have been widely used to quantify interaction risk (Zheng et al., 2021), while speed (S) is commonly incorporated to capture potential collision energy and injury severity. Although previous studies have successfully employed traffic conflicts for crash risk detection, prediction, and forecasting, they provide limited insight into safety diagnosis, such as the identification of the underlying operational deficiencies that generate unsafe conditions. Building on the premise that conflicts are precursors of crashes, this study proposes a framework that integrates conflict characteristics with signal phase information to infer crash risk factors at signalized intersections.

- Research methodology

The proposed framework follows a dual-source diagnostic approach combining conflict characteristics and signal-phase context. Road user trajectories are extracted from video data using automated tracking techniques (Ismail et al., 2009; Laureshyn et al., 2010). Conflicts are identified using TTC, PET, and S, where TTC and PET represent spatiotemporal proximity and S reflects potential collision severity. Each interaction is classified by type, road user category, and geometry based on velocity angles, enabling mapping to standard crash types (e.g., rear-end, angle, sideswipe, head-on) (Chandler et al., 2013; Ogden et al., 1994). Conflicts are then associated with signal phase conditions using established timing principles (Mcgee et al., 2011). A rule-based diagnostic model validated relatively with respect to conflict indicator threshold variation, interprets low TTC/PET and high S as indicators of severe interactions. Conflict type is derived from interaction geometry based on velocity angles, while the occurrence of conflicts within specific signal phases reveals potential operational deficiencies.

Conflict risk mechanisms are inferred and linked to crash risk mechanisms, associated risk factors and appropriate countermeasures, identified from 160 crash-based studies.

- Results

A four-leg signalized intersection was monitored for five days under daytime conditions, for a total of 36 hours (approximately 7 hours per day). Based on threshold values of 3 seconds for TTC and PET, the conflict dataset included 3699 crossing conflicts identified by 987 TTC, 1138 PET and 1574 PET and TTC events with their corresponding speed values. Of these, 3092 occurred during the green phase, 241 during the yellow phase, and 366 during the red phase. The identified crash risk mechanisms include: gap acceptance failure, late clearance, and abrupt braking. The associated risk factors derived from crash-based studies include: permissive turns, high approach speed, and short or inadequate yellow phase. Corresponding countermeasures include: optimising turning phasing, reassessment of clearance interval, and channelisation.

- Discussion and conclusions

This study demonstrates that traffic conflicts can support safety diagnosis, not only detection. By integrating conflict indicators (TTC, PET, and S), interaction typology, and signal-phase context, the proposed framework provides a transparent and interpretable method for identifying operational deficiencies at signalized intersections.

The inclusion of S enhances the framework by incorporating severity potential alongside temporal indicators. The primary contribution lies in establishing a diagnostic link between observable conflict patterns and known crash-based risk factors, enabling targeted and proactive safety interventions.

While the framework does not establish causality and depends on trajectory extraction accuracy, it offers a practical and scalable alternative to traditional crash-based analyses. Overall, integrating conflict characteristics with signal timing enables more proactive and actionable safety assessment in urban intersections.

- References

Chandler, B. E., Myers, M. C., Atkinson, J. E., Bryer, Thomas., Retting, R., Smithline, J., Trim, J., Wojtkiewiez, P., Thomas, G. B., Venglar, S. P., Sunkari, S., Malone, B. J., & Izadpanah, P. (2013). *Signalized Intersections Informational Guide Second Edition*. 1–323. http://sofety.fhwa.dot.gov

Gettman, D., & Head, L. (2003). Surrogate Safety Measures From Traffic Simulation Models Final Report. *Publication No: FHWA-RD-03-050*, 126.

Hyden, C. (1987). *The development of a method for traffic safety evaluation: The Swedish Traffic Conflict Technique*.

Ismail, K., Sayed, T., Saunier, N., & Lim, C. (2009). Automated analysis of pedestrian-vehicle conflicts using video data. *Transportation Research Record*, (2140), 44–54. https://doi.org/10.3141/2140-05

Laureshyn, A., Svensson, Å., & Hydén, C. (2010). Evaluation of traffic safety, based on micro-level behavioural data: Theoretical framework and first implementation. *Accident Analysis and Prevention*, *42*(6), 1637–1646. https://doi.org/10.1016/j.aap.2010.03.021

Mcgee, H., Moriarty, S. K., Eccles, K., Liu, M., Gates, T., & Retting, R. (2011). *Guidelines for Timing Yellow and Red Intervals At Signalized Intersections Final Report Acknowledgment of Sponsorship*. (03).

Ogden, K., Newstead, S., Ryan, P., & Gantzer, S. (1994). Factors Affecting Crashes at Signalised Intersections. *Monash University Accident Research Centre*, (62). http://monash.edu.au/miri/research/reports/muarc062.pdf

Zheng, L., Sayed, T., & Mannering, F. (2021). Modeling traffic conflicts for use in road safety analysis: A review of analytic methods and future directions. *Analytic Methods in Accident Research*, *29*, 100142. https://doi.org/10.1016/j.amar.2020.100142

International Co-operation on Theories and
Concepts in Traffic Safety

A Study on Driving Behavior Characteristics of MCI drivers on Public Roads

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Background and Objective
In Japan, traffic accidents involving older drivers have become a major societal concern, prompting policy interventions such as the introduction of cognitive function assessments during driver's license renewal. However, these evaluations are typically conducted in controlled and artificial environments, which may not accurately reflect drivers' everyday behavior. Many older drivers report discrepancies between their performance in such tests and their habitual driving, raising questions regarding the validity of existing evaluation frameworks. The objective of this study is to elucidate the differences between driving behavior observed in short-term experimental settings and that exhibited in natural, everyday contexts. In particular, this study focuses on older drivers with mild cognitive impairment (MCI) or suspected cognitive decline, aiming to examine the relationship between cognitive function and real-world driving behavior and to identify characteristic risky behaviors in daily driving.

Methodology
The study participants were older adults residing in Zama City, Kanagawa Prefecture. Cognitive function was assessed using the Touch Panel-type Dementia Assessment Scale (TDAS). Participants with TDAS scores of 7 or higher, indicating possible MCI or dementia, were selected for detailed analysis.
Driving recorders and acceleration sensors were installed in the participants' personal vehicles to capture their natural driving behavior over a period of one to two months. The final sample consisted of 30 drivers (mean age: 74.7 years). To mitigate the influence of observation bias due to participants' initial awareness of being monitored, data obtained during the latter half of the observation period were primarily employed in the analysis.
The collected dataset included quantitative measures such as driving time, trip frequency, and instances of sudden acceleration and braking, as well as qualitative observations derived from video recordings, including compliance with traffic नियमs, situational awareness, and attention to surrounding conditions.

Results
The results indicate that older drivers rely on automobiles even for very short trips, typically lasting one to two minutes, underscoring the essential role of driving in their daily lives. Temporal changes in driving behavior were also observed. During the initial phase of the observation period, participants exhibited relatively cautious behavior, including frequent sudden braking, likely attributable to heightened awareness of being monitored. In contrast,

during the later phase, as participants became accustomed to the recording equipment, more naturalistic driving patterns emerged, accompanied by an increased occurrence of risky behaviors.
Commonly observed risky behaviors included failure to stop at stop signs, unsafe right-turn maneuvers (e.g., shortcutting), insufficient attention to pedestrians at intersections, and failure to yield to other road users. Distracted driving behaviors, such as interacting with mobile devices or engaging with passengers, exhibited substantial inter-individual variability.
Furthermore, considerable heterogeneity was observed in driving behavior among participants, even among those with similar levels of cognitive decline. While some drivers frequently violated stop regulations, others demonstrated tendencies such as excessive speed on narrow roads or inadequate situational awareness at intersections. Notably, the presence of passengers was found, in certain instances, to contribute to distraction rather than enhance safety.
A comparison between driving behavior in controlled environments (e.g., driving school assessments) and that observed in daily life revealed significant discrepancies. In experimental settings, drivers often exhibited overly cautious behavior due to psychological tension, resulting in actions such as abrupt braking. However, such behavior did not necessarily correspond to their habitual driving patterns.
Additionally, a single self-inflicted accident was documented during the observation period. The incident involved a collision with a utility pole while the driver was distracted, suggesting that accidents may arise from a combination of routine risky behaviors and situational factors rather than a single conspicuous error.

Discussion and Conclusions

The findings of this study demonstrate that driving behavior in everyday contexts differs substantially from that observed in short-term experimental or evaluative settings. The commonly reported perception among older drivers that their behavior during formal assessments differs from their routine driving is thus empirically supported. While controlled testing environments may induce cautious behavior, they may fail to capture habitual risky actions occurring in real-world contexts.
Moreover, the study highlights that risky driving behaviors among older drivers with cognitive impairment are highly individualized, rather than being uniformly determined by cognitive decline. This variability suggests that standardized, one-size-fits-all evaluation methods may be insufficient for accurately assessing real-world driving safety.
The results further indicate that certain types of risky behavior - particularly those related to inattention or insufficient situational awareness - may not be reflected in conventional indicators such as sudden acceleration or deceleration. This finding points to a critical limitation of current driving evaluation systems that rely primarily on vehicle dynamics.
In conclusion, the study underscores the necessity of developing more comprehensive and ecologically valid approaches to driving assessment, incorporating long-term monitoring and a broader range of behavioral indicators. Such approaches would enable more accurate evaluation of driving safety and contribute to the development of effective interventions aimed at reducing risks among older drivers.

International Co-operation on Theories and Concepts in Traffic Safety

Evaluating Low-Cost Safety Interventions in School Zones: A Driving Simulator Study

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- **Introduction**

School zones are among the most safety-critical environments in urban road networks. Road traffic injuries remain the leading cause of death among children and young adults, with a significant proportion of incidents occurring in areas of high child activity, such as school zones. Infrastructural interventions can address this problem by either physically compelling drivers to adjust their behaviour or heightening their awareness of the approaching zone. However, the comparative effectiveness of pre-zone versus within-zone measures, and particularly the behavioural consequences of combining these intervention types, remains insufficiently studied. This study aims to fill that gap by systematically evaluating the impact of four low-cost interventions, individually and in combination, on driver behaviour within and approaching school zones. The specific objectives are to quantify the effect of each intervention on vehicle speed, acceleration/deceleration, and to determine which intervention combinations produce the most significant behavioural changes.

- **Research Methodology**

A full-scale driving simulator study was conducted at the Transportation Research Institute (IMOB), Hasselt University. The simulator featured a static Ford Mondeo mock-up integrated with a three-projector spherical screen system, operated via STISIM Drive 3 software. The deployed interventions are categorised as pre-zone/within-zone when deployed before or at the school zone, and as physical/perceptual.

Four interventions were examined: coloured surfacing (CS) (perceptual, within-zone), curb extensions using flexible poles (physical, within-zone), advanced warning signs with flashing beacons (perceptual, pre-zone), and chicanes using flexible poles (physical, pre-zone). These were combined into all nine possible conditions, including a no-intervention baseline, and embedded within a 13.8 km simulated route set in a realistic Belgian urban environment.

A total of 56 fully licensed drivers participated, with 51 retained following interquartile range-based outlier exclusion applied across two behavioural parameters. Participants were randomly assigned to one of three scenario orderings to control for sequence effects. Driving behavioural data, including vehicle speed and acceleration/deceleration, were recorded at six data collection points, capturing behaviour at the end of the pre-zone intervention, the school zone entry, mid-zone, the zebra crossing in front of the school, and two further points within the zone. Statistical significance was assessed using exploratory linear mixed models (LMM) in IBM SPSS Statistics, with participant included as a random effect.

- **Results**

All interventions, except advanced warning signs alone and chicane + curb extension, produced a statistically significant reduction in mean speed relative to the baseline (Table 1). The combination of advanced warning signs with curb extensions yielded the largest mean speed reduction (1.919 km/h), followed by curb extensions alone and chicanes alone. Combining two physical interventions (chicane and curb extension) was counterproductive, yielding the smallest mean difference (0.666 km/h) with no statistical significance.

Table 1. Pairwise comparisons of baseline with all other intervention combinations for speed.

Intervention		Mean Difference	Std. Erro	df	Sig	95% Conf. Interval Diff. Lower Bound	Upper Bound
Base+ Base	AWS + Base	0.769	0.268	2605.866	0.149	–0.089	1.627
	AWS + CS	0.899	0.268	2605.866	0.029	0.042	1.756
	AWS + Curb	1.199	0.268	2605.866	<0.001	1.061	2.776
	Base + CS	0.952	0.268	2605.866	0.014	0.095	1.810
	Base + Curb	1.488	0.268	2605.866	<0.001	0.631	2.346
	Chicane + Base	1.319	0.268	2605.866	<0.001	0.461	2.176
	Chicane + CS	1.196	0.268	2605.866	<0.001	0.338	2.053
	Chicane + Curb	0.666	0.268	2605.866	0.467	–0.191	1.524

Table 2 shows the pairwise comparison for acceleration. Chicane-inclusive combinations produced significant upstream deceleration followed by notable post-intervention acceleration, consistent with a stop-and-go behavioural pattern. The chicane paired with colored surfacing showed the strongest deceleration effect (–0.306 m/s²), closely followed by the chicane alone (–0.253 m/s²).

Table 2. Pairwise comparisons of baseline with all other intervention combinations for acceleration.

Intervention		Mean Difference	Std. Erro	df	Sig	95% Conf. Interval Diff. Lower Bound	Upper Bound
Base+ Base	AWS + Base	0.005	0.042	360.276	1.000	–0.131	0.142
	AWS + CS	0.016	0.042	360.276	1.000	–0.121	0.152
	AWS + Curb	0.022	0.042	360.276	1.000	–0.115	0.158
	Base + CS	–0.003	0.042	360.276	1.000	–0.140	0.133
	Base + Curb	0.008	0.042	360.276	1.000	–0.128	0.144
	Chicane + Base	–0.253	0.042	360.276	<0.001	–0.389	–0.117
	Chicane + CS	–0.306	0.042	360.276	<0.001	–0.442	–0.169
	Chicane + Curb	–0.137	0.042	360.276	0.047	–0.274	–0.001

- **Discussion and Conclusions**

The results demonstrate that pairing a visual pre-zone measure with a physical within-zone measure produces the most effective and sustained reduction in driver speed, with the advanced warning sign and curb extension combination yielding the largest statistically significant mean speed reduction (1.919 km/h). This synergy occurs because the advance warning primes drivers to reduce speed earlier, suppressing the post-intervention acceleration rebound that was clearly observed when physical interventions were used in isolation or paired together.

Keywords: School zone; Traffic calming; Driving simulator; Vulnerable road users; Physical interventions; Perceptual interventions.

International Co-operation on Theories and Concepts in Traffic Safety

Legal Awareness and Non-Compliance in E-Scooter Riding Surfaces: Evidence from Slovenia

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Introduction

E-scooters represent an alternative form of urban transportation, especially for short distances; yet, their swift expansion without adequate infrastructure and comprehensive laws and regulations caused safety issues and operational difficulties. In Slovenia, e-scooters are categorised as light motor vehicles according to the Road Traffic Rules Act, defined as seatless, single-rider, standing vehicles with a maximum design speed of 25 km/h, with a handlebar, standing platform, and mandatory safety equipment. Riders must utilise designated cycle paths and lanes when available, or, if unavailable, the right-hand edge of the road on urban roadways with speed limits of 50 km/h or lower; riding in pedestrian zones is allowed exclusively at walking speed without jeopardising pedestrians, while riding on pavements is forbidden.

In practice, e-scooters are used beyond legally permitted surfaces across urban and other areas. This research therefore examines Slovenian e-scooter riders' knowledge of where e-scooter use is permitted and whether this knowledge is reflected in actual riding behavior, providing insight into the effectiveness of information dissemination and rider decision-making.

Research methodology

This research utilises a questionnaire to assess attitudes towards e-scooters and their utilisation in Slovenia. A total of 1,137 respondents participated, with 134 e-scooter users included in the study, suggesting a relatively low rate of e-scooter usage in the dataset. The complete survey consisted of 31 questions covering all aspects of e-scooter usage, whereas this research concentrates on riding behaviour, permitted riding areas, and awareness of applicable legislation. The studied sample includes 80 males (59.7%) and 54 women (40.3%), aged 15 to 65 years (mean = 39.90, SD = 12.84).

Results

E-scooters are predominantly utilised on cycling infrastructure, i.e. cycle paths or tracks (75.74%), cycling lanes (53.68%) and roads in urban areas lacking cycling facilities (48.53%); yet their use in prohibited or ambiguous areas is also prevalent, especially on sidewalks (49.26%), pedestrian zones (30.88%), non-public surfaces (30.15%) and, to a lesser extent, roads outside urban areas (19.85%). In all, 36.76% of respondents (50 persons) indicate that they never ride on prohibited surfaces, whilst 59.56% acknowledge doing so at least

occasionally, however the level of awareness regarding the rule remains unassessed. Most non-compliant riders indicate that they ride exclusively on pavements (39.71%), followed by those who ride just on roads outside urban areas (10.29%) or on both prohibited surfaces (9.56%).

The perceived legality is largest for cycling infrastructure, i.e.cycle paths or tracks (84.56%), cycling lanes (72.06%) and roads within urban areas without cycling facilities (57.35%), while considerable uncertainty continues to exist regarding pedestrian zones (21.32%), pavements (28.68%), roads outside urban areas (32.35%) and non-public surfaces (38.24%). Notwithstanding the significant identification of bicycle infrastructure, the overall legal certainty is inadequate, with just one respondent accurately identifying entirely allowed surfaces. The alignment between legal perception and behaviour is particularly apparent regarding cycling infrastructure (85.19% for cycle paths and 72.59% for cycling lanes), while pedestrian-oriented environments exhibit the highest degree of misunderstanding, indicating that non-compliance is predominantly influenced by regulatory ambiguity.

Self-reported riding in environments perceived as prohibited occurs most frequently on sidewalks (27.74%) and in pedestrian zones (16.30%), followed by roads within built-up areas lacking cycling infrastructure (9.63%) and roads outside built-up areas (6.57%). Such behaviour is least common on non-public surfaces (4.44%) and on cycling infrastructure (2.96% on cycle paths or tracks and 3.70% on cycling lanes).

Discussion

This study's primary contribution is the empirical finding of significant differences between e-scooter riders' actual behaviour and knowledge of permissible riding situations, highlighting regulatory ambiguity as a principal factor in non-compliance. Although riders typically acknowledge the legality of cycling infrastructure, their legal perception of pavements and pedestrian areas is notably lacking, resulting in common misinterpretation and unsuitable surface selection. This highlights two primary concerns: ambiguity regarding pedestrian-oriented areas, linked to elevated violation rates, and the underutilisation of safe, legally sanctioned infrastructure stemming from misinterpretation or uncertainty. Collectively, these data indicate that current methods of providing regulatory information are inadequately successful, leading to a significant and enduring knowledge gap among riders.

Concerning ways to enhance compliance, respondents indicate the most endorsement for increased enforcement, succeeded by elevated fines and awareness initiatives, whilst compulsory registration or testing garners lesser support. This trend indicates that riders may perceive enforcement as both a deterrent and a method for clarifying regulations via visible and consistent execution. The findings suggest that a blend of targeted informational strategies and proportionate enforcement is probably more acceptable and effective than merely imposing additional administrative requirements.

Funding

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Validation of Point Cloud of Active Road Users LiDAR Tracking Data for Road Safety Assessment

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Introduction. It is well established that conflicts among road users help us understand traffic hazards and design the most appropriate safety countermeasures. A conflict occurs when two or more road users approach each other in space and time to the extent that a collision is possible. To use traffic conflicts to estimate safety at a given location, it is necessary to track and record the trajectories of road users and vehicles. Currently, image processing is the main tool for recording trajectory data. However, this approach has several drawbacks, including sensitivity to lighting, high computational demands and costs, information loss, issues caused by projecting the 3D world onto a 2D image, and privacy concerns. Over the last 15 years, LiDAR has become a valid alternative to cameras. It offers several benefits: it is unaffected by ambient lighting, captures 3D data directly, requires relatively little computational effort, and does not record sensitive personal details such as facial features or vehicle plates. As interest and efforts increase to optimise LiDAR deployment for detecting road traffic conflicts, it is also essential to evaluate its reliability, accuracy, drawbacks, and limitations. This study is an early step in validating a LiDAR-based hardware and software system used by the Road Safety Laboratory at Politecnico di Torino to collect trajectory data for traffic conflict analysis. Our primary objective is to expand the system's application to detect traffic conflicts involving active road users such as cyclists and pedestrians.

Method. Two M8-Prime Ultra LiDAR sensors (Quanergy Solutions, Inc.) were used. The sensors provide point-cloud data at 5–20 Hz, with a 360° horizontal field of view and a horizontal frequency-dependent angular resolution of 0.033°–0.132°, accuracy <3 cm, maximum nominal range of 200 m, and a 20° vertical field of view across eight beam layers. Additionally, EMLID REACH RS2+ GNSS receivers were employed in Real Time Kinematic (RTK) method to define high-precision positioning as reference ground truth. The two LiDARs were installed on a 2-meter-high tripod in a large, traffic-free area, where a pedestrian and a bicyclist, both equipped with the EMLID GNSS receivers, were interacting. Participants were asked to remain within the two LiDAR coverage areas and to intentionally interact by getting close to

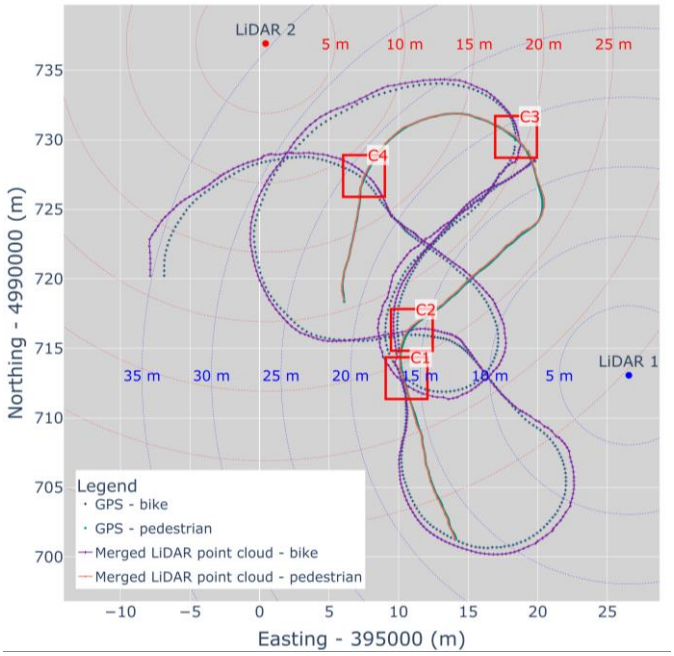


Figure 1. Cyclist and pedestrian trajectories and conflicts (GNSS solutions only)

one another whenever possible (Figure 1). A total of four conflicts were observed and recorded (see Figure 1, conflicts C1, C2, C3 and C4). During post-processing, QORTEX DTC™ processed the point cloud data to extract trajectory details such as position, velocity, acceleration, and heading for all detected objects at each timestamp. It also determined the size of the bounding boxes enclosing the point clouds of interacting participants. Three tracking solutions were created: one from each LiDAR cloud (L1 and L2) and a combined cloud merging points from both LiDARs (L1+2). Pedestrians and cyclists were approximated as bounding boxes from the detected point clouds. For comparison, GNSS tracking points were linked to fixed-size bounding boxes representing pedestrians and cyclists. Time-to-collision (TTC) was calculated using proprietary Python code, accounting for different bounding-box and tracking solutions. TTC was computed only when the code identified a common conflict area based on the trajectories' headings and speeds.

Results and conclusions. Table 1 presents the distances between the centres of the bounding boxes obtained by associating the three LiDAR solutions with the GNSS solution (the reference ground truth). Although the results indicate that L1 provided the best performance in terms of central tendency and dispersion for both cyclists and pedestrians, it is worth noting that when the LiDARs cooperate, more points can be detected. This was true for the bicycle, as the object's shape can be better defined, even when the orientation between the single LiDAR and the bike is not optimal. In this case, the quality is due to possible variations in the boxes, given the LiDAR bike's viewing angle. Table 2 presents the TTC differences between the three LiDAR solutions with the GNSS. Again, the L1 solution was the most successful in terms of root-mean-square error (RMSE), mean absolute error (MAE), and standard deviation of errors (SDE). However, when the bounding boxes and trajectories were obtained by overlapping the point clouds from L1+2, we captured more data and gained a better understanding of the interaction. The four conflicts detected by the GNSS had minimum time-to-collision values of 0.82 s, 1.06 s, 0.08 s, and 1.27 s, respectively. The three LiDAR solutions also detected the same four conflicts, but with different values. The L1+2 solution was closest to the GNSS values: 0.66 s, 0.74 s, 0.03 s, and 0.57 s, respectively. These differences can be attributed to variations in bounding box sizes, trajectories, and headings, which, though small, could yield meaningful differences in TTC values.

This study provides insights into the reliability of a LiDAR-based system for tracking active road users. The accuracy of trajectory data and surrogate safety measures for the two road users reveals limitations when using only one LiDAR sensor. These limitations can be addressed by using two LiDARs and analysing their combined point clouds. However, the differences observed between the LiDAR data and GNSS solutions suggest that further, accurate assessments are necessary.

Table 1. Distances (in m) from LiDAR and GNSS positions for the same timestamp

Statistics	Pedestrian			Bicycle		
	L1	L2	L1+2	L1	L2	L1+2
Mean	0.045	0.066	0.052	0.258	0.269	0.321
Median	0.035	0.051	0.048	0.239	0.237	0.309
Min	0.000	0.000	0.000	0.000	0.001	0.000
Max	0.163	0.224	0.152	1.019	1.937	1.357
RMSE	0.056	0.083	0.062	0.306	0.341	0.380
No. points	523	523	523	469	483	543

Table 2. Differences between the TTC (in s) estimated with the three LiDAR solutions and the reference one (GNSS) at the same timestamp.

Statistics	L1	L2	L1+2
RMSE	0.137	0.215	0.152
MAE	0.114	0.201	0.125
SDE	0.081	0.210	0.122
R^2	0.889	0.839	0.919
No. points	24	29	39

International Co-operation on Theories and
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How Safe Are Takeover Control Mechanisms in Conditionally Automated Vehicles under Distracted Conditions?

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Introduction: Conditionally Automated Driving (CAD) systems represent a major transition stage between conventional driving and full vehicle automation. Under SAE Level 3 automation (also called CAD), the vehicle performs the dynamic driving task within specific operational domains, while the human driver is expected to respond to a take-over request (TOR) whenever system limits are reached. Therefore, the takeover process is one of the most safety-critical aspects of automated driving. Previous research has shown that take-over performance depends on several factors, including TOR lead time, traffic complexity, human-machine interface design, and driver state (Tan & Zhang, 2025). Among these factors, the control mechanism used to regain control has become increasingly relevant. In earlier work by the authors (Karimi, Barbin, et al., 2025; Karimi, Hazoor, et al., 2025), three takeover control (TOC) mechanisms were compared: accelerating/braking pedals, pressing a dedicated button, and steering wheel intervention. Results from motorway diverging, merging, and critical (crash site) scenarios showed that take-over performance in terms of safety and effectiveness differs between TOC methods and depends on the scenario analysed. Despite these insights, an important limitation remains. Previous experiments were conducted under attentive conditions (i.e., without enforced/induced distraction), whereas real-world Level 3 users are suspected to engage in non-driving-related tasks during automated mode. Such tasks may include smartphone interaction, infotainment use, reading, or cognitive multitasking. These activities reduce situational awareness, increase response time, and may alter the relative safety of different TOC mechanisms. To address this research gap, the present study investigates the relative safety and performance of three TOC mechanisms under distracted CAD conditions. The main objective is to determine which mechanism remains effective in terms of safety and performance when drivers are distracted during the automated driving mode.

Method: The experiments were conducted in the TRAFIKKLAB at Nord University using a fixed-base driving simulator. The simulated environment represented a motorway section with standard lane geometry, ramps, and surrounding traffic, including merging, diverging, and critical-event conditions (see Figure 1). A sample of 60 Norwegian licensed drivers participated in the study. All participants had prior driving experience and were familiarised with the simulator prior to the experiment to reduce adaptation effects and improve data reliability. A between-subject experimental design was used, and three groups with 20 participants each were formed, meaning that each participant experienced one TOC mechanism

For the distraction, participants were engaged in a secondary visual-cognitive and manual task during automated driving. Specifically, they were presented with a series of quiz questions designed to simulate in-vehicle non-driving-related activities, such as smartphone use or infotainment interactions. Each question was displayed on the vehicle's centre console

touchscreen, and participants were required to select their answer using the touchscreen interface. Each question had a strict time limit of 20 seconds, after which the next question automatically appeared regardless of whether a response had been submitted. This continuous task ensured sustained visual and cognitive distraction during automated driving mode prior to take-over requests. The dependent variables included TOC time (time from TOR to first driver input), maximum resultant acceleration, minimum time-to-collision (TTC), lane deviation after takeover, collision occurrence, subjective workload, and usability ratings.

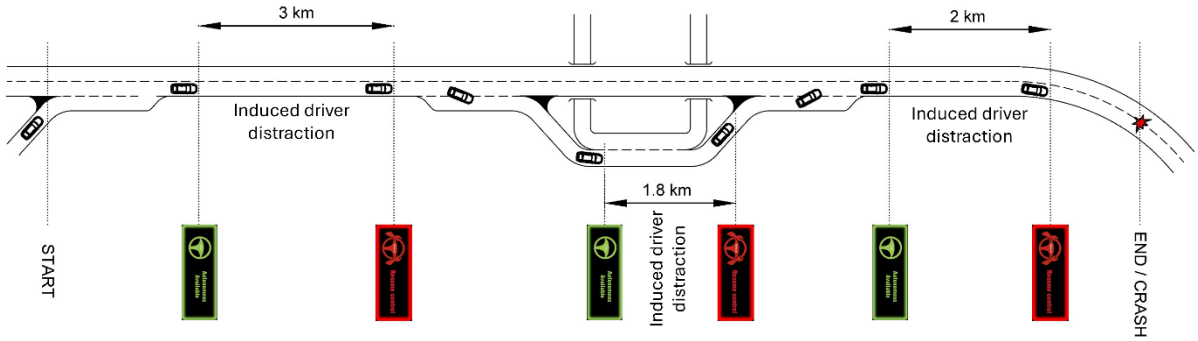


Figure 1. Representation of experimental track and scenario conditions.

Results and Discussion: Data collection for this study is currently ongoing; therefore, final statistical results are not yet available. This section outlines preliminary observations and expected trends based on prior literature and the authors' previous studies. Initial observations suggest that driver distraction negatively affects TOC performance across all TOC mechanisms. Participants engaged in secondary tasks during automated mode appear to require more time to gain attention and respond to the TOR, leading to longer TOC times. Based on previous findings, pedal-based TOC are expected to remain the fastest and most intuitive method under distracted conditions, as they rely on familiar control actions. Button-based TOC may cause longer delays because it requires visually locating and activating the interface. Steering-based TOC are expected to show moderate response times but greater lateral instability during control recovery. Distraction is also expected to reduce TOC quality, reflected in higher acceleration peaks, larger lane deviations, lower time-to-collision values, and increased collision risk, particularly in critical conditions. After data collection is completed, statistical analyses will examine the effects of TOC mechanism, distraction, and manoeuvre type. The findings are expected to provide valuable guidance for designing TOC interfaces that remain safe and effective when drivers are disengaged from the driving task.

Karimi, A., Barbin, A. H., Hazoor, A., Marinelli, G., & Bassani, M. (2025). Comparative Safety Analysis of Take-over Control Mechanisms of Conditionally Automated Vehicles. Accident Analysis & Prevention, 217, Article 108068. https://doi.org/10.1016/j.aap.2025.108068.

Karimi, A., Hazoor, A., Barbin, A. H., Marinelli, G., & Bassani, M. (2025). Impact of take-over control mechanisms on merging operations of conditionally automated vehicles. Transportation Research Part F: Traffic Psychology and Behaviour, 114, 1129-1141. https://doi.org/https://doi.org/10.1016/j.trf.2025.07.024

Tan, X., & Zhang, Y. (2025). Driver Situation Awareness for Regaining Control from Conditionally Automated Vehicles: A Systematic Review of Empirical Studies. Human Factors, 67(4), 367-403. https://doi.org/10.1177/00187208241272071

International Co-operation on Theories and
Concepts in Traffic Safety

Lane change behaviour at turbo roundabouts with markings for lane delineation

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INTRODUCTION

Turbo roundabouts are a relatively new and specific type of roundabout with a non-concentric circulatory roadway with multi-lane sections. Turbo roundabouts have benefits over conventional single-lane roundabouts, such as a higher capacity (Brilon et al., 2014) and ensure a higher level of traffic safety compared to two-lane roundabouts (Fortujin, 2009; Skvain et al., 2017). A key aspect of turbo roundabouts is that, at multi-lane entries, they guide drivers to a specific lane depending on their intended movement prior to entering the roundabout. This reduces the need for lane changes on the roundabout itself, reducing conflict points. Turbo roundabouts are often designed with either physical lane dividers or solid lane markings to discourage drivers from changing lanes after entering the circulatory roadway. Nevertheless, drivers still change lanes at turbo roundabouts with solid lines. This increases the risk of crashes at these locations (Kollascheck et al. 2025) and highlights the importance of studying the use of lane markings on turbo roundabouts. There is, however, limited research into lane changes at turbo roundabouts and how they relate to the layout of turbo roundabouts. The aim of this study is to analyse car drivers' lane changing behaviour at turbo roundabouts with solid lane markings for lane delineation in order to inform decisions on potential design changes aimed at improving safety.

RESEARCH METHODOLOGY

To observe the traffic behaviour at the entire turbo roundabouts, we made use of video observations by drone and trajectories were extracted by using the DataFromSky Viewer. This approach enables the evaluation of the lane choice of car drivers depending on their traffic movement and the roundabout section. For this study, we observed four turbo roundabouts in Germany featuring solid lane markings, as prescribed by the German guidelines, over a twelve-hour period at each location. The locations differ in their infrastructure characteristics, such as the number of arms at the roundabout (either three or four in our case), the shape and size of the central island, and the presence of physical dividers on the approach lanes of the roundabout. To test for differences in the frequency of lane changes, we adopt Chi-square test and pairwise Fisher's exact test.

RESULTS

A considerable number of unauthorised lane changes on the circulatory roadway were observed at all four investigated turbo roundabouts. The frequency of drivers performing lane changes relative to total traffic volume varied significantly across the roundabouts ($p < 0.001$), ranging from 1% to 15%, suggesting that lane changes are influenced by the layout of a turbo roundabout. The relative frequency of lane changes following a wrong entry lane selection for

different movements is shown in Figure 1. Here we can observe that the frequency of drivers making a lane change at the roundabout differs between movement types, with a higher frequency for some U-turns and left-hand turns than for right-hand turns. Comparing the frequency of lane changes between roundabouts for the same movement type shows statistically significant differences ($p < 0.001$) for right-hand turns, left-hand turns and U-turns. Although no correct lane choice prior to entering the roundabout is needed for continuous two-lane movements the frequency of lane changes still ranges from 1.0% to 2.5%. Here we also find significant differences ($p < 0.001$) between the studied roundabouts.

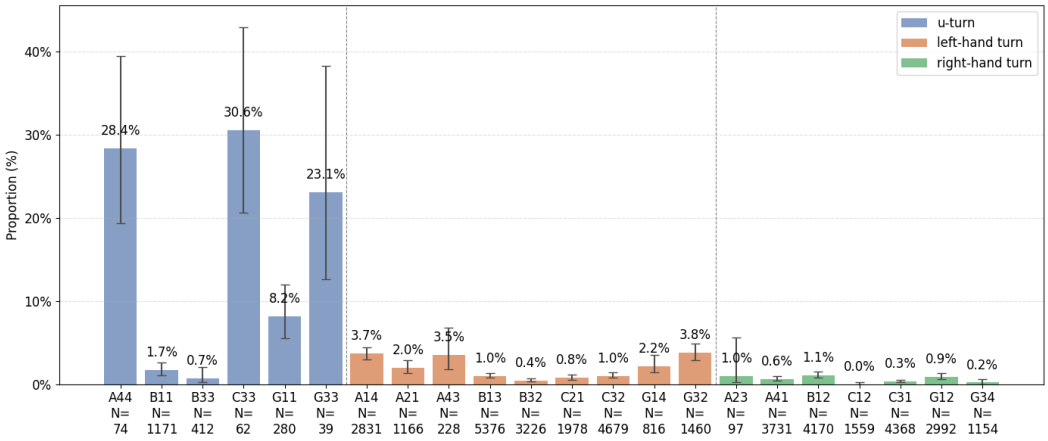


Figure 1: Frequency of lane changes following a wrong entry lane selection by movement. The name of movement denotes the roundabout and the specific movement relation; for example, A44 refers to the movement at the turbo roundabout at Achern from entry arm 4 to exit arm 4. N denotes the total number of observations for each movement.

DISCUSSION AND CONCLUSION

The findings indicate that solid lane markings to delineate the circulatory lanes do not effectively prevent drivers from performing (unsafe) lane changes on the circulatory roadway. The significant differences in lane-change frequency between roundabouts and across movements suggest that the frequencies are not a function of the general layout but are more likely influenced by location-specific characteristics. The lane-change frequencies suggest an insufficient understanding of the required lane selection in the entry sections for left-hand and U-turns at four-arm turbo roundabouts. In contrast, understanding appears to be higher for left-hand turns at 3-arm turbo-roundabouts and at right-hand turns in general. The comparable share of drivers executing lane changes on continuous two-lane movements across all investigated turbo roundabouts indicates that this behaviour constitutes a systematic issue in turbo roundabouts with markings as lane delineation. The frequency of these discretionary lane changes is highest at the two turbo roundabouts with the largest diameters, which suggests that drivers tend to change from the outer lane to the inner lane at the circulator roadway, particularly at larger diameters of around 60 m. A potentially important influencing factor that should be examined more closely in future studies is exposure. Apart from lane addition, drivers can only change lanes if the adjacent lane is unoccupied. The study showed that an observation period of 12 hours per site was insufficient to account for this factor adequately. Although this study took place in Germany, it is possible that similar effects regarding lane changes are present elsewhere as well. This is especially the case for locations where turbo roundabouts are relatively new as is the case in Germany. As such, an international comparison of driver behaviour on turbo roundabouts would be a further avenue of research as well.

International Co-operation on Theories and Concepts in Traffic Safety

Cyclist and pedestrian self-reported accidents – patterns and prevention efforts

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Introduction

Most road safety work is based on official statistics: police accident reports. These data involve substantial levels of underreporting, particularly when it comes to vulnerable road users and/or single(-vehicle) accidents (VRUs). Moreover, in Denmark, as in many other countries, a traffic accident is officially defined as such when at least one moving vehicle is involved. This means that pedestrian falls are not recorded in the official statistics. Pedestrian falls often affect older people with poor balance.

The consequences of all types of VRU accidents can be significant in terms of medical treatment, economic costs, and reduced quality of life. Therefore, they should be included in the available data sources so they can be incorporated into accident prevention efforts.

This paper examines the extent of under reporting in pedestrian and cyclist accidents by comparing official accident data with data from two different projects that incorporate self-reported accident information from injured road users who have attended emergency departments after traffic accidents. The aim is to obtain a more comprehensive overview of both the injured VRUs and the accident circumstances, in order to improve road safety for vulnerable road users.

Research methodology

In two different projects, road users involved in accidents, recruited from hospital emergency departments, self-report their accidents and the circumstances surrounding them.

Patients who are listed in the National Patient Register (hosted by the Danish Health Data Authority) after an accident on public roads receive an invitation to participate in the accident self-reporting surveys. This includes road users who

- project *a*: visit one of the 4 emergency rooms in Region Northern Jutland, Denmark, or
- project *b*: visit one of the emergency rooms in Copenhagen Capital Region and where the accident is geolocated to Copenhagen Municipality

The accident information from the emergency room is compared to accident information recorded by the police (official accident statistics).

Results

	Injured pedestrians	Pedestrian single accidents	Injured bicyclists	Bicyclist single accidents
Copenhagen municipality, self-reporting 2024-2025 (24 months)	327	275 (84%)	1,801	1,042 (58%)
Northern Jutland, self-reporting 2024-2025 (12 months)	385	354 (92%)	367	264 (72%)
Police accident data 2024 (12 months)	326	0 (0%)	780	52 (7%)

Table 1. VRU accidents from different data sources. The specific figures are not directly comparable (different time periods, different geographical catchment areas, but the percentages are).

It is clear that the proportion of single-vehicle accidents is substantially higher in the self-reported data compared with the police-recorded data.

Northern Jutland, self-reporting Aug '24-July '25 (12 months)

Which of the following conditions were present at the time of the accident?	Yes	% of N=385
The road was slippery (snow/ice)	31	8.1%
There was a curb	4	1.0%
It was raining	3	0.8%
There was material from roadworks	3	0.8%
There was a loose stone/tile	3	0.8%
There was a sharp bend	1	0.3%
The road was slippery due to leaves, soil, gravel, oil, etc.	1	0.3%
There was a pothole in the road	1	0.3%

Copenhagen municipality, self-reporting '24-'25 (24 months)

Which of the following conditions were present at the time of the accident?	Yes	% of N=327
I tripped over an uneven paving stone/loose stone	44	13.5%
It was slippery due to ice or snow	39	11.9%
There was an uneven surface/a hole	33	10.1%
I tripped over a curb	33	10.1%
I walked into something or was struck by something from above	7	2.1%
It was slippery due to loose gravel, leaves, or similar	1	0.3%
Other	88	26.9%
Question not applicable	50	15.3%
(blank)	32	9.8%

Figure 1. Circumstances, self-reported single-pedestrian accidents (falls). Project a left, project b right. Figures are not directly comparable due to i.a. differences in methodology.

The circumstances surrounding pedestrian falls from the two self-reporting projects indicate that, in a number of cases (8.1%, 11.9%, resp.), the accidents are related to inadequate winter maintenance and uneven paving stone/loose stone (0.8%, 13.5%, resp.)

Discussion

Self-reporting can combine the advantages of police recorded data and emergency room data by allowing the involved road users themselves to record their accidents and the circumstances surrounding them.

Despite differences in research methodology in the two studies, the example of the circumstances surrounding pedestrian falls highlight the need for (winter) maintenance to prevent pedestrian falls.

The presentation will include updated data. The presentation will compare data for both cyclists and pedestrians from the three data sources mentioned.

International Co-operation on Theories and
Concepts in Traffic Safety

Walking behaviour and fear one year after a pedestrian fall or pedestrian-vehicle collision

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Introduction

Walking is widely recognised as a health-promoting and sustainable form of everyday mobility. At the same time, pedestrians are exposed to the risk of both pedestrian-vehicle collisions and pedestrian falls. Previous research suggests that concerns about falls and collisions are associated with walking less, and that previous fall experience is associated with higher fear of falling. However, little is known about whether and how walking changes among pedestrians who have experienced a fall or collision. As many countries aim to increase walking for transport, it is important to both reduce pedestrian injuries and to understand whether and how walking behaviour changes after people are injured in pedestrian accidents.

This study aims to investigate the long-term impact of pedestrian accidents, with the following research questions:

1. Do pedestrians reduce their walking after fall or pedestrian-vehicle collision?
2. Do injured pedestrian report increased fear of falls and collisions?
3. Are changes in fear associated with changes in walking?

Research methodology

Since May 2024, injured pedestrians who visit hospitals or emergency wards in several Norwegian cities have been invited to register their accident. Following the accident registration, pedestrians aged 16 years or older were invited to participate in a longitudinal study. The study includes retrospective baseline data and prospective follow-up data collected after one, six and twelve months.

The follow-up survey measures weekly walking duration, travel behaviour, walking avoidance, fear of collisions and pedestrian falls, and subjective quality of life. Each questionnaire also includes an open-ended question where respondents may expand on whether and how their walking behaviour has changed following the accident. This presentation will focus on walking and fear of collisions and falls.

Injured pedestrians were recruited from 1st May 2024 to 28th February 2026. Preliminary data include 914 participants who completed the first questionnaire. After excluding participants who were too young (n = 1), had irrelevant accidents (n = 59) and those who answered the first questionnaire more than seven days after the accident (n = 253), the filtered baseline sample

was N = 601. The follow-up surveys are ongoing. At the time of writing, 259 participants had been invited to the final questionnaire and 165 (64 %) had completed it.

Results in this abstract are preliminary and based on paired comparisons between retrospective baseline values and 12-month follow-up. The conference presentation will include additional responses collected before the conference and longitudinal analyses using all available waves among participants who have reached the 12-month follow-up point.

Results

Women make up two-thirds of the participants, which corresponds to the gender distribution in the accident registration. The age ranges from 18 to 82, with a mean age of 52 years. The largest age group is 55-64.

About 90 % were injured in a single pedestrian accident (e.g. fall, stumble) while a few were hit by a vehicle. Almost all stated that they were injured in the accident, and about 16 % were admitted to the hospital. One year after the accident, about a fifth reported that they were “still bothered” by the injury.

Paired comparisons between retrospective baseline and 12-month follow-up suggested a small increase in the fear index and a small reduction in walking, although changes varied substantially between participants for both outcomes. The presentation will further examine whether changes in fear are associated with changes in walking.

More than half of the participants answered the open-ended question. While some reported no impact from the accident, many described concrete changes in their behaviour, such as being more alert when crossing roads, wearing reflective items more consistently, paying closer attention to the traction of their shoes, or choosing different routes or activities. In more striking accounts, participants described how lasting injury and increased fear of another accident had substantially reduced their activity and mobility.

Discussion and conclusions

These preliminary findings suggest small average changes in walking after pedestrian accidents, but that there may be substantial individual variation. While some participants report little or no impact, others describe physical and psychological consequences that affect how, where, and how much they walk one year after the accident. The findings indicate that pedestrian accidents may have long-term implications for a subgroup of injured pedestrians, in the form of both injury-related limitations and fear of new falls or collisions. Further longitudinal analyses will examine changes in walking and fear across all follow-up waves.

Keywords: *pedestrian injury, walking behaviour, fear of collisions and falls, longitudinal*

International Co-operation on Theories and
Concepts in Traffic Safety

Participation for School Travel Safety using Bicycle Simulators with Drone based Photogrammetry Models

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Introduction: The mode of transportation for school students in Germany is subject to controversial discussions. According to “DGUV Barometer Bildungswelt 2025” on school travel safety 65% of parents report problems caused by school runs (by car). According to the study, parents (54%) and teachers (60%) agree that encouraging students to independently conduct their travel to school has the highest potential to increase school travel safety. We investigate the use of bicycle simulators as a tool for assessing possibly dangerous scenarios in a safe environment. While a lot of general recommendations on school travel safety exist, modeling of a scenario for a specific school used to be very time-consuming in the past. These models however can be used to enable participation processes and get the students experience and expertise for possible improvements. We present our work in progress.

Methods: During a project week, 5 groups of high school students will be asked to develop solutions that will encourage more students to travel the route to school independently.



Figure 1: Bicycle Simulator in 3D-CAVE with photogrammetry model

Our scenarios are based on a drone based photogrammetry reconstruction of the surrounding area with data acquisition time of less than one day to ensure a high level of both applicability and transferability. Streets are modelled in the OpenDRIVE®-Standard. Surrounding traffic is simulated through SUMO [3], based on the analysis of drone footage. The bicycle simulator is placed in our 3D-CAVE or in front of a large LED-Wall. After completion of an adjustment phase, subjects will ride the last portion of their way to school from a starting point, which matches the route they would take from their home.

The completion of the study is scheduled for July 22nd 2026. The subjects will rate safety for different scenarios around their school using questionnaires (regarding the scenarios and safety, but also immersion and cyber sickness) and make suggestions contributing to road safety. We will distinguish cyclists and non-cyclists, for both groups there will be subjects with and without a bicycle simulator experience.

Results: The photogrammetry model used is taken from 60m altitude above ground and achieves a ground resolution of 2.5cm/pixel. Acquisition time is around 3 hours of flight time per square kilometre. The models enable students to recognize the immediate surrounding of their school. The scenarios include one, which is likely to be experienced in the current state, but also future scenarios with adapted parking and temporarily adapted entry rules (“school street”).

Discussion: The Case Study of Herrenberg [2] revealed that “there is a recognizable potential for improving urban planning processes by using digital twins in VR as a communication tool”. We will analyse whether participation using a bicycle simulator with visualizations of the current state and scenarios can increase involvement and even encouragement for active independent routes to school.

[1] DGUV Barometer Bildungswelt 2025 “Schulwege sicherer machen – Chancen und Potenziale”

[2] Dembski, Fabian & Wössner, Uwe & Letzgus, Mike & Ruddat, Michael & van der Laag-Yamu, Claudia. (2020). Urban Digital Twins for Smart Cities and Citizens: The Case Study of Herrenberg, Germany. Sustainability. 12. 17p. 10.3390/su12062307.

[3] Álvarez López, Pablo & Behrisch, Michael & Bieker-Walz, Laura & Erdmann, Jakob & Flötteröd, Yun-Pang & Hilbrich, Robert & Lücken, Leonhard & Rummel, Johannes & Wagner, Peter & Wießner, Evamarie. (2018). Microscopic Traffic Simulation using SUMO. 10.1109/ITSC.2018.8569938.

International Co-operation on Theories and Concepts in Traffic Safety

Applicability of TTC and PET for Pedestrian–Vehicle Interactions: Conflict Analysis Using Extreme Value Theory

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Introduction

The use of non-crash traffic events has become increasingly common in studies of pedestrian–vehicle interactions, particularly with the rapid development of video-based road-user trajectory processing. Previous traffic conflict studies have introduced several Surrogate Measures of Safety (SMoS) that can be used to analyse interaction severity. Among these measures, Time-to-Collision (TTC) and Post-Encroachment Time (PET) are the most widely used temporal indicators, as they describe how close the involved road users are in time to a potential conflict point. Recently, Extreme Value Theory (EVT) has been increasingly used in traffic safety studies to estimate the probability of rare and severe events based on SMoS.

Aim of the study

Despite the growing use of Extreme Value Theory in traffic safety analysis, its application to pedestrian–vehicle interactions has not been widely tested. This study addresses this gap by analysing the collected video-based trajectory data. The aim is to estimate the probability of extreme pedestrian–vehicle conflict events under the studied traffic conditions.

Methodology

In the city of Győr, Hungary, an unsignalised pedestrian crossing located on a two-lane road with a refuge island, in front of a primary school, was selected as the study site for recording pedestrian–vehicle interactions. Video data were collected using a Hikvision camera mounted on a lighting pole above the pedestrian crossing at an approximate height of 3 m. The camera provided a 180° wide field of view, enabling the observation of both traffic lanes and the entire crossing area. The recording campaign was conducted over approximately six weeks on weekdays during the morning peak period (06:00–09:00) and the afternoon peak period (14:00–17:00). Overall, the recording period covered 32 days, corresponding to approximately 192 hours of observation. The camera operated in motion-detection mode, resulting in approximately 4,000 video recordings. Videos that did not contain pedestrian–vehicle interactions were excluded from the study.

T-Analyst software, developed by Lund University, Sweden, is a semi-automated video-based tool used to manually track road users through trajectory generation. For the T-Analyst workflow, camera calibration was carried out separately in the companion software T-Calibration before trajectory tracking was performed in T-Analyst. After the trajectories had

been completed, T-Analyst enabled the calculation of selected surrogate safety indicators between the tracked road users. Of the total recording campaign, 26 observation days, corresponding to 156 hours of video data, were retained for the T-Analyst analysis. Pedestrian–vehicle interactions were identified during the video-based analysis workflow and represented by manually tracked trajectories, yielding a final sample of 1,985 cases, all of which corresponded to situations in which the pedestrian arrived first.

Using surrogate safety measures extracted from T-Analyst, the peaks-over-threshold (POT) analysis of TTCmin and PET was applied to pedestrian–vehicle interactions as this approach allowed a more efficient use of the available observations. By modelling the most severe interactions exceeding a selected threshold using the Generalised Pareto Distribution (GPD), the analysis aimed to estimate the likelihood and severity of extreme conflict events under the observed traffic conditions.

Results

The POT analysis was applied to TTCmin and PET for both the full sample and movement-type subgroups. Near-crash events were modelled using thresholds selected based on multiple statistical and diagnostic criteria. The analysis aimed to estimate the probability and recurrence of extreme pedestrian–vehicle conflicts under the observed traffic conditions. The results were further interpreted with respect to vehicle speed and distance-related measures, movement type, and pedestrian crossing configuration, including whether pedestrians approached from the same or opposite side relative to the vehicle. By comparing TTCmin and PET results, the study highlights that different surrogate safety indicators may capture complementary dimensions of conflict severity.

Discussion and conclusions

The comparison between TTCmin and PET further supports the use of EVT as a tool for examining rare conflict conditions that may not be fully captured through descriptive statistics alone. Relating these indicators to vehicle speed, distance-related measures, and movement type can provide a clearer interpretation of the estimated probabilities of severe pedestrian–vehicle conflicts.
As this is ongoing research, the findings are expected to contribute to a clearer understanding of the applicability of surrogate safety indicators in pedestrian–vehicle interaction analysis, particularly by examining how indicators such as TTCmin and PET can be used to identify severe conflict conditions, interpret their criticality, and assess their relationships with explanatory factors through univariate and bivariate modelling approaches.

International Co-operation on Theories and Concepts in Traffic Safety

Salience, Effort and Expectancy at Intersections: How Infrastructure Design Affects Driver Perception of Cyclists

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Background

Cyclists are disproportionately involved in severe traffic crashes. A substantial share of these crashes occurs at intersections, where turning movements create conflicts between drivers and cyclists who have right of way (Alrutz et al., 2015; Berghoefer et al., 2023). One cause is that drivers fail to detect crossing cyclists, either by not looking at all (Räsänen & Summala, 1998), or by looking without perceiving them, the so-called looked-but-failed-to-see error (Summala et al., 1996).

This study examines infrastructure measures designed to reduce the risk of overlooking cyclists at intersections and roundabouts. The measures were selected to address different contributing factors to the overlooking of cyclists: excessive speed, high complexity, missing expectancy of cyclists, and inadequate scanning behavior, which in turn influence the underlying mechanisms explaining the overlooking of cyclists (reducing speed, resource demand, lack of expectancy, insufficient salience and high effort to detect cyclists. These mechanisms draw from a combined theoretical framework based on the SEEV model of visual attention allocation (Wickens et al., 2003) and Applied Attention Theory (Wickens, 2021). On one hand, measures such as visual markings raise expectancy. On the other hand, measures that reduce approach speed, such as a raised entry, operate by allowing for more cognitive resources being available to detect cyclists. The aim was to assess which measures most effectively prevent the overlooking of cyclists.

Methodology

A VR driving simulator experiment was conducted with 68 participants who navigated 24 controlled traffic scenarios covering three critical constellations. Constellation are defined here as combinations of intersection type, approach speed, and the direction of the conflicting cyclist trajectory. The constellations were: left-turning across oncoming cyclists at 50 km/h on a priority road, left-turning at a yield-controlled intersection with cyclists approaching from the left at 30 km/h, and entering a roundabout with crossing cyclists. In all three constellations, cyclists had right of way. These constellations represent the majority of crashes involving cars and cyclists.

Five measures were tested against a reference condition. The measures were: a raised entry, a separate cycle path, a red-coloured cycle lane, a red-coloured separate cycle path, and a raised centre island (roundabout only). The reference condition represented current as-built infrastructure: a standard bike lane at intersections and no dedicated cycling provision at the roundabout. The experiment combined eye-tracking, speed measurements, verbal reports, and a follow-up questionnaire. This abstract reports findings from the follow-up questionnaire.

The questionnaire used images of the VR traffic scenarios to assess subjective perception using the SEEV framework (Wickens, 2021; Wickens et al., 2003), covering salience, effort, expectancy, and cognitive resource demand across conditions.

Results

Preliminary results are based on repeated measures ANOVA, accounting for the within-subject structure of the experiment. Effects of the measures varied substantially across constellations. In the roundabout, no significant differences were found between measures for salience, effort, or expectancy. At the yield-controlled intersection (30 km/h approach), the red-coloured cycle lane produced significantly higher salience and lower effort than all other conditions, including the reference, while resource demand remained comparable to the reference. Separate cycle paths, with or without red colouring, scored lower on salience and demanded more cognitive resources than the reference. At the priority road intersection (50 km/h approach), effects were strongest overall. The red-coloured cycle lane again outperformed all other measures on salience, effort, and expectancy. The separated cycle path with red colouring increased resource demand substantially without a corresponding gain in salience. Across both intersection constellations, all measures raised expectancy relative to the reference, with no significant differences between them.

Discussion and conclusions

For both intersection constellations all measures raised driver expectancy of cyclist presence relative to the reference. This is line with Berghoefer et al. (2023), who found that drivers' expectancy of crossing cyclists influenced their gaze behaviour at T-junctions, and suggests that any deliberate infrastructure modification, regardless of type, indicates to drivers that cyclists may be present.

The specific design of the measure appears to matter less for expectancy than for salience, as for salience differences could be found between treatments. The red-coloured cycle lane outperformed other measures, including separation of cyclists and cars, on perceived visibility. Separation, in contrast, appeared to move cyclists out of the driver's visual attentional field, reducing perceived salience despite the physical demarcation between car and cyclist trajectories. The resource demand findings require further interpretation. Within the SEEV model, effort is defined as the cost of redirecting gaze between areas of interest. A greater spatial separation increases that cost and inhibits scanning toward that location (Wickens, 2021; Wickens et al., 2003). This suggests two competing mechanisms are at hand. Infrastructure complexity may slow drivers down, which is beneficial for information processing, the potential to stop in time, and can reduce crash severity. At the same time, a higher resource demand, it might reduce attention toward cyclists, which works against the goal of reducing overlooking.

The red-coloured separated cycle path illustrates this: it reveals higher required resources but lower salience. A possible explanation is that separation moves the cyclist out of the driver's natural line of sight and requires a larger head turn to the left. The red cycle lane shows the opposite pattern: resources are comparable to the reference, but reveal highest salience across conditions. The SEEV model would predict this as an effective design. The separated path does the opposite: it increases effort without a salience gain.

Whether this translates into actual gaze behaviour and speed choice will be addressed by the eye-tracking and speed data from the same experiment.

References

Alrutz, D., Bohle, W., Maier, R., Enke, M., Pohle, M., Zimmermann, F., Ortlepp, J., & Schreiber, M. (2015). *Einfluss von Radverkehrsaufkommen und Radverkehrsinfrastruktur auf das Unfallgeschehen* (Nr. 29; Forschungsbericht GDV).

Berghoefer, F. L., Huemer, A. K., & Vollrath, M. (2023). Look right! The influence of bicycle crossing design on drivers' approaching behavior. *Transportation Research Part F: Traffic Psychology and Behaviour*, *95*, 98–111. https://doi.org/10.1016/j.trf.2023.03.017

Räsänen, M., & Summala, H. (1998). Attention and expectation problems in bicycle–car collisions: An in-depth study. *Accident Analysis & Prevention*, *30*(5), 657–666. https://doi.org/10.1016/S0001-4575(98)00007-4

Summala, H., Pasanen, E., Räsänen, M., & Sievänen, J. (1996). Bicycle accidents and drivers' visual search at left and right turns. *Accident Analysis & Prevention*, *28*(2), 147–153. https://doi.org/10.1016/0001-4575(95)00041-0

Wickens, C. D. (2021). Attention: Theory, Principles, Models and Applications. *International Journal of Human–Computer Interaction*, *37*(5), 403–417. https://doi.org/10.1080/10447318.2021.1874741

Wickens, C. D., Goh, J., Helleberg, J., Horrey, W. J., & Talleur, D. A. (2003). Attentional Models of Multitask Pilot Performance Using Advanced Display Technology. *Human Factors: The Journal of the Human Factors and Ergonomics Society*, *45*(3), 360–380.

International Co-operation on Theories and Concepts in Traffic Safety

Platform work by bicycle: Road safety of delivery riders in Germany

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Introduction: In Germany, as in many other countries, app-based food and goods delivery by bicycle has become widespread in urban areas. In Germany, employment in this sector has grown rapidly since 2018, with estimates based on national social insurance data indicating that around 94.000 people were working for such services over the course of 2022[1].
Although delivery riders have become a common sight in urban traffic, very little is currently known about how safe they actually are on the road. Official crash statistics cannot be consulted since "delivery (e-)bike" is not specifically coded as a distinct mode of transport in the event of a crash. Still, numbers from occupational safety and health associations suggest that the risk of work-related crashes is more than 4 times higher for delivery riders than for related jobs, such as mail carriers[2]. International findings point in a similar direction, with, e.g., 67% of delivery riders in Norway reporting at least one crash while working[3]. Moreover, existing findings indicate a link between working conditions (economic insecurity, time pressure, incentives, lack of systematic safety work, exposure to elements) and road safety risks[3].
The study presented here is one of the first to examine road safety issues among delivery riders in Germany and was set out to examine crash experiences, assess associated risk factors, explore exposure, and detail crash events and mechanisms, safety equipment, and reported risky behavior.

Method: An online survey was conducted in March and April 2026, including a final sample of 709 valid cases. The survey comprised four parts: experiences of safety-critical events in traffic, protective strategies and equipment, prevention strategies and training, and sociodemographics. Survey participation was incentivized through a raffle for fifty gift cards. Speeder checks were implemented to ensure appropriate data quality.
Participants were approached primarily through a workers' council and via Instagram and LinkedIn. In addition, delivery riders were approached directly on the street at hubs where they bring or pick up their bikes for maintenance, at hubs where they collect goods, and at restaurants where they pick up food.

Results: Among the surveyed delivery riders, 31.6% had been working in the job for less than one year, and 51.8% reported at least one work-related crash. Among riders with crash

[1] Friedrich, M., Helm, I., Jost, R., Lang, J., & Müller, C. (2024). Gig-Work bei Lieferdiensten in Deutschland: Beschäftigung hat in den letzten Jahren stark zugenommen. *IAB-Forum*, 202404. https://doi.org/10.48720/IAB.FOO.20240403
[2] *Schnelllieferdienste: Wie können Arbeitsunfälle verhindert werden?* (S. Mehta). (2023, 25. Mai). www.dvr.de. Abgerufen am 30. April 2026, von https://www.dvr.de/aktuelle-infos/interview-schnelllieferdienste
[3] Uhlving, V. M., Blom, J., Nævestad, T.-O., & George, C. (2025). *Hvor farlig er det å være sykkelbud? En studie av hva som påvirker trafikksikkerhet for plattformarbeidende sykkelbud i matleveringsbransjen* (TØI Report No. 2090/2024). Transportøkonomisk Institutt. https://www.toi.no

experience, 73.3% reported more than one crash, indicating that repeated crash involvement was common.
Single-vehicle crashes were the most frequent incident type, accounting for 49.9% of examined crash cases. These incidents were most commonly attributed to slippery or uneven surfaces, including wet roads, potholes, and tram tracks (52.6% of reported crash events). Among riders with previous crashes, 67.4% reported at least one injury requiring medical treatment. Reported use of protective equipment was comparatively high, with 81.5% regularly wearing a helmet and 77.1% using reflective gear. At the same time, perceived insecurity in traffic was substantial: 46.3% stated that they regularly feared doing something wrong while riding in traffic. Spearman rank-order correlations were conducted to examine associations between perceived time pressure and self-reported traffic violations. Perceived time pressure from delivery deadlines or app instructions was positively associated with more frequent weaving through traffic, red light violations, and riding against the direction of traffic (ρs = .22–.24, 95% CIs ranged from [.15, .29] to [.16, .31], ps < .001), with all effects in the small range.

Discussion and Conclusions: The findings suggest that bicycle delivery riders in Germany face a substantial road safety burden, characterized by frequent crashes, repeated crash involvement, and a high proportion of medically treated injuries. As in cycling more generally, infrastructure and maintenance problems appear to be key risk factors in delivery riding as well, while the association between perceived time pressure and self-reported rule violations highlights the relevance of work organization. Given that a large share of riders are relatively new to the job and many report insecurity in traffic, prevention should combine safer infrastructure, targeted training and onboarding, and improved safety management by delivery companies. Better identification of delivery riders in official crash statistics is also needed to support evidence-based prevention.

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International Co-operation on Theories and
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Understanding the Relationship Between Modal Split and Road Safety: A Machine Learning Approach

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Introduction

In recent years, European cities have increasingly promoted shifts towards more sustainable modes of transport, aiming to reduce environmental impacts, improve accessibility, and enhance overall urban quality of life. Within this context, the modal split is often implicitly linked to road safety improvements, particularly through reductions in private vehicle use and the promotion of active and public transport. However, the extent to which changes in modal distribution alone translate into improved safety outcomes remains insufficiently understood.

Existing research has shown that a complex interaction of behavioural, infrastructural, and socio-economic factors shapes road safety outcomes. While modal split is frequently used as an indicator of mobility patterns, its independent contribution to traffic safety outcomes at the urban level is still unclear, especially when considered alongside structural characteristics such as motorisation levels, travel distances, and city size. This paper aims to examine the relationship between modal split and road safety across European cities, and to assess the extent to which modal structure explains differences in safety outcomes relative to broader urban and transport system characteristics.

Research methodology

The analysis is based on a dataset covering 205 cities across ten European countries. The dataset integrates indicators related to modal split (private motor vehicle, public transport, cycling, and walking), travel characteristics (average travel time and distance), motorisation levels (cars per 1,000 inhabitants), and basic socio-economic variables such a population size and GDP per capita. Road safety is represented by the fatality rate per 10,000 inhabitants, allowing for comparability across cities of different sizes.

The modelling approach follows a two-stage framework. In the first stage, models are developed using only modal split variables to assess the explanatory power of travel behaviour alone. In the second stage, structural variables are introduced to evaluate their additional contribution. A set of complementary machine learning models is applied, including Random Forest (RF), Gradient Boosting (XGBoost and LightGBM), Explainable Boosting Machine (EBM), Support Vector Regression (SVR), and k-Nearest Neighbours (kNN). Model performance is evaluated using a 70/30 train–test split. Evaluation metrics include the

coefficient of determination (R^2), mean absolute error (MAE), and root mean squared error (RMSE).

Results

The results indicate that modal split alone explains a meaningful share of the variation in road safety outcomes across cities. Depending on the model, the coefficient of determination (R^2) ranges between approximately 0.30 and 0.45, suggesting that travel behaviour plays a relevant role in shaping safety conditions. However, when structural variables are included, the explanatory power of the models increases substantially, reaching values of up to approximately 0.60. This improvement highlights the importance of factors such as motorisation levels, travel distance, and city size in explaining differences in safety outcomes.

Among the tested models, k-Nearest Neighbors (R^2=0.63) and Gradient Boosting (R^2=0.62) approaches achieve the highest predictive performance, while Explainable Boosting Machine (R^2=0.48) provides additional insight into non-linear relationships between variables and safety outcomes. Overall, the results demonstrate that although modal split is a significant factor, it does not fully capture the complexity of urban road safety. The performances of the models with included control parameters are presented in Table 1.

Machine Learning Model	R^2	MAE	RMSE	MPD (%)
kNN Regressor	0.633	0.137	0.181	65.182
XGBoost Regressor	0.620	0.149	0.185	74.606
RandomForest Regressor	0.590	0.154	0.192	78.069
LightGBM Regressor	0.503	0.169	0.211	89.958
Explainable Boosting Machine	0.475	0.139	0.217	66.085
Support Vector Regression	0.135	0.200	0.279	84.972

Discussion and conclusions

The findings of this study suggest that modal split should not be considered in isolation when analysing or addressing road safety at the urban level. While shifts towards more sustainable modes of transport are often associated with safety benefits, their actual impact depends on the broader structural context in which they occur. The substantial increase in explanatory power when structural variables are included indicates that road safety is strongly influenced by underlying characteristics of the urban and transport system, including levels of motorisation, spatial organisation of travel, and city scale. This highlights the need for a more integrated approach to road safety, in line with system-based perspectives such as the Safe System approach.

From a policy perspective, the results imply that modal shift strategies alone are unlikely to deliver significant safety improvements unless they are accompanied by measures addressing infrastructure, exposure, and traffic composition. In this regard, machine learning methods can serve as a useful analytical tool, not only for prediction but also for supporting a more comprehensive understanding of the relationships between mobility patterns and safety outcomes.

International Co-operation on Theories and
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Accompanied driving and driving test outcomes: evidence from Slovenia

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Introduction

Accompanied driving aims to reduce crash-related risk in the early driving career by gradually introducing young drivers to independent driving under the supervision of an experienced driver. It provides exposure to real traffic conditions while supporting the development of traffic situation management and more realistic self-assessment as an addition to formal driving school education. In Slovenia, the system is regulated under the Drivers Act and allows participation from the age of 16, subject to legally defined requirements for prior training and conditions for accompanying drivers (age >27, >5 years of driving experience, <5 penalty points). Despite long-term implementation, empirical evidence on the effectiveness of the system remains limited. This study examines whether accompanied driving in Slovenia is associated with improved driving skill development and higher success rates in the category B practical driving test. Candidates with and without an accompanying driver are compared in terms of the number of test attempts and driving school hours required for licence acquisition, using data from all category B candidates within a selected 20-month period in Slovenia.

Research methodology

The study analyses data from the Slovenian Traffic Safety Agency on category B driving test candidates, their participation in the accompanied driving system, and performance in the practical driving test. The data cover the period from early 2024 to 24 September 2025 and include 48,952 candidates with registered accompanying drivers and 105,281 accompanying driver registrations. The final analytical sample consists of 70,513 candidates who attempted the practical driving test, with an approximately balanced proportion of candidates that were included in the accompanied driving system (49.2%) and those that were not (50.8%). All test attempts were included in the analysis. Differences between candidates with and without an accompanying driver were examined using descriptive statistics and independent-samples t-tests, focusing on the number of test attempts and the number of driving school hours required for successful licence acquisition; effect sizes were assessed using Cohen's d.

Results

Participation in the accompanied driving system is most common among late adolescents and young adults: 8.1% of candidates were aged 16–17, 26.0% 17–18, 46.8% 18–20, and 13.3% 20–25 years, while 5.8% were older than 25 years. Most candidates registered one (26.97%) or two (48.75%) accompanying drivers, with smaller proportions registering three (12.96%) or more. Accompanying drivers were mostly candidates' mothers (37.52%) and fathers (35.43%).

Most candidates attempted the practical driving test relatively soon after entering the accompanied driving system: 9.2% within the first 30 days, an additional 33% within three months, and 60.2% within the first six months after registration. For some candidates, however, the accompanied driving period lasted one year or more, particularly among those who entered the system at age 16. In 7.1% of cases, participation in the system followed an unsuccessful first attempt at the practical driving test. Pass rates were highest at the first test attempt in both groups, but the distribution across subsequent attempts differed. At the first attempt, 73.0% of candidates without an accompanying driver passed the test, compared to 58.1% of those with an accompanying driver; at the second attempt, the respective shares were 17.6% and 25.4%, and at the third attempt 5.7% and 11.1%.

The difference in the number of test attempts between the groups was statistically significant ($t(44{,}310) = -29.97$; $p < 0.001$). Candidates with an accompanying driver passed the test in an average of 1.72 attempts, compared to 1.46 attempts among candidates without an accompanying driver, with a small effect size (Cohen's $d = -0.29$). A statistically significant difference was also found in the number of driving hours completed in driving school ($t(43{,}995) = -59.23$; $p < 0.001$): candidates with an accompanying driver required an average of 36.65 hours (SD = 14.63), whereas those without an accompanying driver required 28.26 hours (SD = 15.07), representing a mean difference of 8.39 hours and a medium effect size (Cohen's $d = -0.565$).

Discussion

The results show statistically significant differences between candidates with and without an accompanying driver in both the number of test attempts and the number of driving hours completed in driving school. However, the administrative data do not allow conclusions about causal mechanisms. One plausible contributing factor is candidates' age and earlier entry into training, as some candidates enter the system at age 16, resulting in a longer and more heterogeneous learning period.

Candidates who trained with an accompanying driver were less successful at first test attempt but performed better in subsequent attempts compared to candidates without an accompanying driver. This pattern may partly reflect entry into the system after an initial failed attempt, as well as the gradual development of driving skills and other factors. The findings suggest that accompanied driving does not primarily enhance immediate test performance but rather supports longer-term learning. The results further confirm that the quantity of practice alone is not a sufficient indicator of progress; the quality and diversity of driving experiences, as well as reflection and feedback, seem to be crucial. From the perspective of the Goals for Driver Education framework, accompanied driving represents an important transitional phase between driving school and independent driving, supporting traffic situation management (GDE level 2), driving in different contexts (GDE level 3), and risk awareness and regulation (GDE level 4). Introducing a structured transitional lesson and a phased training model with intermediate progress checks could strengthen the developmental role of the accompanying driver.

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International Co-operation on Theories and
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Video-Based Analysis of Crossing Behavior of Pedestrians with Assisting and Walking Devices at a Signalized Intersection

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Introduction

Crossing the street is the most dangerous time for pedestrians when walking in cities. Studying crossing behavior is therefore crucial to improve their comfort and safety, even more for pedestrians using Assisting and Walking Devices (AWDs) such as canes, walkers, strollers, and grocery carts. Existing studies have examined pedestrian crossing speed and related behaviors with respect to factors such as age, gender, and traffic conditions, but much less attention has been paid to systematic comparisons involving AWD use. Video-based trajectory extraction has been widely adopted in pedestrian behavior studies; however, the reliability of current automatic detection and tracking methods for AWD-related pedestrian categories remains uncertain.

This study aims to address these gaps through a video-based analysis of crossing behavior. It has two objectives. First, it evaluates whether a detection and tracking pipeline can reliably identify several categories of pedestrians with AWDs in a real-world intersection. Second, it compares the crossing behavior of five pedestrian categories, including pedestrians without AWDs and users of canes, walkers, strollers, and grocery carts, using three trajectory-based indicators.

Methodology

The video data were collected at a signalized intersection in Montréal between 10am and 3pm using a fixed GoPro camera mounted near the intersection. The site was selected for its relatively high pedestrian volume and nearby bus stops, which resulted in a diverse pedestrian population. A 17-minute continuous video was used for pedestrians without AWDs, while 74 clips of 18–30 seconds were extracted to capture pedestrians with AWDs.

The methodological workflow consists of three steps: video acquisition, trajectory generation, and crossing behavior analysis. Trajectories were initially intended to be produced automatically using a fine-tuned YOLOv11 detector combined with the BoT-SORT tracker. However, because the detection performance for AWD-related categories remained insufficient, manual annotations were ultimately used for the behavior analysis. Three indicators were then derived from the trajectories. First, the average crossing speed was obtained from the known crosswalk widths and the crossing duration between trajectory entry and exit from the predefined crossing zones (corresponding to the crosswalks). Second, the ratio between the real travelled crossing distance (RD) and the direct (straight) distance (DD) is computed to evaluate deviation from a straight crossing path. Third, the mean instantaneous

pedestrian speed in a crossing zone was analyzed as a function of the number of pedestrians present, whether at least one pedestrian with an AWD was present or not.

Results

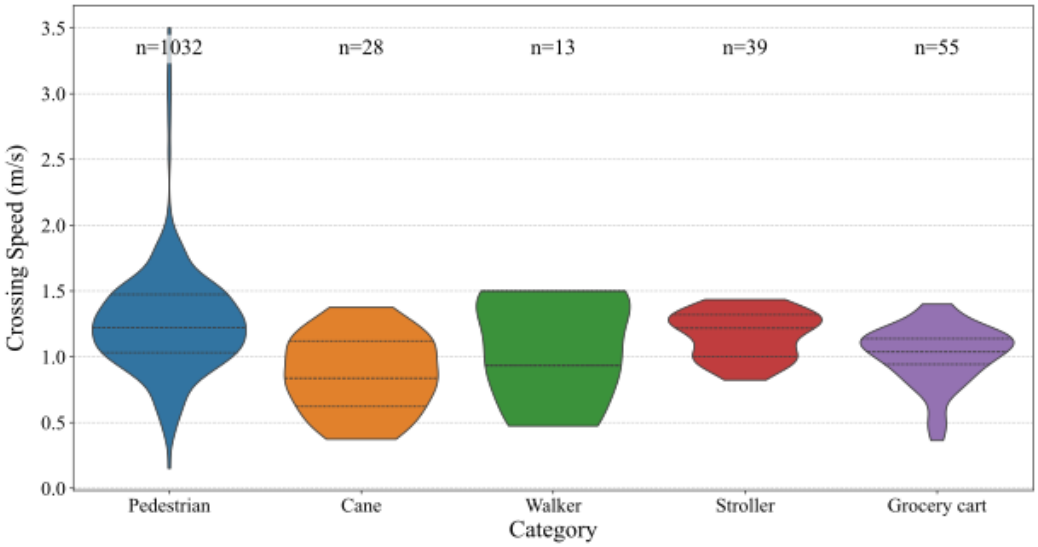


Figure 1. Average crossing speed distributions across the pedestrian categories

A Kruskal–Wallis (KW) test showed statistically significant different average crossing speeds among pedestrian categories (Figure 1). Pairwise Dunn tests indicated that cane users and grocery-cart users crossed significantly more slowly than pedestrians without AWDs. Stroller users displayed crossing speeds close to those of pedestrians without AWDs, while walker users also showed a lower median speed, although the difference was not statistically significant, likely because of the small sample size. The distributions show greater variability in some AWD categories, especially cane and walker users, whereas wheeled devices showed more consistent movement patterns. The RD/DD ratio remained similar across all five categories, as supported by the KW test. This indicates that most pedestrians, regardless of AWD usage, followed nearly straight crossing paths through the crossing zones. The speed–density analysis showed that mean walking speeds remained broadly stable as the number of pedestrians increased, without any visible difference in the presence of pedestrians with AWDs. However, the 90th percentile tended to decrease as pedestrian numbers increased, showing that higher densities mainly constrained faster walkers while leaving typical walking speed relatively stable.

Discussion and conclusion

This study shows that pedestrians with AWDs differ from pedestrians without AWDs mainly in terms of average crossing speed rather than path geometry. These findings highlight the importance of explicitly distinguishing pedestrians with AWDs in crossing behavior studies. The study also identifies a clear methodological limitation of current computer vision pipelines: underrepresented AWD-related categories remain difficult to detect and classify reliably in real-world intersection scenarios. Future work should extend the dataset to more sites and longer duration to increase the sample size of pedestrians with AWDs.

International Co-operation on Theories and
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Spatial Analysis of Cyclist-Related Road Accidents in Urban area

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Introduction

Cyclist-related road accidents pose a critical challenge for urban road safety, as vulnerable road users are disproportionately exposed to severe injuries and fatal outcomes. Identifying the infrastructural, environmental, and spatial factors that govern accident occurrence is therefore essential for designing effective safety interventions and advancing sustainable urban mobility. Despite a growing body of research, significant gaps persist in the literature. Built environment features and environmental elements are frequently overlooked, particularly at spatial scales where collision dynamics are most visible. Traditional statistical approaches that rely on aggregated indicators and spatially heterogeneous data tend to obscure the local dynamics of accident hotspots, thereby limiting the identification of critical concentration areas. Furthermore, reliance on data from a single local source constrains the ability to capture complex interactions among road geometry, environmental conditions, and traffic control. Integrating accident data across spatial, temporal, and environmental dimensions and representing them through data-driven cartographic outputs provides a more advanced analytical framework that explains accident occurrence mechanisms and road user behavior patterns with greater accuracy and realism.

In response to these gaps, this study introduces a multi-stage spatial analysis framework centered on Kernel Density Estimation (KDE) within a Geographic Information Systems (GIS) environment. The research aims to identify spatial patterns of road traffic accidents, analyze their spatial concentrations, and examine relationships between these concentrations and infrastructural and environmental characteristics, ultimately providing a robust, data-driven basis for targeted safety policy.

Research Methodology

The analysis draws on a dataset of 7,289 urban accidents recorded between 2022 and 2023 across multiple Italian cities. Accident records were sourced from the Italian National Institute of Statistics (ISTAT) national accident database, encompassing attributes such as weather conditions, accident typology, geographic localization, vehicle type, driver age and gender, and accident circumstances. These were integrated with vector-based geospatial datasets (including road networks, intersections, traffic signs, pedestrian crossings, land-use classifications, and barrier elements), extracted from OpenStreetMap using the QuickOSM plugin for QGIS.

The methodological framework proceeded in three stages. In the first stage, accident records were cleaned and merged with environmental and infrastructural variables, and the resulting dataset was processed in QGIS to ensure spatial consistency and analytical accuracy. In the second stage, statistical analyses were performed in SPSS to explore associations between accident type (multi-vehicle versus single-vehicle) and explanatory variables. Binary logistic regression was applied to quantify the influence of individual factors, while Multiple

Correspondence Analysis (MCA) and clustering techniques were employed to detect latent structural patterns and accident-environment typologies.
In the third stage, KDE was applied to generate continuous spatial density surfaces, enabling the identification and visualization of accident hotspots across urban areas. KDE was selected as the primary spatial analysis technique because, as a nonparametric technique, it requires no assumptions about the underlying distribution of events, making it robust to the skewed, spatially heterogeneous patterns typical of real-world accident data. Furthermore, overlaying the KDE density surface with OpenStreetMap-derived infrastructural and environmental layers enables the spatial correspondence between accident concentrations and built environment characteristics to be examined directly, supporting an explanatory rather than purely descriptive analysis.

Preliminary Results
The dependent variable was coded as a binary indicator distinguishing multi-vehicle accidents (76.6% of the sample) from single or non-multi-vehicle accidents (23.4%). Bivariate screening through Pearson's chi-square tests and Cramér's V coefficients revealed that intersection classification carried the strongest association with accident type, followed by traffic signal, zebra crossing presence, season, day/night condition, and barrier type. Weather conditions showed negligible and non-significant associations.
MCA was conducted using nine categorical variables representing road geometry, crossing infrastructure, traffic control, temporal conditions, and road surface characteristics. The two-dimensional solution explained 38.78% of the total inertia. Discrimination measures indicated that zebra crossing presence and intersection classification were the most influential variables structuring the latent space, while temporal and road-surface variables contributed only marginally. These findings confirm that the latent structure of accident environments is primarily driven by infrastructural and geometric characteristics rather than by meteorological, surface, or temporal factors.
To strengthen the analytical link between statistical findings and spatial patterns, the most influential variables identified in the preceding logistic regression and MCA will be used to stratify and weight the KDE surfaces.

Discussion & conclusions
The expected results will demonstrate KDE's effectiveness as a powerful, interpretable tool for detecting spatial patterns in cyclist-related road accidents in urban environments. By integrating accident records with fine-grained infrastructural and environmental data within a GIS framework, this study identifies accident hotspots and establishes empirical links between spatial concentrations and specific road design features. The convergence of statistical modeling and spatial analysis provides a methodologically rigorous foundation for evidence-based safety planning.

International Co-operation on Theories and
Concepts in Traffic Safety

How In-Vehicle Tablet Interface Design Influences Driver Eyes-Off-Road Behavior: Eye-Tracking AOI Analysis in Simulation

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Introduction, including research aim and objectives

In-vehicle touchscreens support navigation, comfort settings and vehicle functions, but they also compete with the forward roadway for visual attention. This extended abstract presents an eye-tracking AOI analysis of a driving-simulator study comparing two right-side tablet concepts from the interface family reported by Nagy et al. (2026): a Bring-Your-Own-Device graphical user interface (BYOD GUI) and a Context-Driven Adaptive Dashboard System (ConDash). The key distinction is that BYOD may look visually cleaner, but many functions are hidden in menus. ConDash may look more information-rich, but it provides context-dependent quick-access buttons designed to reduce menu wandering and improve usability while driving. The aim is to examine how these interface designs influence driver eyes-off-road behavior and to demonstrate a reproducible workflow for transforming Pupil Labs Neon recordings into auditable traffic-safety metrics.

Research methodology

The analysis used scene video and eye-tracking exports from simulator recordings in which the tablet was positioned in the driver's right-side center-console interaction region. The pipeline synchronized gaze samples with video timestamps, localized and tracked the tablet AOI, and tested each gaze point against the AOI boundary. Consecutive inside-AOI samples were grouped into glances, and nearby glances were merged into dwell episodes. The outputs included AOI tracks, gaze-in-AOI tables, tablet-glance tables, dwell tables and summary metrics.

Metrics were grouped into off-road attention, stabilization, ocular-state and scan-structure families. Off-road attention included glance count, total eyes-off-road time toward the tablet (TEORT), percentage eyes-off-road time (PEORT), mean and maximum glance duration, and long-glance percentage. Stabilization included fixation rate, fixation duration and AOI-specific fixation measures. Ocular state included blink rate, blink duration and PERCLOS from validated eye-state data. Scan structure was described by saccade-amplitude metrics. Fixed thresholds were applied consistently for AOI membership, glance construction, dwell merging, fixation construction and PERCLOS classification. After quality control, 37 recordings remained, including 17 paired BYOD-ConDash comparisons and 22 reported metrics.

Results

The clearest paired difference appeared in mean saccade amplitude. BYOD showed a slightly higher median than ConDash (2.672° versus 2.611°), with $p = 0.0056$ and effect size $r = 0.672$. Several duration-based tablet-looking metrics were also higher in BYOD: TEORT was 39.3 s versus 34.5 s, PEORT was 7.28% versus 6.10%, mean glance duration was 890 ms versus 701 ms, maximum glance duration was 5400 ms versus 4279 ms, and long-glance percentage was 7.55% versus 5.17%. These higher duration values do not mean that BYOD is better; rather,

they suggest that the visually cleaner but menu-based BYOD interface may require longer sustained inspection while the driver searches through the interface structure.

ConDash showed a different profile. Blink rate was higher in ConDash (9.68 versus 7.95 blinks/min), and PERCLOS was also higher (0.617 versus 0.425). Some AOI-specific fixation-duration measures were higher in ConDash, suggesting more localized processing when the driver actually looked at the display. These findings are consistent with the design intention of ConDash: although it appears more complex visually, context-driven quick functions may reduce the need for longer menu navigation. A high-confidence sensitivity check indicated that the saccade-amplitude direction remained stable, while TEORT and PEORT were more sensitive to the included paired subset; therefore, off-road duration metrics are interpreted cautiously rather than as a single winner-or-loser result.

The Spearman heatmap was used descriptively to examine metric structure. Off-road and glance-duration metrics formed one block, fixation-duration variables formed another, and PERCLOS was most strongly associated with blink rate (|rho| = 0.805), followed by saccade-amplitude indicators. This supports the interpretation that the pipeline captured structured visual-behavior patterns rather than unrelated numerical outputs.

Discussion and conclusions

The findings clarify the difference between visual simplicity and operational simplicity. A clean-looking interface can still demand attention if the driver must enter menus to reach common functions. Conversely, an adaptive interface can look more complex but be easier to use if relevant functions are presented as direct shortcuts at the right time. This explains why BYOD showed higher duration-based tablet-looking metrics, while ConDash did not simply increase all off-road measures despite its richer layout. Traffic-safety evaluation should therefore not rely only on the labels “simple” and “complex”, but should examine how the design shapes visual search, glance duration, scan structure and ocular state.

The practical contribution is a reusable AOI-based workflow for simulator studies of in-vehicle displays. Future interface evaluation should quantify complexity through objective properties such as button size, contrast, visual density, menu depth, number of clicks required for a function and availability of context-sensitive shortcuts. The take-home message is that context-driven interface design can be safety-relevant not because it always looks simpler, but because it can reduce unnecessary visual search and change how drivers distribute attention between the road and the display.

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Medical Insight into Micromobility Related Accidents in Relation with Urban Network Topographies

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Micromobility has become an increasingly visible component of urban transportation systems, particularly in dense metropolitan areas where short-distance travel demand, congestion, limited parking space, and the need for flexible mobility options encourage the use of bicycles, e-scooters, and other light mobility modes. Although micromobility provides important advantages in terms of accessibility, sustainability, low spatial occupation, and first–last mile connectivity, its rapid integration into urban traffic environments has also introduced new safety challenges. Unlike motorized vehicles, micromobility users are physically exposed to direct impact, surface irregularities, sudden braking manoeuvres, conflicts with pedestrians and vehicles, and discontinuities in the urban road environment. Therefore, understanding micromobility-related accidents requires not only a conventional traffic safety perspective but also a medical and biomechanical interpretation of injury outcomes.

This study presents a hospital-based investigation of micromobility-related accident cases in Istanbul by using a focused subset of medical records obtained from a large research and education hospital. The analysis is based on accident cases selected from the available hospital database. The dataset includes medically relevant variables such as patient age, gender, accident time, vehicle type, injury region, injury type, fracture occurrence, and clinical outcome. These variables provide an opportunity to examine micromobility safety through the consequences observed on the human body rather than only through accident counts or police-reported crash statistics. In this respect, the study aims to identify the dominant injury patterns, vulnerable user groups, treatment requirements, and potential severity indicators associated with micromobility-related accidents.

The medical component of the study focuses on descriptive and exploratory statistical analyses. Age and gender distributions are examined to understand which user groups are more frequently represented in the hospital records. Injury regions are evaluated to determine whether upper extremity, lower extremity, head–neck, thoracic, or multiple-region injuries dominate the clinical profile. Fracture occurrence is considered as a key indicator of injury severity.

In addition to the hospital-based injury analysis, the study introduces an urban network topography perspective through fractal analysis of the Bağcılar road network in Istanbul. Bağcılar represents a dense and complex urban district where heterogeneous street patterns, high intersection density, mixed traffic conditions, and discontinuous mobility environments may affect the safety performance of vulnerable road users. Fractal analysis is used to characterize the spatial complexity and structural irregularity of the road network. In this

context, box-counting fractal dimension can provide an indicator of how densely and irregularly the road network occupies urban space, while complementary network indicators such as segment density, intersection density, connectivity, and lacunarity may help describe the morphological conditions that shape micromobility exposure. The Bağcılar district was selected as an illustrative urban network environment due to its dense street structure, heterogeneous road hierarchy, and high level of spatial complexity. The road network layout used for fractal characterization is shown in Fig. 1.

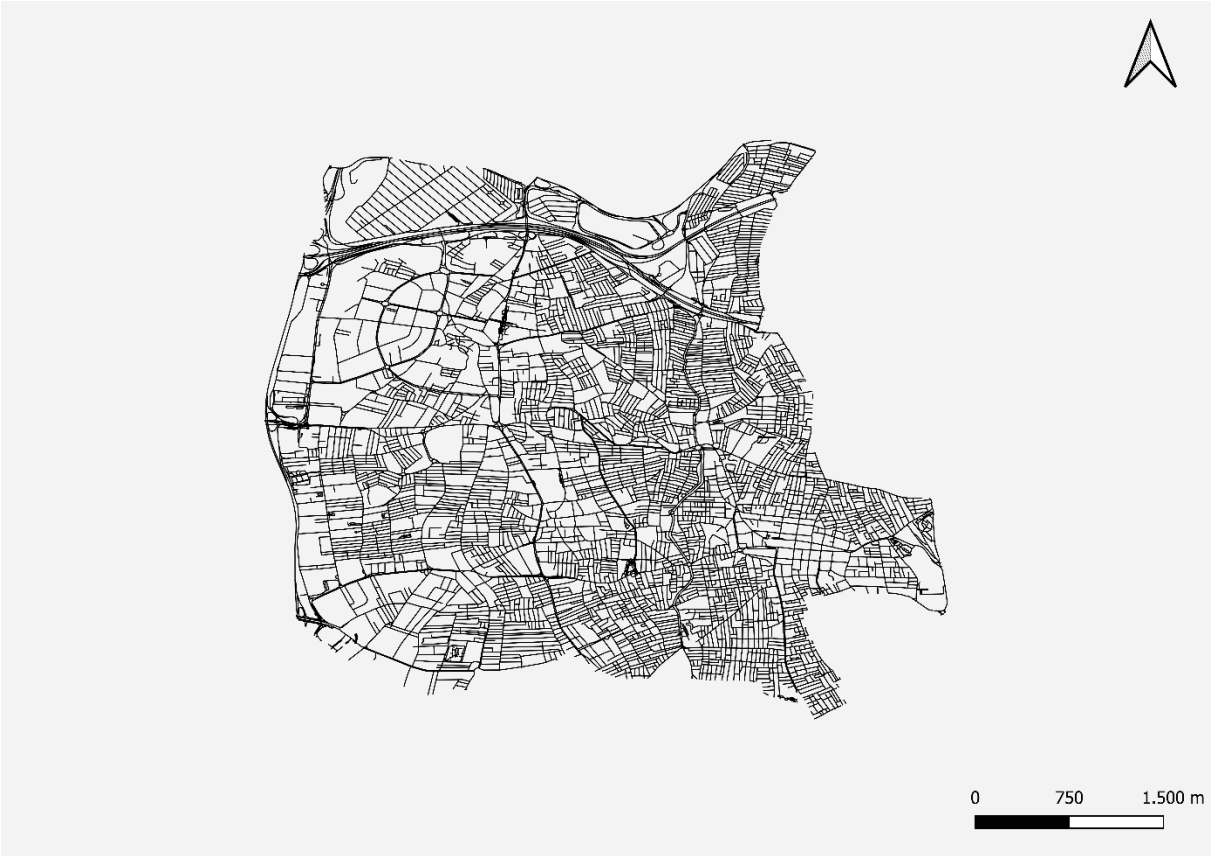


Fig. 1. Road network topology of the Bağcılar district, Istanbul.

However, an important outcome of this research is the discovery of the lack of useful engineering information in medical records. The hospital records used in this study do not include precise geocoded accident locations. From a medical point of view, the nature of the injury is the main concern whereas any correlations between the occurrence of an accident and the related urban roadway network qualities would be an engineering concern that can prevent or reduce the likelihood of the accident happening in the first place. For this reason, the road-network analysis is interpreted as a contextual and methodological layer rather than a direct spatial crash-risk model and the study highlights the important data gap and the urgent need to upgrade medical record keeping. If geocoded crash locations become available, future studies could directly investigate whether injury severity and fracture occurrence differ across urban zones with different road-network characteristics. For example, local fractal dimension, intersection density, road-segment irregularity, and network discontinuity could be compared with spatially referenced injury outcomes. Such an integrated approach would allow

researchers and urban planners to move beyond general accident descriptions and identify specific network morphologies that may increase risk for micromobility users.

The expected contribution of this study is threefold. First, it provides a medical characterization of micromobility-related accident injuries using hospital records, thereby highlighting the bodily consequences of micromobility crashes. Second, it introduces fractal road-network analysis as a complementary tool for understanding the urban spatial context in which micromobility risks emerge. Third, it discusses the methodological importance of integrating medical data with geocoded crash information and network-topological indicators in future studies. This combined perspective may support safer micromobility planning, improved infrastructure design, better emergency data collection, and more risk-sensitive urban transport management.

Overall, this study discusses that micromobility safety should be evaluated through an interdisciplinary framework that connects transportation engineering, medical injury analysis, and urban network morphology. While the current dataset provides strong insight into injury mechanisms and clinical consequences, the lack of accident-location information limits direct spatial inference. Nevertheless, the proposed framework offers a foundation for future studies in which hospital-based injury records can be integrated with geocoded crash data and fractal urban network indicators. Such an approach can contribute to the development of safer micromobility systems in urban environments.

Keywords: Micromobility; injury analysis; hospital records; urban road network; fractal analysis; Istanbul.

International Co-operation on Theories and
Concepts in Traffic Safety

Development of a Novel Wearable Instrumentation System for Micromobility Studies

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Civil engineering design involves an extensive engineering domain. Transportation engineering is a branch of civil engineering that support the mobility and accessibility needs of humans, living things and matter. This support is made possible through designs and developments of intricate webs of transportation modes, transportation infrastructure and services. Each suggested solution to a transportation need must be tailored to meet the economic, geophysical, urban and social aspects of the societies. Therefore, it is futile to seek a one-size-fits-all solution.

As a part of this extensive array of transportation needs, micromobility is a rising method of transportation in urban environments. Perceived simplicity and safety of micromobility led to its rapid implementation in urban environments without the proper evaluation of the sufficiency and appropriateness of urban network topographies for this new mode of transportation. Development and implementation of user age and safety protocols also lagged behind the uncontrolled fusion of micromobility into urban environments that resulted in many accidents related to micromobility.

Civil engineering research requires interdisciplinary solutions. The needs of civil engineering design and production rely heavily on data that must be collected under different service conditions and in large quantities that are sufficient to support inquisitive research. Transportation engineering relies heavily on human and animal physiology to determine the limits of motion for its design elements. Mechanical and geometric aspects of any transportation engineering design involve human and animal tolerances to accelerations and rates of changes of accelerations. Such being the case, the effects of motion under varying conditions must be measured and evaluated for design. Micromobility, requires an in-depth evaluation of human experience in terms of kinematics since this experience is what effects the control and guidance of the micromobility vehicles, loss of which results in accidents. To this end, the second and the third authors from the Department of Civil Engineering of Istanbul University – Cerrahpaşa collaborated with the first author from the Department of Electric and Electronic Engineering Department to establish the **Mi**cromobility **Re**search **La**boratory (Mi.Re.La – **E**.**D**.**A**).

This study presents the development of a patent-pending wearable instrumentation structure that can collect multi-channel triaxial acceleration data at 1000 Hz. The lightweight device, developed by the first author based on the requirements and needs presented by the authors from the civil engineering department, includes a power supply, a data acquisition system and

a multi-channel sensor interface board. The calibrated data acquisition system and its associated components are carried within a backpack that is carried by the user. The system can be remotely controlled via a smartphone using the built-in Wi-Fi capability of the data acquisition system. The sensors are attached to the scooter and the user at the needed locations and the system collects data at high frequency as the scooter moves at different speeds over differing surface qualities. Figure 1 presents and instant of a test as the scooter travels over a test target at 10 km/h and Figure 2 presents the accelerations along the x, y and z axis.



Figure 1. Instant of test.

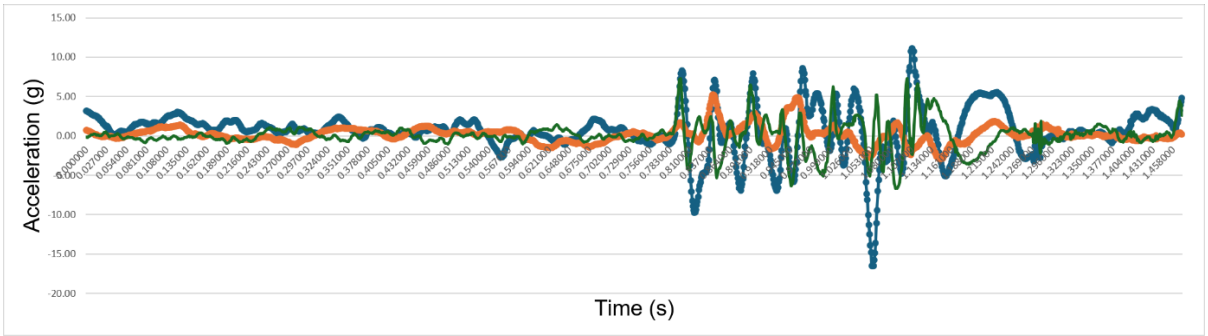


Figure 2. Collected acceleration data.

This study, will present the system architecture along with the quality and the characteristics of the collected data. The study will highlight human physiological constraints in terms of control and guidance and also evaluate these constraints in relation to the information extracted from the measured data.

This study will also highlight the pressing need for collaboration between different engineering departments and emphasize the need for establishment of senior year or post

graduate classes dedicated to sensor technology, instrumentation and data collection architectures.

International Co-operation on Theories and Concepts in Traffic Safety

Crash Frequency Modelling for Italian Road Tunnels

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Background

Road tunnels constitute a unique road environment in which driver behaviour, visibility, and available manoeuvring space differ substantially from those on open motorway sections. Rapid luminance transitions at tunnel portals, confined geometries, limited escape opportunities, and restricted recovery areas create operating conditions that cannot be adequately represented by conventional motorway safety models. Although crashes inside tunnels are generally less frequent than on adjacent open-road sections, they often result in more severe consequences, particularly when they involve fires or multiple vehicles. Consequently, reliable crash-frequency models specifically developed for tunnel environments are essential for safety assessment and infrastructure management.

Aim

This study aims to develop Safety Performance Functions (SPFs) for Italian motorway tunnels and to investigate whether including heavy-vehicle traffic improves the prediction of crash frequency beyond the traditional explanatory variables of traffic exposure and tunnel length.

Data and Methods

The analysis is based on a nationwide database of 198 motorway tunnel entities located along major Italian motorway corridors (A1, A7, A10, A11, A12, and A26). The dataset combines tunnel characteristics, traffic volumes, and police-reported crashes occurring between 2017 and 2021. Because fatal crashes were relatively rare, separate models for fatal crashes were not estimated.

Negative Binomial regression models were developed to account for overdispersion in crash counts. Separate SPFs were estimated for total crashes, property-damage-only (PDO) crashes, and injury crashes. Two model specifications were evaluated: a baseline model including Annual Average Daily Traffic (AADT) and tunnel length, and an extended model additionally incorporating the proportion of heavy vehicles. The basic models use total AADT and tunnel length:

$$E(Y_i) = exp\left(\beta_0 + \beta_1 ln(AADT_i) + \beta_2 ln(L_i)\right)$$

The advanced models extend that structure with heavy-vehicle proportion availability:

$$E(Y_i) = exp\left(\beta_0 + \beta_1 ln(AADT_i) + \beta_2 HV_i + \beta_3 ln(L_i)\right)$$

where Y_i is the five-year crash count in tunnel i, L_i is tunnel length in meters, and HV_i is heavy-vehicle proportion in percentage points, Also, AADT is annual average daily traffic (veh/day). Separate models were estimated for total crashes, PDO crashes, and injury crashes.

Results

The developed SPFs demonstrate that traffic exposure and tunnel length are significant predictors of crash frequency across all crash severity categories. Furthermore, incorporating heavy-vehicle proportion significantly improves model performance, indicating that traffic composition provides additional explanatory power beyond overall traffic volume. The resulting models offer practical tools for estimating expected crash frequencies in Italian motorway tunnels using variables that are routinely available to infrastructure managers.

Conclusions

The study demonstrates that simple yet robust Safety Performance Functions can be developed specifically for motorway tunnels using a limited number of readily available variables. The inclusion of heavy-vehicle proportion improves predictive capability, highlighting the importance of considering traffic composition when assessing tunnel safety. These findings contribute to more reliable network-level safety analyses and provide practical support for tunnel risk assessment, infrastructure planning, and evidence-based safety management.