International Cooperation on Theories and Concepts in Traffic Safety

ICTCT 2025: Data and methods for evidence-based safety measures and applications

Book of abstracts

1. EU-ASIA Platform for Safety Performance Indicators (SPIs) Benchmarking and Exchange of Best Practices

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In many Asian countries, traffic accidents are a major contributor to fatalities and serious injuries, imposing substantial economic burdens on society. Traffic accidents are now the leading cause of death for children and young people worldwide. ASIASAFE is an EU-funded project (2021-2024) aimed at strengthening traffic safety collaboration between universities and stakeholders within EU (Italy, Portugal, and Sweden) and Asian (Indonesia, Malaysia, and Vietnam) partners. This study focuses on assessing and benchmarking national road safety performance across EU and Asian partner countries through an innovative platform that facilitates data collection, analysis, and knowledge exchange. The objective of the study is to provide policymakers in Asia with evidence-based recommendations to enhance road safety strategies in line with national targets and the Sustainable Development Goals (SDGs) for 2030. Methodology: The study utilises comprehensive national road safety data to measure, assess, benchmark and monitor the Safety Performance Indicators (SPIs) at the country level. The platform standardises data collection and presents results in an accessible format, enabling comparisons across participating countries. The benchmarking framework covers five key dimensions of SPIs: 1) Road Safety Management; 2) Safer Roads and Mobility; 3) Safer Vehicles; 4) Safer Road Users; 5) Post-Crash Response. Pilot testing has been conducted using national datasets, with subsequent validation for wider international application. By offering a comprehensive benchmarking system, the platform aims to foster collaboration between EU and Asian countries, enabling them to share best practices and improve road safety policies at the national level. This study will highlight the ASIASAFE project's key activities, and results achieved, with a particular focus on benchmarking, academia-stakeholder collaboration and the EU-Asia Handbook of Best Practices in Road Safety. The study will conclude with a set of policy recommendations tailored to Asian partner countries, aimed at supporting their efforts to meet 2030 road safety targets and SDGs. This study is based on the results of the EU-Asia Handbook of Best Practices in Road Safety, produced under ASIASAFE project: https://asiasafe.info/wp-content/uploads/2024/05/Asiasafe-Handbook-2024.pdf.

2. Implementing Driving Hours Regulations for Commercial Vehicles in Nigeria: Challenges and Impacts

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Implementing driving hour rules for commercial vehicles is crucial to improving road safety and mitigating the negative impacts of driver fatigue. This research provides an in-depth analysis of the effects and challenges related with the implementation of driving hours for commercial vehicles in Nigeria. With the overarching objective of shedding light on the topic, this study pursued two specific objectives: first, to assess the perceived impact of implementing driving hour regulations on commercial drivers in Nigeria; and second, to identify and analyse the challenges that arise during the implementation of these driving hour regulations. In the course of the investigation, a comprehensive literature review was undertaken. This included an analysis of the effects of prolong driving hours on driver fatigue and its consequent impact on safety. In addition, the historical evolution of driving hours regulations and comparative analyses of similar regulations in other nations were analysed in depth. A survey was conducted with commercial drivers from Nigeria and the United Kingdom in order to provide empirical insights on the study. The study effectively examined the experiences and perspectives of drivers by juxtaposing two distinct climates: Nigeria, where such rules have not been enforced, and the United Kingdom, where such regulations are in effect. The findings of this study indicated that the absence of driving hour regulations in Nigeria leads to increased instances of driver fatigue, as evidenced by reported cases of drowsiness, exhaustion, and an increased likelihood of being involved in accidents, compared to their counterparts in the United Kingdom. This study finishes with a number of recommendations based on these findings. Notably, there is an urgent need for joint efforts between the government and industry partners to raise awareness about the consequences of prolonged driving and its impact on driver safety and health. Digital monitoring technologies should facilitate the implementation of driving hour rules, hence reducing the likelihood of harassment and extortion by security agents. In addition, the report proposes re-evaluating driver compensation schemes to make compliance with driving hours a key component. In addition, the study highlights the importance of establishing tougher penalties for noncompliance in order to enforce compliance with the standards. This thesis contributes to the discourse on driving hour regulations in Nigeria by emphasising the need of establishing such regulations to ensure road safety, safeguard driver welfare, and improve the overall efficiency of commercial vehicle operations.

3. Influence of weather on car-following at an urban intersection

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Introduction

Weather conditions like rain, snow, and fog significantly impact road safety. While drivers reduce speed and increase following distances in adverse weather, collision risk still rises by 50-100% due to reduced visibility and slippery roads [1]. On motorways, speed reductions are more noticeable, as drivers are much closer to the physical limits of their vehicles and high speeds amplify the effects of reduced friction. In urban areas, where speeds are lower, these effects are less apparent. However, wet pavement typically reduces speed by 10-30% [2]. This study quantifies how weather affects car-following behaviour by analysing speed, acceleration, and time-to-collision at an urban intersection.

Research methodology

Trajectory data was recorded at the AIM Research Intersection in Braunschweig, Germany, from January to September 2019 (excluding April). Up to 40,000 road users cross this inter-section daily, which has separate lanes for most traffic relations. Cameras capture data on time, position, speed, acceleration, road user type and size at 25 fps. Processed trajectories were analysed using safety measures such as time-to-collision (TTC) and aligned with hourly weather data from a weather station 6.3 km away. Over the study period, 25 different weather types were recorded. This study presents descriptive results.

Results

Figure 1 shows median TTC_{min} values for different traffic relations under various weather conditions. Right-turns generally have lower TTC_{min} (4.1–6.3 s) than left-turns (5.7–8.2 s) and straight movements (9.7–14.6 s), except for the unprotected left-turn (1.0–3.9 s). Also, the TTC_{min} can be different within the same relation. For instance, while driving straight "straight e2w 1" is similar to "straight w2e 1", they appear to be much different from driving straight "straight n2s 2" and "straight s2n 1". While weather has weak overall impact on TTC_{min}, some relations are more affected than others. For example, freezing rain shows inconsistent effects, and heavy rain can increase or decrease TTC_{min} depending on the relation. For instance, in case of freezing rain the relation "straight e2w 1" appears to be large for 155 (moderate freezing spray rain) and small for 164 (light freezing rain). Different rain types mostly increase TTC_{min}. In case of heavy rain (e.g. 153), TTC_{min} appears to either increase (e.g. relations "straight s2n 1", "right s2e 2") or decrease (relation "left e2s 2"). Further analysis, including kinematic profiles, will be presented at the conference.

Discussion and conclusions

Results indicate that car-following behaviour depends more on traffic relations than weather. Right-turns have TTC_{min} values 1.6–1.9 s lower than left-turns and 5.6–8.3 s lower than straight driving, likely due to speed differences and following distances. While the road users that drive straight follow each other with higher speeds (and larger distances), in turning manoeuvres the distances in car-following are smaller. Unprotected left-turns show even lower TTC_{min}, as drivers may rush to cross oncoming traffic. Variations within the same relation, such as lane changes on lane 1 to lane 2 in relation "straight n2s", also affect TTC_{min}. Weather influences behaviour, sometimes unexpectedly. Certain extreme conditions (e.g. 164) cause TTC_{min} to increase (due to greater distances and lower speeds) or decrease (closer following). Detection issues in bad weather and the weather station's distance (6.3 km away) may explain some discrepancies. Our next steps are to get a much more detailed view on the data and also to consider kinematic data.

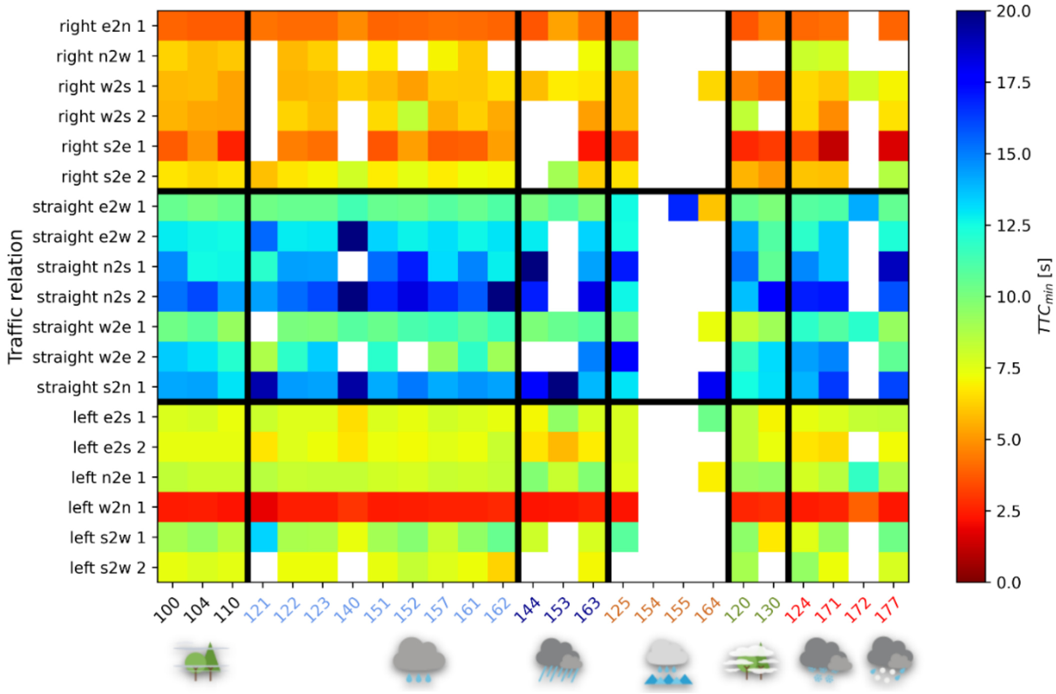

Figure 1. Medians of TTC_{min} plotted for each traffic relation (y-axis) and weather type (x-axis). Each line is characterised by direction (turning right/left, straight), relation (e.g. east to north: 'e2n') and lane (1/2: right/left lane). The weather is encoded by numbers, which can be roughly described as cloudy, haze/wet haze (100, 104, 110), light/moderate rain (140, 151, 152, 157, 161, 162), heavy rain (144, 153, 163), light/moderate freezing rain (154, 155, 164), fog (130), light/moderate snow and snow drizzle (171, 172, 177), and 'after event conditions' such as 120 (fog), 121-123 (rain), 124 (snow) and 125 (freezing rain). Note that white boxes relate to too few data.

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4. Interpretable Video Anomaly Detection for Enhancing Cyclist Safety

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Cyclist safety is a critical concern in urban environments, involving interactions with other road users such as cyclists, vehicles, pedestrians, and objects on the road. Monitoring cyclists' behavior in such a setting is essential to identify risks and requires innovative approaches to mitigate them in real-time. This research investigates the application of AI empowered video anomaly detection (VAD) algorithms to detect unsafe cycling behaviors and interactions in urban settings. Current manual methods for analyzing cyclist behavior in video footage require significant expertise and are not scalable. To address these challenges, we propose an automated approach that leverages a VAD algorithm to extract the potentially anomalous segments from long video recordings, enabling researchers and traffic safety professionals to focus on detailed analysis of shorter, high-priority moments.

This study builds on the VAD methodology proposed by Reiss and Hoshen [1], which demonstrated the effectiveness of combining interpretable visual features with deep embeddings extracted from a pre-trained deep neural network to enhance anomaly detection in video data. Our approach integrates velocity as an interpretable feature alongside deep representations to achieve robust and interpretable anomaly detection. Object detection and optical flow estimation were employed to extract these features, which were then analysed using density-based methods. Unique models were trained for each feature type: a Gaussian Mixture Model (GMM) for velocity features and k-Nearest Neighbors (kNN) for deep representations. The anomaly scores from these models were aggregated to produce a final anomaly score, enabling detection of abnormal moments as those with a higher anomaly score at both frame-level and object-level.

We trained and evaluated this model on a real-world dataset captured in The Netherlands, containing footage of the cycling path and the road. Video clips were annotated by the traffic safety specialists with normal and anomalous event labels at both frame-level and object-level. For training, we used 153 normal video clips and after training, we evaluated the performance of the model on a collection of 71 normal and 103 anomalous video clips. Notably, the proposed method achieved an AUROC of 94.6% in frame-level evaluations. Object-level evaluations yielded an AUROC of 55.5%, a significant drop compared to frame-level evaluation. This drop can be primarily attributed to the use of an off-the-shelf object detector which introduces noise and inaccuracies in feature extraction. Addressing these limitations remains a priority for future research.

References

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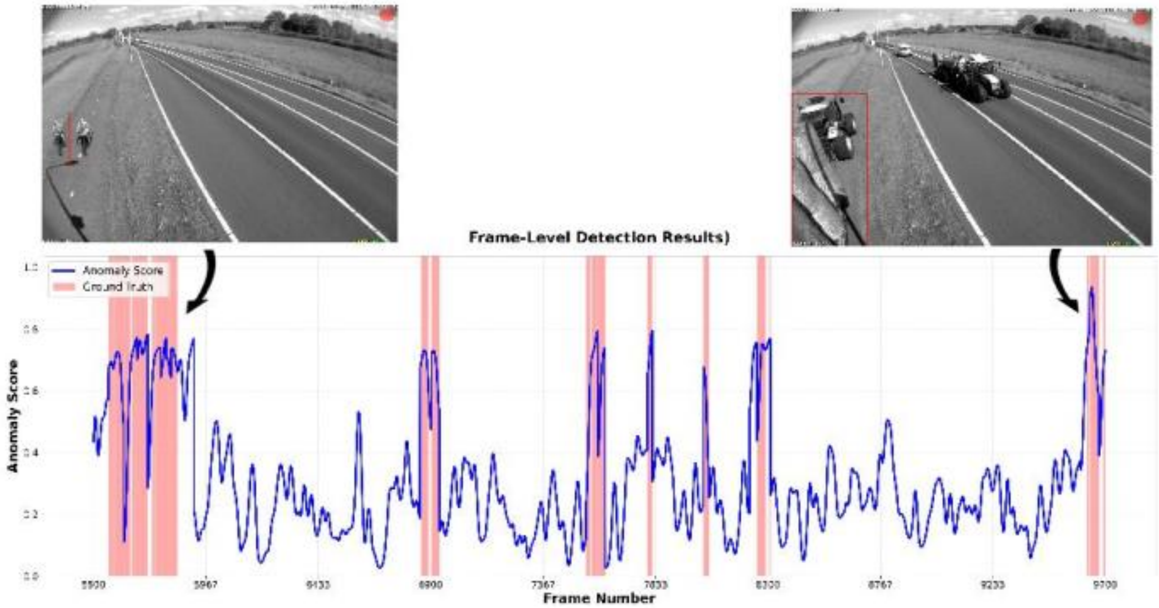

Figure 1. Frame-Level anomaly detection results: comparison of the predicted anomaly scores (blue) and the anomaly ground truth (red). Two example frames predicted as anomalous are shown: the left image shows the example of a cyclist riding on the wrong side of the bike lane while the right image shows an example of an agricultural vehicle riding within the bike lane.

5. Surrogate Measures of Safety (SMoS) for Right-Hook Crashes between Cars and Motorbikes

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Right-hook crashes [1] between right-turning cars and through-ahead two-wheelers (Figure 1) have severe consequences, as motorcyclists are not only motorists but also vulnerable users themselves. Motorbikes' operational characteristics (small size and width, higher power-to-weight ratio, etc.) allow them to percolate during jammed conditions and perform lane splitting in free flow (Figure 2), giving rise to motorbikes' unsafe positions relative to the cars, e.g., in the blind spot of cars.

Safety surrogate methods have the advantage of proactive measures [2] without having to wait until crashes and avoid the moral hazard of needing more crashes to generate statistical significance. This study adopts such methodology with the aim of enhancing mixed flow safety, the research objectives are: (i) develop SMoS for the right-hook crash; (ii) investigate the additional insights that can offered by conflicts (PRE-crash), but not by crash reports; and (iii) apply the proposed method to reduce right-hook crash.

Methodological Issues

The information from the conventional collision diagrams is not sufficient to identify all the right-turning vehicles since a right-turner may crash with motorbikes before cars' full steering to the right (CAT-III in Figure 3). To be specific, a collision between a right-turning car and a through-ahead motorbike may be recorded by police as either 'Right-hook' or 'Sideswipe' (last row in Figure 3). Such Conjoint Risks of CAT-I and CAT-II, between a pair of right-turning cars and through-ahead vehicles confounds police officers as subject vehicles stop after crashes without revealing their destination. By contrast, SMoS offers potential Pre-crash origin-destination information that cannot be acquired from police records. Still, it is not appropriate to solely map 1-to-1 from conflict events (CAT I, II, and III) to collisions. SMoS may be obtained by the three following possible arrangements.

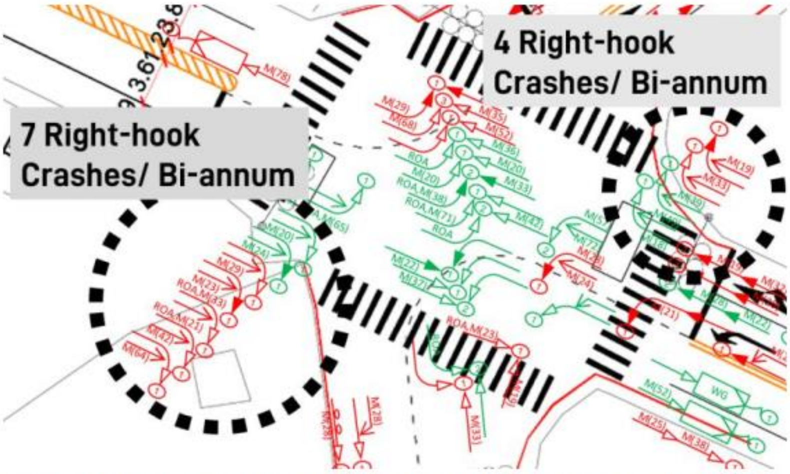

Figure 1 Right-hook crashes are unneglectable in the collision diagram.

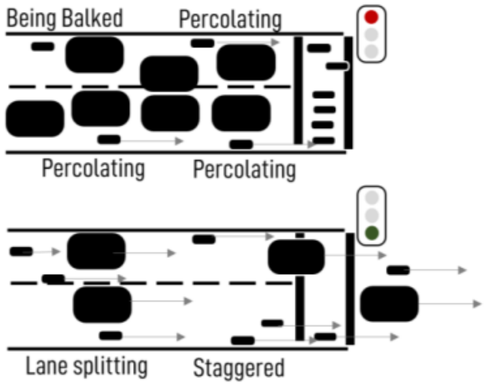

Figure 2 Motorbike positions

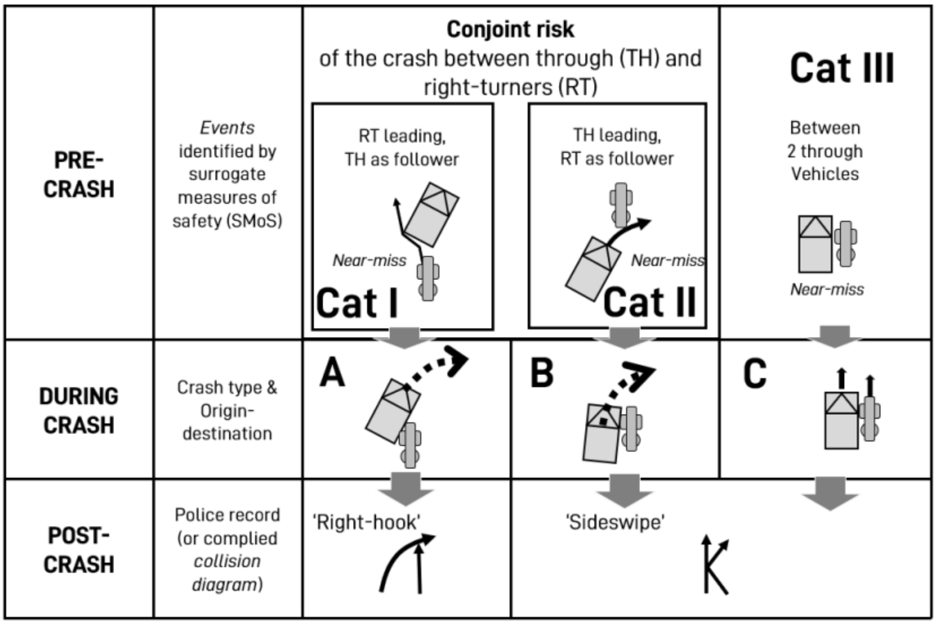

Figure 3 Pre-crash events may not map to post-crash police records.

Matching	Relations	Comments
Aspirational	{Cat I }→ **A** → {"Right-hook"} {Cat II }→ **B** → { **B**-related 'Sideswipe'} {Cat III } → **C** → { **C**-related 'Sideswipe'}	This is aspirational but not possible due to non-omniscience of police officers
Method 1: Separating Comb. A and B	{Cat I } → **A** → {"Right-hook"} {Cat II } → **B** ≼ { 'Sideswipe'}	Since B ≼ { 'Sideswipe'}, meaning there is a potential that recorded 'Sideswipe' cannot recognise the differences between combination B and C.
Method 2: Aggregated	{Cat I ∪ Cat II } → {**A** ∪ **B** } ≼ {'Right-hook' ∪ 'Side-swipe'}	Since Cat III is not the subject pre-crash of those between a pair of right-turner and through-ahead traffic, one may overcount in { 'Right-hook' ∪ 'Sideswipe'}.
Method 3: only Combination A is considered.	{Cat I } → **A** → { 'Right-hook' }	This is the most naïve method one can think of. However, Conjoint Risk is not considered, and the 'Right-hook' crashes recorded by police may underestimate the total potential right-hook crash.

Results & Applications

The results in the following table below show that the proposed matching methods of SMoS for right-hook crashes can indeed reflect the number of crashes.

Although the most naïve method without considering the potential mismatch between police record and behaviour considering origin-destination, Matching Method 3 still generates a fairly high Spearman Rank Correlation Coefficient, which is useful in following decisions when ranking the junctions with improvement promises. Method 2 captures the linear relations between the SMoS and crashes, while considering the problem nature.

Applications

The characteristics of mixed flow traffic make it right-hook crash-prone, and the proposed approach, founded on SMoS, can be proactive in the early detection of junction improvement treatments. Figure 4 shows before-and-after site photos showing the indication of right-turners-keep-right, even within a lane, as a reminder additional to legislation.

Figure 4 Before and after: when kerb-side lane is too wide, deploy ‘half right-turn lane may reduce conflicts

Closing

SMoS can serve as a proactive detection of Right-hook related crashes. Three matching methods are proposed to capture the Conjoint Risks of through and right-turn traffic. The performances and possible application of the proposed approach show some promises.

References

[1] Jannat et al. (2020), ASCE, J. Transp. Engineering A.

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6. Average Speed Control in the Latvian Road Network

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One of the preventive tools to reduce non-observance of the permitted driving speed in road traffic and prevent road traffic accidents is average speed control. Its basic purpose is to control the flow of road traffic in time and space in order to avoid or reduce the risk of road traffic accidents and their impact on the overall traffic flow, thus aiming to make the traffic flow smooth. Speed is one of the main factors that both contribute to causing CSNg and affect the severity of CSNg. In the national road network of Latvia, the highest traffic intensity is on the country's main roads, but when evaluating the average driving speed data, a significant number of speeding cases are recorded on regional roads as well. Also, the technical condition and equipment of the road is safer on the main roads of the country, therefore, to adopt and create a system for controlling the average speed for equipping roads, it is necessary to evaluate several criteria. The aim of the study is to improve traffic safety by introducing average speed control. The study found out the effect of actual driving speed on traffic accidents on Latvian roads.

7. Does Changing Perspective Improve Safety? Examining Camera Views for the Remote Operator of Highly Automated Vehicles

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Background

Highly automated vehicles (HAVs) are expected to positively affect safety, comfort, reliability, and availability of mobility. However, the robustness of driving automation systems is still lacking. To make large-scale HAV operations more robust, specifically at system limits or in corner cases, a human operator can support the vehicles remotely. Hence, remote operation can actively contribute to making HAV systems safer. In order for a remote operator to accurately assess the traffic situation around the supported HAV, a representation of the situation is necessary. Situations are usually represented at the remote operator's workplace as video streams. Attention needs to be given to the location and perspective of the camera recording the video stream as it may affect the remote operator's situation awareness, performance, and thus, safety. In general, the camera perspective transmitted to the remote operator resembles the driver's perspective. However, this first-person view is associated with shortcomings including the occlusion of relevant objects on the road or the distortion of distance and angle perception. These shortcomings may lead to less safe and performant remote operation interventions.

Aim

Thus, we aim at examining alternative camera perspectives for HAV remote operators regarding safety, performance and situation awareness. An additional camera perspective can be transmitted from an infrastructural support unit, such as cameras mounted on polls, for example at critical intersections, or by visualizing LiDAR point clouds to create perspective from virtual sensors. The following study will investigate if camera perspectives other than the commonly used driver's first-person view will positively affect safety, situation awareness, and other user-related variables. Additionally, the interplay of camera perspectives with a novel concept for augmenting the video feed by visualizing senor data will be investigated in a poor-visibility environment.

Method

In an experimental user study, participants were asked to resolve a typical remote operation task displayed in a simulation environment. Participants were tasked to give clearance to a complex left-turn maneuver at an urban intersection. The video stream was presented from three camera perspectives: the driver's first-person view, a videogame-like third-person view, and a bird's-eye view from above the supported HAV. In addition to camera perspective, a novel concept for an augmented human-machine interface (HMI) was incorporated in the study. This HMI concept is based on visualizing the HAV's sensor data. It has been shown to enhance safety and situation awareness by highlighting relevant road users in poor-visibility conditions. The effects of camera perspective and augmentation on several outcome variables were measured. Most critically to safety, the rate of collisions with vulnerable road users, consisting of pedestrians and cyclists, as well as other vehicles was measured. Additionally, the shortest distance to surrounding road users during the turning maneuver was collected. As an indicator for performance, decision time was recorded. Additionally, situation awareness, workload and usability were measured by self-report. Benefits are expected for the additional perspectives compared to the first-person view: The third-person perspective may provide a better overview of the traffic situation than the first-person perspective. The bird's-eye perspective could outperform the first-person perspective since it is likely to provide a better overview of the holistic traffic situation, comparable to a map. Additionally, in situations with poor visibility, the augmented conditions are expected to outperform the non-augmented ones across camera perspectives.

Results

Initial findings suggest a beneficial effect of augmentations on both safety, performance, and situation awareness. The specific effects of camera perspective on the outcome variables are currently under investigation.

Conclusion

Findings will contribute to the iterative socio-technical development of a workplace HMI for remote operation. Specifically, the ideal camera perspective for the remote operator performing complex left-turn maneuvers at critical intersections will be ascertained. The results will add evidence to the question if infrastructure support and visualized sensor data for the remote operator provide added value for the remote operator in assessing a difficult traffic situation.

8. How does reference point determination influence trajectory estimation?

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Background

Automated video-based analyses have become an essential component of road safety research, undergoing substantial advancements and widespread adoption over the past two decades. Numerous studies, particularly those focusing on traffic conflicts, rely on determination of objects trajectories from video recordings. The objects trajectories are derived from the ordered sequences of points representing object's position (x_i, y_i) at time t_i. Usually, the object's trajectory is determined by connecting the centres of objects bounding boxes over time. However, if the recording camera is positioned at an acute angle, relative to the ground plane, the estimated trajectories of objects may be projected away from the actual object's positions, leading to distortions in trajectory placement. If it occurs, distorted estimates of trajectories are provided. Consequently, it affects any other derived measures from those trajectories, such as PET (post encroachment time).

Aim

The aim of this contribution is to highlight the issue arising from the standard method of determining trajectories based on object bounding box centres. We propose a solution that improves the determination of an object's representative point to minimize trajectory distortion.

Method

We propose a novel method for estimation of pedestrian and cyclist trajectories using convolutional neural networks (CNNs). A key part of the method is determining a representative point that better corresponds to the actual position of the object in space. We demonstrate the application of this method on two use case scenarios: 1) estimation of lateral position of cyclists on a cycling path, 2) calculation of PET for pedestrian-car interactions on a pedestrian crossing.

Results

In the first experiment, the results indicated that trajectory estimation method influenced the calculated lateral position of bicycles in a traffic space with significant shift in the position of the trajectory. We thus obtained more reliable information about the actual use of the cycling path space by bicyclists.

In the second experiment, more than 100 intersections between car and pedestrian trajectories on a pedestrian crossing were identified. All PET values calculated using CNN method provided lower values than those calculated using the standard method. This means that the actual risk of collision was higher than estimated by the standard method.

Conclusions

We demonstrated that bicyclists' trajectories estimated with the proposed CNN-based method align more accurately with geographical space than conventional methods using bounding box centres. Furthermore, we indicated that the PET values computed from these corrected trajectories differ significantly from those obtained using conventional trajectory estimation methods. This approach is particularly crucial when traffic situations are recorded from the side. The farther the camera is positioned from an overhead view, the greater the benefit of this method, and conversely, the greater the distortion introduced by the standard approach.

In many behavioural studies of vulnerable road users found in the literature, trajectory estimation is not explicitly described in the methodology. Many researchers rely on tools—often proprietary—that lack documentation on trajectory construction and do not allow users to modify the calculation process. We strongly recommend including this information in the methodology, as it directly impacts the results.

9. Micromobility braking performance in real-world safety-critical events from naturalistic data

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Introduction

Recent years have seen a proliferation of micro-mobility vehicles in urban environments, with these vehicles' vulnerable users experiencing an increased incidence of involvement in accidents. In the event of an emergency, it is important to consider the vehicles' capacity to enable avoidance. While previous studies have established the braking performances of these vehicles through controlled track tests, revealing notably low efficiency for e-scooters and e-monowheels, there remains a critical need to examine their real-world performance. This study aims to bridge this gap by investigating the braking capabilities of e-scooters, e-monowheels, and e-bikes in authentic dangerous urban scenarios.

Material and methods

A total of 143 participants, consisting of 56 e-scooter riders, 24 e-monowheel users, and 63 e-bike riders, were tracked over two-month periods, covering all daily journeys, in three different regions of France: South (Marseille and small surrounding cities, Oct-Nov 2022), East (Lyon, May-June 2023) and Centre (Paris, Nov-Dec 2023). Data collection utilized removable smartphones as recorders, secured in 3D-printed supports on e-scooters and e-bike handlebars, and placed in chest harnesses for e-monowheel users. A dedicated application captured: GPS position and speed (1 Hz), accelerations and rotation velocities (100 Hz), and video of the scene ahead (30 fps). Riders reported real time risky situations, including dangerous interactions with other road users, infrastructure issues, and their own behaviour. Subsequent analysis identified braking manoeuvres when present, and extracted mean deceleration level during braking from filtered longitudinal acceleration data.

Results

From 7,365 recorded trips covering a total traveling distance of approximately 26,000 km, participants reported 645 risky events that could be identified in the data, 385 of which involved braking (Table 1).

Table 1. Available data

Vehicle	e-scooter	e-monowheel	e-bike	total
N. trips	2,745	1,471	3,149	7,365
Distance (km)	6,083	6,504	13,404	25,991
Duration (h)	401	410	831	1,642
N. found reported risky events	209	134	302	645
N. risky events involving a braking	117	83	185	385

Figure 1 shows the deceleration distribution for each rider type during these events. Average deceleration in reported risky situations was 4.3 m/s^2 for e-scooter compared to 3.0 m/s^2 for e-monowheels and 3.6 m/s^2 for e-bike. Pairwise t-tests confirmed significant differences between these averages. Comparison of these real-world braking performances to track test results evaluating deceleration capacity in hard braking [1] reveals that e-scooter deceleration is slightly higher in safety-critical events than in controlled hard braking tests, while e-monowheel performance remains similar in both scenarios (Table 2). Conversely, e-bike users brake less intensely in real risk situations than in track tests, rarely using their bike's maximum braking capacity. The naturalistic study showed greater value dispersion due to varied situations, from emergency to moderate braking, and differing vehicle braking capacities.

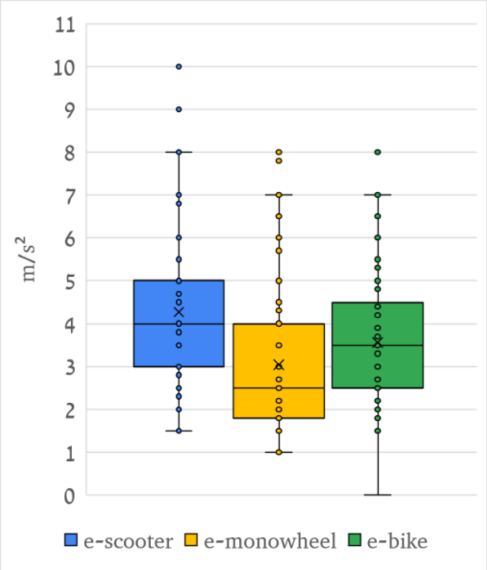

Figure 1. Decelerations in risky situations

Conclusions

The methodology enabled a comprehensive examination of real-world braking performance and safety issues across various micro-mobility vehicles in different urban environments. Analysis of 385 reported risky events involving braking revealed that electromobility vehicles have significantly lower deceleration levels (3-4.4 m/s^2 on average) compared to cars or motorbikes (8 m/s^2). These findings align with track performance studies, except for e-bike users who rarely utilize their vehicles' full braking capacity. Future research should focus on detecting all sudden braking events in natural traffic to include undeclared risk situations and common braking manoeuvres.

The low actual braking performance of these vehicles in high-risk situations may explain their higher accident risk, especially given their capability to travel at much higher speeds than conventional personal transport devices. This underscores the need for improved safety measures, enhanced vehicle design, and targeted user training to mitigate risks associated with the growing adoption of micro-mobility solutions in urban areas.

Table 2. Comparison of braking performances between track test and naturalistic driving risky situations

Average deceleration (m/s^2) [Standard Deviation]	e-scooter	e-monowheel	e-bike
Braking in risky events during naturalistic study	4.4 [1.5]	2.9 [2.3]	3.8 [1.2]
Hard Braking on track	3.7 [0.3]	3.1 [0.3]	6.1 [1.0]

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10.Systemic Causal Analysis of Nigerian Petroleum Tanker Road Crashes

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Road transportation is crucial for distributing petroleum products in Nigeria, but it has been plagued by safety issues such as road crashes, rollovers, fires, and explosions. For instance, two hundred and fifty-five (255) human fatalities were recorded in three hundred and seventy (370) road crashes involving petroleum tanker trucks in Nigeria in 2020, averaging thirty-one (31) crashes per month (FRSC, 2021). This high accident profile has implicitly continued to interrogate the potency of the existing safety management practices in controlling the emergent safety risks that characterize Nigeria's modern road transportation system. This characteristic high accident profile and inherent tendency towards releasing hazardous processes have reinforced the designation of road transportation of petroleum products as a safety-critical system (Cikara, 2022). In seizing these opportunities for achieving the safety objective, numerous crash causation analyses and investigation approaches have been developed and being implemented to understand the accident aetiological mechanisms (Obasanjo et al., 2014; Liu, 2017; Naevestad et al., 2020; Odogwu, 2021; Mohammadfam, 2021). Incidentally, many of these crashes causation analyses adopt reductionist and sequential methodologies that narrowly focus on identifying traffic-vehicle-driver failures within the immediate environment of the crash scenes. These reductionist and sequential methodologies have nevertheless been criticized for excluding complex systems of higher-order factors that interact to elicit hazardous conditions and unsafe driver behaviour in themselves (Salmon et al., 2016). Modern road transportation has morphed into a complex socio-technical system, defiling the traditional deterministic safety management paradigms. Thus, systemic safety management predicated upon systemic accident causal analysis has emerged as an alternative management approach for road transport risk. Some prominent models and methods under the systemic classification include Rasmussen’s Risk Management Framework, AcciMap Analysis Method, Functional Resonance Analysis Method (FRAM), and the Systems–Theoretic Accident Model (STAMP).

The lack of research into systemic crashes in the road haulage industry for petroleum products in Nigeria has prevented regulators and operators from understanding safety risks. Therefore, this study aims to conduct a systemic safety analysis of road traffic crashes involving petroleum products transportation with tanker trucks in Nigeria from 2013 to 2022 to determine the extent to which systemic factors contributed to these crashes. The AcciMap methodology was used to analyze the contributory causal factors involved in representative petroleum tanker crashes in Nigeria.

Method

This study embraced a mixed-method research design. The research design choice was predicated upon its capability to adequately guide the capturing, analyses and interpretation of both the quantitative and quantitative components of road crash causality for AcciMap analysis. The study collected data on road traffic crashes and safety practices in the transportation of petroleum products in Nigeria from various stakeholders. The data was gathered from regulators, operators, and other relevant parties. The Federal Road Safety Corps provided the main source of research data. The study utilized three datasets, including standardized road traffic crash reports, crash investigation reports, and data on causality information and safety intervention suggestions from industry players. 5% of the crash investigation reports were purposively sampled to ensure thorough representation.

In conducting the descriptive analyses involved in this study, MS Excel version 2019 and SPSS version 27 were deployed. The coding and sorting of identified causation factors from the crash investigation reports was undertaken using Microsoft Excel version 2019 and NVivo 12. The actual construction of AcciMap for the representational crash cases was implemented using the MS Visio application program. Likewise, the Thematic Analysis of the semi-structured interviews was undertaken with the MAXQDA application, a powerful, multi-purpose and easy-to-use software. Rasmussen's AcciMap methodology demonstrates superlative advantages in compiling numerous and broad ranges of causal factors into a single coherent diagram, promoting a systemic view of accident causations, and developing proactive safety recommendations. (Branford et al. 2009; McIlroy et al. 2021).

Results

The descriptive analysis of 2979 Road Traffic Crashes Information Reports over the research period established the subsistence of high and unacceptable scale of crash incidents, fatalities and injuries involving petroleum product transportation by road in Nigeria. These crash variables expressed per billion litres of product transport, however, depicted summarily an erratically declining trend over the period under investigation. Descriptive causality analysis based on identified causative factors in these crash reports by the regulators indicated only low-level factors that reside within the immediate scene of the crash, thus, validating the none or weak entrenchment of systemic crash and safety analysis in the risk management in road transportation of petroleum products in the country as it was being practised in developed countries and even in the aviation industry. The application of the AcciMap methodology for systemic analysis of six representative crash cases elicited systemic causalities and the construction of a generic AcciMap, identifying contributory factors and their interactions across the entire six sociotechnical levels in tandem with Rasmussen (1997). The AcciMap produced eighty-two (82) contributing factors with 141 causal interrelationships among the factors. Based on the generic AcciMap, forty-eight (48) safety recommendations, mapped across Rasmussen's Risk Management Framework levels, were developed for implementation. The study established that crash causality in petroleum product transportation is multi-causal and systemic. It validated the assertions of Rasmussen and Svedung (2000) that treatments of the high-order factors have a wider range of impacts on the control of accident or safety performance than the low-order factors that reside in Levels I and II in a sociotechnical system due to its over-bearing effects.

Benefits to Road Safety

Implementing the forty-eight (48) safety recommendations elicited by the study will greatly improve the safety regulations and practices in the road transportation system for petroleum products in Nigeria. It can be generalized to operating environments with similar contexts. For operators and regulators in the road transportation of petroleum products, this study demonstrated that AcciMap methodology with safety recommendations could contribute tremendously to comprehensive risk and incident analyses in organizational HSE and safety management system programs if adopted to provide a deep understanding of accident aetiology.

Implications for Policy and Practice

The study could catalyze the review of extant standard operating procedures for road crash investigation by industry operators and government agencies such as Nigeria Midstream and Downstream Petroleum Regulatory Authority, Federal Road Safety Corps, Nigeria Police and the State Vehicle Inspection Services for embracement of system-wide investigative approach. Significantly, the study will assist immensely in operationalizing the safety components of the Nigeria Petroleum Industry Act (2021) by providing critical perspectives.

Conclusions

The research discussed in this work demonstrates and substantiates the AcciMap methodological potency in the explication of the complex system of contributing factors involved in the causation of petroleum tanker truck crashes in Nigeria. It validates the seminal studies of Rasmussen and Stanton on the systemic nature of crashes in the road transportation system and their usefulness in developing proactive safety interventions.

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11. Involvement in Traffic Accidents Among Drivers with Neurological Conditions and Reporting Medically Unfit Drivers

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Background

In Sweden, physicians are obligated to report patients who are deemed medically unfit to hold a driving license to the Swedish Transport Agency. However, the physician is not required to submit a written report if it is assumed that the patient will comply with the physician's verbal recommendation not to drive.

Assessing whether a patient meets the medical requirements to hold a driving license is not always a straightforward task within healthcare. It is often a challenging responsibility that must be managed alongside other duties. Furthermore, there might be difficulty in determining the extent to which a disease or disability may affect driving. The medical regulations provide guidelines for conditions such as impaired vision or epilepsy, but for other neurological diseases the guidelines are less clear which increases the risk of misjudgement and potential traffic accidents. Moreover, the medical standards for a driver's license differ between countries and affect transferability. To reduce the number of traffic accidents and enhance road safety efforts, further research is needed. Thus, as a road traffic accident is a complex event, more factors need to be considered, such as medical conditions.

Aim

The purpose of the study was to investigate Swedish drivers' licenses that have been revoked for medical reasons. Furthermore, another aim was to examine road traffic crashes among drivers with neurological conditions.

Method

Based on the Swedish driving license authority and their register, driving license revocations were compiled. Moreover, drivers involved in a crash (national data from the Swedish Traffic Accident Data Acquisition, i.e., Strada) between 2010-2019 were matched with pre-existing diagnoses, i.e., Stroke, Parkinson's disease (PD) and multiple sclerosis (MS), retrieved from the National Patient Register. The types of road traffic crashes among drivers with neurological diagnoses were compared to a group of neurologically unaffected individuals with inflammatory bowel disease, most likely not to affect driving competences.

Result

In 2024, a total of 38,709 driver's licenses were revoked in Sweden, representing a 5.8% increase compared to the previous year. Of these, nearly one-third were due to medical reasons (Figure 1). However, the medical conditions that were reported remain unknown. From the national registers, a total of 2145 drivers with a stroke diagnosis, 199 drivers with PD and 385 drivers with MS, had been involved in a road traffic crash during 2010-2019. Only a few crashes occurred during the first months among the drivers with post stroke. However, within five years from diagnosis, traffic accidents had occurred in

51% of the PD group drivers. The drivers with MS did not differ from the reference group. Furthermore, the drivers with Parkinson's disease were more involved in single-vehicle accidents, and more seriously injured.

Conclusions

The study showed that some of the neurological diagnosis differ in terms of type of traffic accident, but also in terms of the severity of the injury compared to other neurological diseases and a comparison group. Although numerous factors contribute to car accidents, the driving abilities of drivers with neurological conditions could be more comprehensively evaluated by clinical physicians, even early after diagnosis, as the impairments and the severity vary greatly, which requires careful individual assessments. The findings of this study suggest that the system in which physicians are responsible for assessing the patients’ driving fitness in Sweden is generally effective.

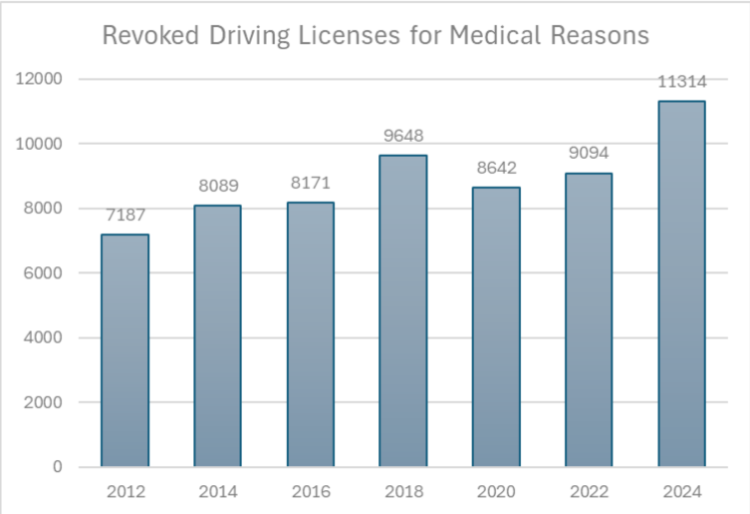

Figure 1. Number of revoked driving licenses for medical reasons in Sweden between 2012-2024.

12. Developing variations of a driving simulator screening test: A step toward fairer driver tests and safer drivers

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Background

Traffic accidents are a leading cause of death among young people, partly due to underdeveloped executive functions like planning and impulse control. Young drivers often underestimate risks and overestimate their abilities, highlighting the need for more accurate driving tests. One solution is to use driving simulators alongside Sweden's current on-road and theoretical exams. While simulator tests show promise, further development is needed. A screening test has been created to identify risky drivers, using challenging situations to assess hazard perception and risk awareness. To make it viable, multiple versions of these scenarios must be developed and validated.

Aim

This study aimed to assess how small variations in the simulator screening test affect the results. This knowledge is essential for creating numerous unpredictable, fair, and reliable variations of the screening test. The following research questions were formulated:

- How do small changes in the road environment or traffic impact test outcomes?
- To what degree do the different test versions maintain consistent difficulty levels?

Method

A between-group design was used, with participants divided into three groups, each completing one of three versions of the same simulator test. All three versions included the same 14 situations, with small variations in the road environment or surrounding traffic. The independent variable was the version (1-3) and the situations (S1-S14), while the dependent variable was participants' overall performance and performance on individual situations (pass/ fail).

Participants

Data were collected at five automotive high schools, recruiting 126 students—92 men and 14 women. All participants were 17 years old and had extensive prior experience with the simulator used (Figure 1).

Figure 1: Data collection at one of the automotive schools.

Equipment

A fixed-base high-fidelity driving simulator with Skillster software was used (skillster.se). Three tests versions were administered, each containing 14 challenging and potentially dangerous situations, set in urban traffic, on country roads, and highways. For instance, one scenario tested merging onto a highway, another handling a left turn on a country road with oncoming traffic, and a third avoiding a hidden pedestrian. The 14 scenarios had slight variations across the versions, such as different colored cars and houses or buses replaced by trucks (Figure 2). The goal was to introduce small changes between version 1 and 2, and slightly more changes in version 3. In one situation, version 3 was made even more complex to test the extent of possible variations.

Procedure

Before starting the simulator test, participants were informed of their anonymity and right to withdraw. After giving consent, they were randomly assigned to one of three versions, each taking approximately 24 minutes. Each situation had specific evaluation criteria, such as giving way, driving at a safe speed, and maintaining distance from other vehicles. To pass the entire test, participants had to pass all 14 situations. Participants were not informed of their results.

Figure 2: Example of variation between situations.

Procedure

Before starting the simulator test, participants were informed of their anonymity and right to withdraw. After giving consent, they were randomly assigned to one of three versions, each taking approximately 24 minutes. Each situation had specific evaluation criteria, such as giving way, driving at a safe speed, and maintaining distance from other vehicles. To pass the entire test, participants had to pass all 14 situations. Participants were not informed of their results.

Analysis

Data was compiled in Excel, with separate files for each version, and then analyzed in Jamovi. Rasch analysis was used to assess the difficulty of the 14 situations across the three versions, producing three corresponding result tables (Table 1-3). Situation difficulty was evaluated using the Measure parameter from the Rasch analysis, where higher values indicate more difficult situations and lower values indicate easier ones.

Results

Results show similarities between situations across versions. For instance, situation 13 was the most difficult in all versions, though slightly more so in version 3. Situation 11 was consistently the easiest. The pass rate for each situation was also similar across versions. However, some variations in difficulty warrant further examination. For example, the difficulty of situation 8 increased from version 1 to 2, and more so from version 2 to 3. Situations 3 and 9 were more difficult in version 3 than in the others.

Conclusion

Small variations in simulator test situations do not significantly affect the outcome. However, adding more changes and increasing complexity can alter the difficulty level. These insights are crucial for creating multiple unpredictable simulator screening tests with consistent difficulty. Further analysis will be conducted, and additional results will be presented at the conference.

Table 1: Results from test version 1

Item Statistics

	Proportion	Measure	S.E.Measure	Infit	Outfit
S1	0.811	−1.863	0.495	1.597	2.391
S2	0.622	−0.560	0.390	1.132	1.184
S3	0.838	−2.124	0.527	0.898	0.810
S4	0.892	−2.779	0.625	0.499	0.198
S5	0.838	−2.124	0.527	0.681	0.577
S6	0.838	−2.124	0.527	0.756	0.846
S7	0.757	−1.421	0.449	0.883	0.895
S8	0.459	0.298	0.373	1.259	1.505
S9	0.676	−0.876	0.407	0.940	0.982
S10	0.730	−1.227	0.432	1.078	1.052
S11	0.919	−3.219	0.706	0.779	0.741
S12	0.892	−2.779	0.625	0.729	0.584
S13	0.324	1.017	0.391	1.087	1.033
S14	0.730	−1.227	0.432	0.972	1.040

Note. Infit= Information-weighted mean square statistic; Outfit= Outlier-sensitive means square statistic.

Table 2: Results from test version 2

Item Statistics

	Proportion	Measure	S.E.Measure	Infit	Outfit
S1	0.795	−1.782	0.473	1.269	1.673
S2	0.769	−1.568	0.452	0.895	0.759
S3	0.769	−1.568	0.452	0.894	0.753
S4	0.821	−2.017	0.498	0.941	0.991
S5	0.897	−2.935	0.624	0.691	0.452
S6	0.821	−2.017	0.498	1.336	1.391
S7	0.462	0.302	0.370	1.057	1.056
S8	0.385	0.716	0.375	1.165	1.124
S9	0.564	−0.251	0.377	1.014	1.100
S10	0.667	−0.850	0.401	0.891	1.057
S11	0.821	−2.017	0.498	0.564	0.320
S12	0.744	−1.371	0.436	0.803	0.856
S13	0.308	1.152	0.390	1.137	1.089
S14	0.641	−0.693	0.393	1.018	1.237

Note. Infit= Information-weighted mean square statistic; Outfit= Outlier-sensitive means square statistic.

Table 3: Results from test version 3

Item Statistics

	Proportion	Measure	S.E.Measure	Infit	Outfit
S1	0.843	−2.9004	0.528	0.728	0.699
S2	0.569	−0.2502	0.379	1.028	0.932
S3	0.647	−0.8533	0.399	1.207	2.663
S4	0.686	−1.1839	0.414	0.646	0.392
S5	0.647	−0.8533	0.399	0.808	0.543
S6	0.686	−1.1839	0.414	0.873	0.626
S7	0.529	0.0320	0.373	1.049	1.026
S8	0.235	2.1374	0.402	1.431	1.676
S9	0.510	0.1701	0.370	0.999	0.830
S10	0.588	−0.3954	0.383	0.839	0.610
S11	0.863	−3.1922	0.553	0.943	0.513
S12	0.686	−1.1839	0.414	1.128	0.984
S13	0.137	3.0678	0.472	1.030	0.589
S14	0.588	−0.3954	0.383	1.052	1.042

Note. Infit= Information-weighted mean square statistic; Outfit= Outlier-sensitive means square statistic.

13. Province-Based Crash Frequency Prediction on Two-Lane Rural Highways Segments Using a Random Parameter Zero-Inflated Negative Binomial Model

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Introduction

Two-lane rural highways account for about 88% of rural roads in Piemonte, Italy. These highways often face high crash frequency due to geometric constraints and variable traffic flows. Safety Performance Functions (SPFs) play a central role in understanding and predicting crash frequency. By linking crash data with road, traffic, and environmental characteristics, SPFs help identify high-risk sections and support the planning of targeted safety interventions.

Two major issues arise when developing SPFs for rural networks. First, a large number of road segments report zero crashes over the study period, which can distort standard modelling approaches. Second, unobserved heterogeneity across provinces in terms of differences in terrain, infrastructure quality, and enforcement practices which can influence crash occurrence in ways not captured by observed variables. Addressing both issues is essential for producing reliable and regionally meaningful SPFs. In this context, the present study focuses on developing an SPF for two-lane rural highways in the Piedmont region using a Random Parameter Zero-Inflated Negative Binomial model (RP-ZINB).

Methodology

In Italy, crash records only include events with fatalities and injuries. In the Piemonte region, a total of 5147 crashes occurred on two-lane rural highway sections in the period 2012-2022 (Istituto Nazionale di Statistica). Regional official data from the traffic and mobility administration and the regional cartography (BDTRE) were merged and used. Several key variables such as the Average Annual Daily Traffic (AADT) and the segment length (length) were used as exposure variables. Tortuosity, defined as the ratio of the actual segment length to the direct distance between its endpoints, quantifies roadway curvature. A binary variable for public transport indicates the presence of public transport services.

Three variants of a zero-inflated negative binomial (ZINB) model were estimated to examine unobserved heterogeneity across the eight provinces in the Piedmont region. RP-ZINB specified random parameters (RP) for *ln*(AADT), *ln*(length), and the intercept, allowing these effects to vary by province. This approach captures potential differences in traffic exposure, segment length, and baseline crash risk. In the RI-ZINB (Random Intercept-ZINB) model, only the intercept was treated as random. Finally, ZINB was estimated without any random parameters, serving as a baseline for comparison.

Results

Several count data models were fitted to the data using the glmmTMB package in the R software. Table 1 illustrates the estimated parameters for the three mentioned models. The Likelihood Ratio (LR) test revealed no significant differences between RI-ZINB and RP-ZINB ($p = .553$), implying that the coefficients of *ln*(AADT), and *ln*(length) did not vary significantly across provinces. This is further supported by the small standard deviations shown in Table 1. However, LR test indicated a significant difference between RI-ZINB and ZINB ($p < .001$), indicating that the inclusion of a random intercept accounts for variation across provinces. Additionally, a comparison of AIC and BIC values showed that RI-ZINB outperformed the other models. The overall significance of RI-ZINB was evaluated using the LR test, which were significant at the 95% confidence level ($p < .001$). All variables used in model development were highly significant. For the zero-count state, only length was significant.

Discussion and conclusions

The RI-ZINB model revealed significant heterogeneity across provinces, addressed by including a random intercept. This suggests that unobserved factors such as topography, road infrastructure quality, and driver behaviour contribute to variations in crash frequency. The results showed that AADT has a significant effect at the 95% confidence level so that 1% increase in AADT will result 0.753% increase in expected crash frequency. The results also revealed that length has a significant effect at the 95% confidence level, so that increases in segment length are associated with higher expected crash frequency, reflecting both increased exposure and a reduced likelihood of being in the zero-count state.

The tortuosity also had a significant negative effect on the expected crash frequency. For every one unit increase in tortuosity, the expected crash frequency is reduced by approximately 24% when all the other factors are kept constant. This may indicate that highly curved segments encourage slower vehicle speeds, which can be reflected in reduced frequency of certain types of crashes. A positive and significant effect of variable public transport suggests that segments with public transport have more crashes, possibly reflecting higher pedestrian/bus-stop activity or other local factors. The result implied that when public transport is present, the expected crash frequency is approximately 61% higher compared to when it is absent.

The developed SPF offers a robust framework for predicting crash frequencies and guiding targeted safety interventions on rural highways in the Piemonte region, and can be adapted for use in other regions of Italy or internationally. Given the presence of unobserved heterogeneity across provinces, identifying its sources in future research could help further enhance the predictive capabilities and transferability of SPFs.

Table 1: Estimation of Models Parameters

Variables	RP-ZINB		RI-ZINB		ZINB	
	β	*p*-value	β	*p*-value	β	*p*-value
Negative binomial count state						
ln(AADT)	0.744	<.001	0.753	<.001	0.831	<.001
ln(length)	0.952	<.001	0.924	<.001	0.943	<.001
tortuosity	-0.274	<.001	-0.276	<.001	-0.271	<.001
public transport	0.470	<.001	0.475	<.001	0.478	<.001
intercept	-14.865	<.001	-14.768	<.001	-15.475	<.001
Zero-count state (Logit model)						
ln(AADT)	-	-	-	-	-	-
ln(length)	-3.101	<.001	-3.178	<.001	-3.574	<.001
intercept	13.566	<.001	13.853	<.001	15.454	<.001
Random parameters	Standard deviation		Standard deviation		Standard deviation	
Negative binomial count state						
ln(AADT)	0.06297		-		-	
ln(length)	0.07085		-		-	
intercept	0.44673		0.2405		-	
Test	χ^2	*p*-value	χ^2	*p*-value	χ^2	*p*-value
Overall model evaluation LR test	6157.06	<.001	6154.97	<.001	7627.72	<.001
AIC	38622.3		38618.4		38755.6	
BIC	38743.6		38709.4		38836.4	
Number of observations	180752		180752		180752	
Number of zero observations	176135		176135		176135	

14. Analysing Safety in Numbers in a large data-set

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Introduction

Safety in numbers (SiN) is a charming idea: if there is a lot of bicycle (or pedestrian) traffic Q_{cyc} on a road, then this road becomes safer for bicyclists. This safety is measured in terms of the number of crashes N_{cyc} in a certain time interval. Different views are possible what safer actually means, in some cases people believe that the number of crashes does really decrease with the number of VRU (vulnerable road users) [1]. Although questionable in general, in extreme cases as depicted in Figure 1, this might be actually true. For further reference, this effect will be named SiLN, Safety in Large Numbers; it is different from the "normal" SiN.

Except for SiLN, there is anecdotal evidence that in some cases, bicycle crash numbers have been even *decreasing* with larger bicycle traffic, especially when followed over longer time-scales [2]. We do not think this to be true, we will use the opportunity of a nice data-set to set this record straight (somewhat).

In traffic safety research, SiN is associated with a sub-linear growth of the number of bicycle crashes with the number of bicycles on the road [3,4]. It claims that

$$N_{\text{cyc}} \sim Q_{\text{cyc}}^{\beta}$$

where the exponent $\beta < 1$ represents this sub-linear growth. This is not the strongest argument either, since it has been observed in almost all investigations where the influence of the other crash partner has been left-out, which is even true for cars [5]. Which is left for another investigation. Here, the following two data-sets have been utilized:

- The German Accident Atlas (GAA) 2016 – 2023 [6], which samples crashes with injured and killed participants,
- Bicycle count data from the company eco-counter (ECC – eco counter cycling) over the years 2016 – 2024.

Figure 1: An example of a very large bicycle flow. From: Michael W. Parenteau (mwparenteau at English Wikipedia), Public domain, via Wikimedia Commons

Note, that both data-sets are open: the GAA data can been downloaded directly, while the ECC [7] can be obtained through EcoCounter's API [8].

Research methodology

These two data-sets have been fused, so that the bicycle counts can be correlated to the crash numbers of the bicyclists. The ECC data are monthly averages for each detector, the GAA data may have a finer time resolution, but get aggregated to monthly data as well. In addition, they have to be scaled so that they can be compared to each other.

This should be straightforward: compute the monthly average of the ECC, and the same for the crashes with bicyclists, and fit them together. Doing this naively, gives a counterintuitive result: the number of bicyclists that are counted in the ECC declines over the years, in contradiction to travel surveys. A deeper analysis found the most likely culprit: the number of eco-counters increased strongly from about 150 in 2016 to well over 800 in 2024. This presumably introduces a bias: later eco-counters are positioned at places with less bicycle traffic. After correcting for this effect by analyzing the time course of each detector individually, the ECC data were no longer at odds with travel surveys.

Results

These modified counts of the detectors, are now used to compute a monthly index of bicycling in Germany. And again, they are correlated with the share of bicycle crashes in the GAA. The results are displayed in Figure 2.

Discussion and conclusions

On this level of the aggregation of bicycle traffic flow one can rule out that the number of injured bicyclists is actually decreasing with the number of bicycles traveling on Germany's roads. Instead, the total number grows sub-linearly in the number of bicycles, so in the sense that SiN is interpreted in traffic safety research, a very robust SiN effect is indeed visible.

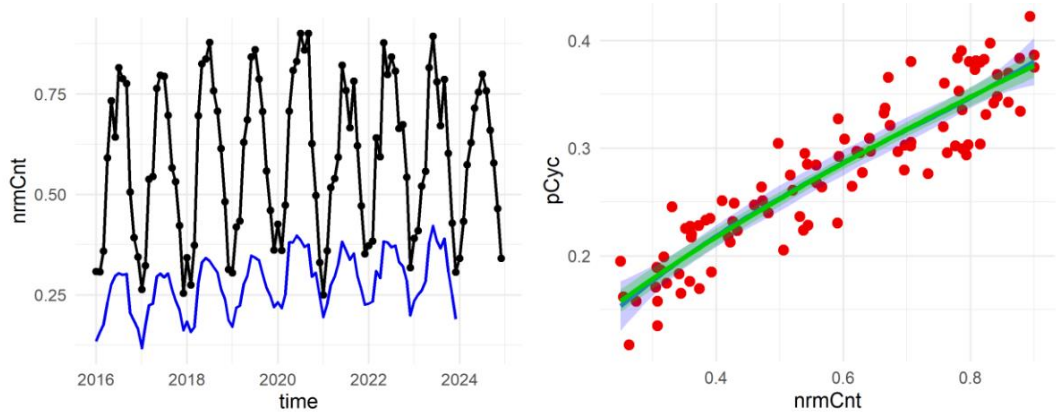

Figure 2. Left: The monthly scaled values of the share of crashes (blue) and the bicycle traffic in Germany (black). Note the strong synchronicity between the two curves. Right: Scaled number of bicycle crashes versus the scaled number of bicycles, together with a GLM-fit (green) to Eq (1) and a local smoothing spline (blue).

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15.Long-Term Analysis of Driver Behaviour in the Dilemma Zone at a Signalized Intersection

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Introduction

Intersections are widely recognized as some of the most hazardous locations within road networks due to the diverse behaviors and interactions of road users (Shirazi und Morris 2017). At intersections, injuries occur during rear-end or side-impact conflicts, particularly when vehicles engage in abrupt deceleration within the dilemma zone (Najmi et al. 2019; Papaioannou 2007). The dilemma zone was first studied in the 1960s and was defined as the area where vehicles approaching a signalized intersection, upon the onset of a yellow signal, are unable to either safely stop before the stop line or clear the intersection before the signal turns red (Gazis et al. 1960).

Our study concentrates on acceleration and deceleration patterns in the dilemma zone. This approach aligns with Papaioannou et al. (2021), allowing for a direct comparison of our findings. The contribution of our research is the usage of a large-scale trajectory dataset and inclusion of night-time driving behavior, which has been largely overlooked in previous studies except in the study from Gates und Noyce (2010). The night-time data, in particular, allow us to test the hypothesis that road users in the dilemma zone are more likely to proceed through the intersection rather than brake during night-time conditions. Furthermore, the extended data collection period increases the likelihood of identifying rare or extreme cases, contributing to a more nuanced understanding of driver behavior in the dilemma zone.

Methodology

Data for this study were recorded over multiple months at the Application Platform for Intelligent Mobility (AIM) Research Intersection (Knake-Langhorst und Gimm 2016). The dataset includes 20 Hz vehicle trajectory data, traffic light data, and weather data. A sample dataset from one day in 2023 is publicly available (Schicktanz et al. 2025).

Our study focuses on the Type II dilemma zone and follows the assumption by Hurwitz et al. (2012) that it can be characterized by the time to intersection (TTI). Therefore, we will extract the vehicles in the dilemma zone from the trajectory data and categorize these vehicles into four groups: stop, go, passed with red, and stop after the stop line. Using these classifications, we generate descriptive statistics in line with the methodology of Papaioannou et al. (2021). His results are depicted in Figure 1. We then compare and interpret our findings against their results, placing particular emphasis on extreme values. The objective is to evaluate whether utilizing a larger dataset facilitates the identification of additional extreme cases and to conduct a more in-depth analysis of the behavioral patterns within them.

Results

Since up to 40,000 road users are detected daily at the AIM Research Intersection, this long-term study is based on a large dataset collected over several months, comprising several million trajectories. Accordingly, tens of thousands of road users are expected to have been recorded within the dilemma zone. Given that the speed limits in the study by Papaioannou et al. (2021) were higher than those at the AIM Research Intersection, the recorded distances, speeds, and braking maneuvers in our dataset are expected to be lower. This study will also provide a descriptive analysis of how these lower speeds influence the following traffic when vehicles engage in braking maneuvers.

Furthermore, due to the larger volume of analyzed data, we anticipate more pronounced extreme values, leading to greater standard deviations. The recorded extreme situations will be examined in detail, also in scene videos, to provide deeper insights into safety critical driving behaviors.

Variable	Description	Behavior	Mean	Std. Deviation	Minimum	Maximum
Distance (m)	Distance from stop line at the onset of the yellow signal	Stop	97.14	21.78	39.06	128.90
		Go	48.39	23.89	6.55	104.10
		Passed with red	95.80	16.81	61.15	127.90
		Stop after stop line	86.54	18.69	61.32	125.70
Speed (m/s)	Approaching speed at the onset of the yellow signal	Stop	17.66	3.59	3.92	27.37
		Go	22.65	3.40	11.81	32.95
		Passed with red	20.59	3.07	12.81	26.34
		Stop after stop line	18.91	3.26	13.35	25.10
Acceleration/Deceleration (m/s^2)	Acceleration/Deceleration at the onset of the yellow signal	Stop	0.27	0.87	−2.52	2.72
		Go	1.13	1.13	−2.00	10.06
		Passed with red	0.94	0.70	−0.18	2.92
		Stop after stop line	0.14	1.24	−2.79	1.34

Figure 1: "Descriptive statistics of main variables based on drivers' behavior" from Papaioannou et al. (2021) Table 3.

Discussion and Conclusions

Unlike previous studies (Liu et al. 2007; Gates et al. 2007; Chauhan et al. 2022), who analysed multiple locations, our study focuses on data from a single intersection. This enables a detailed examination of behavior under consistent traffic signal conditions while allowing for a more comprehensive dataset over an extended period. By utilizing long-term recording, we aim to capture behavioral patterns that may have been previously unobserved. The extended data collection period increases the likelihood of identifying rare or extreme cases, contributing to a more nuanced understanding of driver behavior in the dilemma zone.

Additionally, our implementation of real-time processing algorithms demonstrates the feasibility of analyzing ongoing traffic conditions. This capability opens possibilities for real-time monitoring and adaptive traffic signal control, potentially improving intersection safety and efficiency.

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16.Potential assessment of future V2X solutions in car-bicycle accidents

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Background

In the context of the mobility transition and efforts to achieve various climate targets, bicycles play a special role in transportation. The number of bicycles is constantly increasing - statistically speaking, every German citizen now owns a bicycle. In terms of accidents, these numbers, coupled with continuously rising usage rates of these vehicles, are reflected in rising or stagnating accident figures. According to the Federal Statistical Office, cyclists accounted for 17.0% of the 2,788 people killed in road accidents in 2022 (previous year: 14.5%).

Aim

Cars dominate as the opponents of bicycles in accidents, with the most frequent causes of accidents in these conflicts being errors when turning off or on. Our analyses of the GIDAS accident database show that visual obstructions are a factor in these accidents, particularly in urban areas. Our study examines the potential of future V2X systems that enable two-way communication between road users even before visual visibility is achieved. With the help of the MARA "Multiple Accident Recalculation App" program developed by VUFO, calculation options can be examined and selected combinations evaluated.

Method or methodological issues

The study is based on accident data from the GIDAS database (German In-Depth Accident Study). The first step is to characterize car-bicycle accidents using descriptive statistics in order to quantify the relevance of the problem and to understand the peculiarities of this accident constellation. A relevant car-bicycle accident scenario is then evaluated with MARA and various systems, e.g. standard AEB and advanced AEB, are compared to a possible V2X model. Reconstructed, real-life scenarios in PCM format (pre-crash matrix) are used as the basis for this. On the one hand, an emergency braking system (AEB) with cross-traffic detection and VRU detection is applied and its potential for accident avoidance and accident consequence reduction is quantified. On the other hand, a tool developed in cooperation with the TU Dresden for radio channel modeling in the urban environment is used to derive the communication possibility in the pre-collision phase at discrete time steps.

Results obtained or expected

A comparison of the various functions is then carried out with regard to the accident avoidance and mitigation potential. The time saved by V2X networking compared to current emergency braking systems, which require a direct line of sight (radar, lidar or camera systems), is also determined.

Conclusions

In summary, this study combines many relevant road safety topics. The data collection, through the use of GIDAS. Furthermore, MARA is presented as a method for data modelling and data enhancement for equipping virtual real traffic accidents with future safety systems (ADAS and V2X) and estimating their potential. This procedure is explained using a data analysis of a bicycle-car accident scenario as an example. This closes the circle of how the documentation of real accident scenarios can be used with the utilization of current calculation possibilities for future safety systems in order to increase traffic safety in the future.

17. Prioritizing Pedestrian Safety: A Traffic Hazard Assessment of School Routes

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Background

Traffic danger is one of the most pressing public health and safety concerns in urban environments, causing over a million deaths globally each year and severely limiting people's right to move safely through their communities. For school-aged children, traffic danger presents a significant barrier to safe and independent mobility. While walking to school supports daily physical activity and overall well-being, its adoption is often hindered by concerns over traffic hazards—especially in low-income neighborhoods, where children are more likely to walk to school and face greater exposure to unsafe street conditions. Traditional collision-based analyses often fail to capture broader traffic hazard risks, particularly where crash data is lacking. To address this gap, our team at Polytechnique Montréal developed a comprehensive Traffic Hazard Tool using a Multi-Criteria Decision Aiding (MCDA) approach. In this study, we apply the tool in a new context—assessing traffic danger around schools in Montreal by integrating it with socio-demographic, spatial, and exposure data to identify areas most in need of intervention.

Objective

This study has two main objectives. First, we apply the Traffic Hazard Tool to assess traffic danger in school environments and identify streets and intersections that pose the highest risks to children. Second, we integrate socio-demographic and exposure data to evaluate how traffic danger disproportionately affects schools in lower socio-economic neighborhoods. The goal is to provide a data-driven, equity-focused framework for prioritizing safety interventions.

Methodology

This study builds on the previously developed Traffic Hazard Tool, created using the MACBETH Multi-Criteria Decision Aiding (MCDA) method. Input from children, parents, and experts guided the selection of criteria. Then, a panel of experts worked together on the definition of performance levels and the weighting of each criterion for intersection evaluation. Using this framework, each intersection in Montreal was assessed and assigned a traffic hazard score.

In the school context, we analyzed primary schools in Montreal boroughs where the data was complete. Schools were classified based on socio-demographic vulnerability, using a combination of deprivation indices, enrolment size, and the number of dangerous intersections within a 250-meter buffer. The enrolment size relates to the number of children exposed to the hazards and the density of dangerous intersections relate to the exposure frequency. The deprivation indices help account for issues of equity. This allowed for a vulnerability ranking across schools.

To help prioritize intersections, we estimated the number of children that might walk along different routes. We used postal codes within walking distance (~750 meters) as origin points. Housing unit counts were used as a proxy for the number of children. By combining these exposure estimates with traffic hazard scores, we identified not only dangerous locations but also the likelihood of child pedestrian presence—providing a clearer picture of overall risk.

Results

Our analysis revealed significant disparities in traffic danger across school zones. Schools in lower socio-economic neighbourhoods were more often surrounded by high-hazard street segments and dangerous intersections. previous studies found that children in lower income areas are more likely to walk, which increased children's exposure to traffic risks.

By combining hazard scores with child exposure estimates, we identified specific streets and intersections that are both hazardous and have a high potential number of children using them. We propose that such locations should be prioritized for safety improvements. The analysis also exposed the lack of basic infrastructure—such as speed bumps, curb extensions, and pedestrian crossings—in many high-risk zones. Without these measures, traffic danger remains a daily reality for many children walking to school.

Conclusion

This study highlights the urgent need to address traffic danger in school environments through an equity-focused approach. By applying a validated Traffic Hazard Tool and integrating spatial and demographic data, we offer a robust method for identifying where safety interventions will be most impactful. The findings show that children in low-income areas face disproportionate risks due to both more hazardous conditions and higher walking rates. The framework presented here supports more strategic, data-driven decision-making for planners and policymakers. Investments in traffic calming, safe school routes, and pedestrian infrastructure should be directed toward the most vulnerable zones identified in this study. Reducing traffic danger for children—especially those in underserved neighbourhoods—is essential to building healthier, safer, and more inclusive cities.

18.Distance-Related Behaviour on German Motorways

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Introduction

There was a total of 19,980 accidents involving personal injury on Germany's motorways in 2019. If the period 2009 to 2019 is considered, it can be seen that the driving error "insufficient safety distance" (accident cause 14) has continuously increased as a proportion of total driving errors, rising from 20 to 30 percent, and has thus replaced "inappropriate speed" as the main cause of accidents. Due to this increase in the number of accidents due to insufficient safety distance, the present research project was launched.

The purpose of the research project was to analyse and provide a scientific description of distance-related behaviour on German motorways and to use this as a basis for deriving recommendations for improving road traffic safety on these motorways.

Method

In the first step, a macroscopic traffic accident analysis of accidents with accident cause 14 as well as an analysis of the accident description of a sample of 300 accidents were carried out. In the second step, accident black spots were identified, which are characterized by an accumulation of accidents with insufficient safety distance. These accident black spots were the basis for the selection of 25 measuring points (20 on the open road and 5 at junctions) at which the driving behaviour (speed, distance, lane changes) was observed and evaluated with drones. The 20 measuring points on the open road consist of 10 accident black spots and 10 associated control points where no accident black spot has been detected in order to check whether the driving behaviour at the accident black spots differs.

Results

The analysis of accident causes shows that the most frequently cited accident cause for accidents involving personal injury is insufficient safety distance (accident cause 14). Cars are often cited as the cause of accidents, but as the severity of accidents increases, the proportion of trucks as the cause of accidents increases. Rear-end collisions often occur during daylight hours and dry roads. The analysis of the time of the accidents shows that accidents involving insufficient safety distance occurred primarily during periods with high traffic volumes. The evaluation of accident descriptions also shows that more than 50 percent of the accidents were due to a high traffic volume or disruptions to the traffic flow at the time of the accident. Overall, the results of the accident analysis indicate a high correlation between traffic volume and accident events with the accident cause 14.

The analyses of distance-related behaviour show that the inter-vehicle distances on a motorway section are primarily determined by the distance-related behaviour of cars. The number of accidents increases at high traffic volumes; at the same time, the number of time intervals of under two seconds (critical distances) increases at higher traffic volumes. Rear-end collisions occur frequently in the left-hand lane, where the proportion of critical distances is largest. However, concrete reasons for the occurrence of accident black spots with accident cause 14 could not be derived from the analysed distance behaviour.

During lane changes the observed vehicles often maintain distances of less than 50 metres and use gaps of under 100 metres, in particular in the case of lane changes to the left. At the same time, lane changes to the left often create situations that can be classified as critical because the following vehicle is faster in at least 80 percent of these changes and therefore has to brake in order to prevent a collision.

Conclusions

Recommendations were derived from the results of the analyses which aim at improving traffic flow and timely adapting driving behaviour in the case of disruptions in the traffic flow. In addition, traffic participants can be supported by driver assistance systems and made aware of potential hazards of traffic disruptions through appropriate campaigns. In addition, further research is needed on the influence of visibility on safety distances and accidents as well as on the influence of lane changes on the traffic flow.

19. Analysis of driver reaction to a pedestrian crossing the road outside pedestrian markings

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Introduction

Pedestrian accidents remain one of the primary causes of urban traffic accidents and, due to the exposure of vulnerable individuals, often result in severe consequences. Many pedestrian-related accidents occur outside designated crosswalks (such as zebra crossings) because pedestrians choose to cross in unauthorized areas. Such actions are completely unexpected for drivers, who require time to comprehend the situation and decide on the best, semi-automatic response. This research aimed to analyse driver reactions to sudden pedestrian crossings, evaluating the pedestrian sighting times in relation to the driver's gaze position, as well as the reaction times and type of reaction (braking or steering) once the pedestrian's presence is noticed.

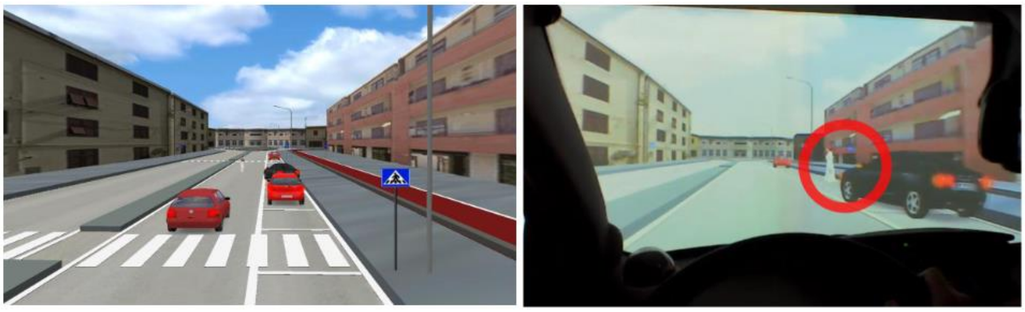
Research Methodology

The study was carried out in a controlled environment using a driving simulator with six degrees of freedom, which allows to collect all cinematic data (such as speed, pressure on brake pedal, pressure on accelerator pedal, steering angle), and an eye-tracker system, which allows to monitor where the driver's gaze was directed and determine their fixation points. Two different scenarios have been considered. The first scenario assumes that the pedestrian is crossing the street in front of a vehicle approaching at a distance such that, traveling at 50 km/h, the vehicle is perfectly able to stop. The second scenario considers a shorter distance, that is a stopping distance starting from a speed of 30 km/h. In both scenarios, the following have been analysed:

- the time it takes for the driver to realize that there is a pedestrian present and subsequently shift their gaze to the pedestrian;
- the time it takes for the driver to react once they are aware of the pedestrian;
- the type of maneuver the driver chooses to perform.

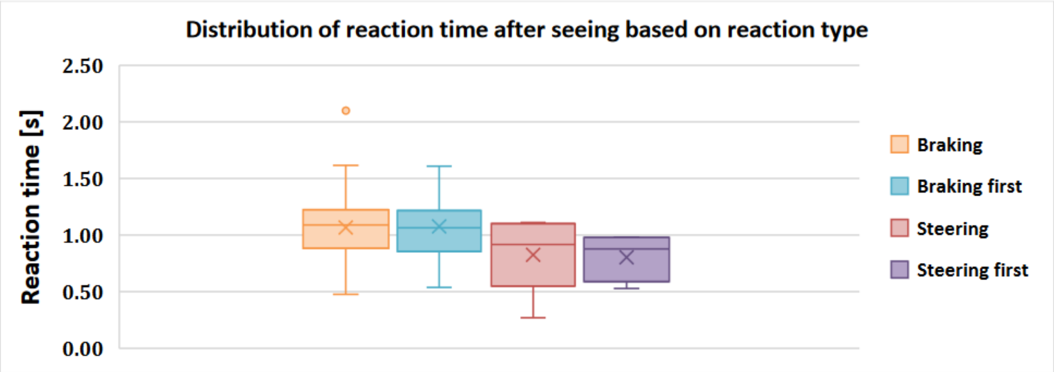
Additionally, the relationships between the following have been studied:

- The time taken to perceive the presence of the pedestrian and the distance of the pedestrian from the point looked at by the driver at the moment the pedestrian began to cross;
- The proximity to the pedestrian and the type of reaction;
- The times and type of reaction in relation to the age and experience of the driver.



Results

The results highlighted that pedestrians crossing in areas not recognized by the driver (e.g., zebra crossings) are in a very risky condition, mainly because the driver's gaze is often not directed at the crossing point, leading to a delay of a fraction of a second in perceiving the pedestrian. This delay translates into a critical distance of a few meters, which can be decisive in the possibility of accident occurrence. Additionally, the primary reaction adopted by drivers is braking, while only a few choose to steer to avoid pedestrians. The type of maneuver chosen is influenced by the distance to the pedestrian: the closer the pedestrian, the higher the likelihood of steering. Additionally, it has been found that the farther the gaze is from the pedestrian when they pop up, the higher the time required to see the pedestrian. For this reason, a high number of distractors outside the margins of the street can have a negative impact, particularly if the street is outside a 30 km/m zone.



Conclusions

The research conducted has confirmed many of the findings identified in previous studies and has brought new ones. In particular, it emerged that sudden pedestrian crossings outside of marked crosswalks are very dangerous. On roads where the operating speed is 50 km/h or more, crossings should be prevented as much as possible. On this type of road, it would also be advisable to limit roadside distractions and conduct enforcement campaigns against pedestrians who do not follow the rules. Given the perceptual limitations of humans, another system to prevent accidents related to sudden crossings is to use Advanced Driver Assistance Systems (ADAS). ADAS could provide better safety assurance by intervening before human reaction.

20.Modeling Speed Behavior on High-Risk Mountainous Roads: A Simulator Study of Professional and Non-Professional Drivers

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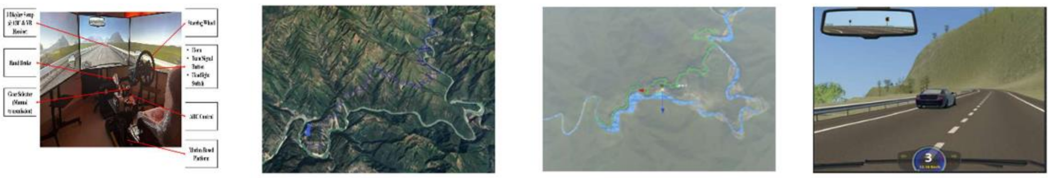
Introduction

Mountainous roads pose distinct driving challenges due to sharp curves, steep gradients, limited visibility, and rapidly changing elevations. These dynamic and often unpredictable conditions demand heightened driver attention and precise speed control, making such environments particularly high-risk. In this context, the interaction between the driver and roadway geometry becomes critical, especially during transitions between tangents and curves. Recognizing the need to better understand the interaction between human and infrastructural factors in such environments, the present study examines how driver demographics and road geometry influence speed behavior on mountainous roads, with a specific focus on the differing responses of professional and non-professional drivers.

Research Methodology

To investigate driver behavior, a motion-based, fully-configured open-cockpit driving simulator was utilized (Figure 1(a)). A 21 km stretch of the two-lane, two-way, undivided mountainous NH-7 highway (Kaudiyala to Devprayag, Uttarakhand, India) was replicated using Unity3D software (Figure 1(b-d)). Road geometric data such as curve radius, gradients, segment lengths, extra widening, etc., were obtained from the Public Works Department (PWD), Uttarakhand.



(a) **(b)** **(c)** **(d)**

Figure 1: (a) Driving simulator setup (b) Real-world view (c) Replicated terrain view (d) Perspective view of the driver

The driving scenario consisted of 280 curves (145 left, 135 right) ranging in radius from 20 m to 800 m, each preceded by tangent lengths varying from 7 m to 153 m. The roadway was designed with a speed limit of 40 km/h, a lane width of 3.5 m, a shoulder width of 1.5 m, and a longitudinal gradient ranging from -7.854 to 8.76% from start to end (-8.76 to 7.854% end to start). The study involved 23 professional drivers from Uttarakhand and 40 non-professional drivers (postgraduates and faculty from IIT Roorkee), all holding valid licenses and with at least one year of mountainous driving experience. One non-professional participant was excluded due to simulator discomfort. Each participant drove in both directions (totaling ~42 km). The experiment, conducted in daylight under dry, minimal traffic conditions, comprised three phases: (i) a pre-drive questionnaire and briefing, (ii) a 15-minute training session, and (iii) a ~21 km test drive. A post-drive evaluation was completed after the session.

Results

The present study examined the influence of driver demographics (age, experience, monthly mileage) and road geometric factors (tangent length/gradient, curve length/gradient, curvature, deflection angle, curve direction, etc.) on driving speed using a mixed-effects linear regression model. Separate 85th-percentile speed models (evaluated at the midpoint) were developed for professional and non-professional drivers, focusing on two critical alignment segments: tangent and curve. Variables were categorized to reflect typical geometric design standards of two-lane undivided mountainous roads. Age was grouped into Young (21–26 years) and Middle-aged (27–50 years). Professional drivers were classified by experience (<5, >5 years); non-professionals into 1–2, 2–5, 5–10, >10 years. Monthly mileage for professionals was >5000 km; for non-professionals, it ranged from <100 km to >5000 km. Tangent/curve lengths were classified as Short (<50 m), Medium (51–100 m), Medium-Long (101–150 m), Long (151–200 m), and Very-Long (>200 m). Gradients (tangent/curve) were grouped into Flat/Gentle (−2% to 2%) to Extreme Up/Down (>8% / <−8%). Curve direction was labelled as Left or Right, and superelevation as 7% for curves with radius >100 m, and 10% for <100 m.

For professional drivers, the tangent model showed that middle-aged drivers travelled 17.9% slower than younger ones. Very long tangents increased speed by 14.6%, while very steep uphill and downhill gradients influenced speed by +9.1% and −25.1%, respectively. Tangents leading into right-hand curves showed a 5.7% reduction in speed, reflecting cautious behavior. In the curve model, middle-aged drivers maintained lower speeds (−18.1% on left curves, −19.0% on right). Very long tangent approaches increased speed (16.3%), while short curve lengths reduced it (3.2%). Steep and medium up gradients raised speed (up to 13.7%), while steep and very steep down gradients reduced it (8.1%–17.8%). Curvature was a key factor—sharper curves led to significant speed reductions. Right-hand curves proved more difficult to negotiate, led to greater deceleration. For non-professional drivers, the tangent model showed that drivers with 5–10 years of experience and 100–300 km/month mileage drove 28.6% and 18.4% faster, respectively. Tangent lengths positively influenced speed (increases from 9.6% to 19.6%). Lower speeds were recorded on tangents leading into right-hand curves. In the curve model, experience and mileage were associated with increased speed by 26.7% and 16.1%, respectively. Short curve lengths reduced speed, while curvature exerted a significant decelerating influence. On right-hand curves, 5–10 years of experience increased speed by 26.3%, and medium-long tangents led to a 14.6% decrease in speed.

Discussion and Conclusion

The present study highlights key factors influencing speed behavior on high-risk two-lane, two-way, undivided mountainous roads. Professional drivers showed more consistent and cautious speed choices, with age and geometric features like curvature, length, and gradients significantly affecting speed. Non-professional drivers were more reactive to geometry, with moderately experienced (5-10 years) and frequently driving (100-300 km/month) individuals exhibiting higher speeds. Overall, professional drivers regulate speed through experience and situational awareness, whereas non-professionals rely on immediate roadway cues, resulting in higher variability. These findings underline the need for improved geometric design, such as smoother curve alignment, gradient transitions, and advance warnings, especially at sharp, steep, and right-hand curves. Additionally, ADAS technologies (e.g., curve alerts and up/downhill assist) may further enhance safety, particularly for less experienced drivers.

21. Effectiveness of digital media in accident prevention – a comparison between VR- and tablet-based approaches

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Despite preventive efforts, fatal accidents remain alarmingly frequent. The changing traffic landscape together with rising complexity due to distractions (such as smartphones) and increasing traffic volume, poses significant risks. A recent study by the General German Automobile Association revealed that 50% of parents fear their children's safety in traffic accidents [1]. Consequently, parents increasingly opt for the "parent taxi"-approach, limiting their children's independent participation in road traffic. Unfortunately, this hinders children's development towards a more self-reliant and secure traffic behaviour while also needlessly impacting the environment.

Current training methods inadequately address the varying age-specific developmental stages of children and adolescents [2]. Additionally, traffic education lacks appeal especially in the context of the children's everyday use of digital media. However, the use of digital media demonstrated significant success in training and enhancing the change of perspective as part of accident prevention. For this reason, Fraunhofer IVI developed an accident prevention program that incorporates digital media. In the initial development stage of the accident prevention program FAPS, tablets were used. In the subsequent development, the use of virtual reality (VR) glasses was added to the program.

Working with tablets in FAPS helps children to understand the causes of accidents by simulating them statically in virtual space using special software. The software allows children to reconstruct the positions of all parties involved in the accident and to analyse their perspective and obstacles before the collision. By adopting different angles, they can assess which perspectives each party had shortly before the accident and whether the parties involved were able to see each other in time from their respective angles. They further analyse the behaviour of involved accident parties, consider how the accident could have been avoided and thus gain a deeper understanding of the causes of the accident.

In the further development, a VR module was developed based on official accident data. Relevant situations were selected by analyzing and filtering for particularly serious and frequent pedestrian and bicycle accidents. These accidents were analyzed in detail, leading to the selection and virtual simulation of representative real accidents. This involved determining the exact sightlines and obstacles that caused the accidents as well as the reconstruction of trajectories and vehicle dynamics. As a result, children can dynamically perceive the time before the collision from different perspectives.

A survey was conducted to evaluate the two digital learning methods. One focus was on the differences in the general perception of the old perspective module (static situations on the tablet) and the new perspective module (dynamic situation based on VR). The other focus was on the ability of the VR glasses to be used by the children themselves and to understand the situations they experience. In addition, it will be evaluated whether the VR module helps to raise children's awareness of certain risks in road traffic (beyond the current prevention programme). As a basis for the evaluation, a questionnaire was given to the children immediately after the prevention programme has been implemented at their school. To evaluate the impact of the new VR module, both versions of FAPS will be implemented in Saxony and in the city of Munich. In Munich, FAPS is presented in schools with the static perspective module, while the new VR module is used in schools in Saxony. The questionnaire in Munich and Saxony consists of common questions that enable a direct comparison between the two versions. In addition, the Saxon questionnaire is supplemented by further questions especially on the VR module.

The questionnaires contained general questions for children about their perception of the learning method, for instance whether they would recommend this method to others or if they could draw conclusions for their own behaviour in relation to road safety. The questionnaire related to the VR module additionally included questions, such as whether they were able to use the VR glasses independently and whether the VR experience helped them understand the particular risks motorised road users pose to pedestrians and cyclists.

The key findings from the survey are as follows:

- Higher satisfaction with the VR module: In Saxony, 93% of the children with the VR module rated the accident prevention program as "good" or "rather good." In Munich, without the VR module, just under two-thirds did so. This indicates that the VR module significantly increased the children's satisfaction with the program.
- Greater willingness of recommendation: More than 80% of participants in Saxony would recommend FAPS to a friend, whereas in Munich, just over 53% would do so. The inclusion of the VR module appears to enhance the program's appeal among children.
- Lasting impact and increased safety awareness: Children in Saxony were more confident that this form of learning would have a lasting effect on them, with approximately three-quarters indicating they would pay more attention to road safety in the future. In Munich, only about 16% expected a lasting impact. This suggests that the VR module contributes to a more enduring awareness of road safety.
- Direct influence of the VR module on attitude change: 80% of Saxon children who reported a change in attitude towards road safety attributed it directly to the VR module. This highlights that the VR module significantly contributed to raising awareness of road traffic risks and positively influences children's attitudes toward road safety.

In summary, the integration of the VR module into the accident prevention program led to significantly higher satisfaction of children, a greater willingness to recommend the course, a lasting impact of the learning experience, and increased awareness and a more positive attitude towards road safety.

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22. Unconscious and conscious strategies of older drivers for compensating for age-related changes when driving a motor vehicle

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Motivation and theoretical background

Many EU countries and industrialized nations are confronted with a growing and ageing population structure. In addition to the economic and financial effects of demographic change, the road safety of older people is also increasingly being addressed. The reason for this is the interaction between demographic change and increasing mobility (Schlag, 2008). The demographic development and the increasing mobility of persons with an age of 65 and above are countered by findings from gerontological research, as various abilities are subject to age-related limitations with increasing age, which also have an impact on driving a motor vehicle. Driving a car makes diverse and complex demands and requires resources from the perception, attention, cognition and motor skills sections at the same time. It is often assumed that older drivers are at an increased risk of accidents due to age-related changes. In particular, there is a higher risk of accidents in complex traffic situations such as junctions. Drivers aged 75 to 84 are four to six times more likely to be involved in accidents resulting in personal injury than middle-aged drivers (Brorsson, 1989). However, older drivers are not necessarily more dangerous to others. Their higher fatality rates in accidents are mainly due to physical frailty rather than unsafe driving behavior (Mcknight, 2003).

A deficit-oriented view promotes the negative stereotype of the older driver. However, there is often a lack of data that both describes a deficit and establishes its direct link to the accident at the same time. Age-related loss of resources can be measured with the help of psychophysical performance tests (Weller et al., 2015). According to Weller et al. (2015), based on psychophysical performance tests, the driving behavior of older car drivers can only be predicted to a limited extent for both real-life traffic and the driving simulator. To compensate for age-related changes, older car drivers use various strategies (Henriksson et al., 2014; Karthaus et al., 2015; King & Scott-Parker, 2017).

Research question & method

Does the compensation of psychophysical performance losses in old age occur consciously or unconsciously at the various levels? To clarify these relationships, the following data from older car drivers was examined:

- Various parameters from driving tests with older car drivers
- Results from cognitive, sensory and motor skills performance tests
- Subjectively perceived limitations in reaction time, vision, resilience and concentration (collected via questionnaire)
- Subjective assessment of the compensatory planning behavior

To verify this data, the most important predictors were added step by step to check whether the objective psychophysical performance variables offer additional explanatory value to the subjectively perceived limitations and the reported compensatory behavior (i.e., a significant increase in the explained variance – R^2). If they do, this finding could be interpreted as unconscious compensation.

Results

The analyses revealed significant results for various aspects of driving behavior on highways. The selected variables of driving behavior on highways were:

- Number of overtaking maneuvers
- Total time in the overtaking lane
- Maximum speed on the highway on different route sections

Subjectively perceived limitations in reaction, vision, resilience and concentration rarely or never show a significant increase in the explained variance in the variables number of overtaking maneuvers and total time in the overtaking lane. Compensatory planning behaviour partially leads to an increase in the explained variance in all selected variables of driving behavior on highways. The addition of objective performance variables from the psychophysical tests (Stroop test, RT test) increases the variance, in part significantly, for the named variables (from 2 % to 43 %).

Subjectively perceived limitations in reaction vision, resilience and concentration show, in part, a significant increase in the explained variance in the variable maximum speed on the highway on different route sections. The addition of the compensatory planning behavior predictor leads in part to an increase in the explained variance in the maximum speed on the highway. The explained variance again increases significantly after adding objective psychophysical performance measures (variables of the IfADO GoNoGo test).

Conclusion

Subjectively perceived limitations in reaction, vision, resilience and concentration have the least to no influence on the selected variables of driving behavior. Subjectively reported compensatory planning behavior and objective psychophysical performance measures are suitable predictors for predicting certain variables of driving behavior. A general statement about conscious and unconscious compensation of performance losses when driving on the highway cannot be made based on the present results.

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23.Challenges and Lessons Learned in Tram-VRU Conflict Study

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Introduction

Traffic conflicts are situations in which two or more road users risk colliding if their movements remain unchanged. Analyzing traffic conflicts can assist in identifying and addressing safety issues before accidents occur, inform efforts to improve safety, and evaluate the efficacy of traffic safety measures. Despite their importance, traffic conflict studies have been less commonly used to investigate safety issues between trams and vulnerable road users (VRU). Our work analyses such conflicts in a real urban setting and shares lessons learned for future conflict studies between trams and VRUs.

The study area is in Helsinki, Finland, in the neighbourhood of Viikki, where a light rail began operating in 2023. We focused on one intersection where pedestrians and cyclists cross the light rail route (see Figure 1). We chose this location since the road design configuration creates a blind spot between light rail drivers and VRUs, potentially increasing the risk of collisions. Additionally, unlike all other unsignalized VRU crossings in Finland, light rail crossings give trams the right of way, which can also be a safety issue if VRUs are unaware. This study aims to analyse conflicts before and after installing a real-time light and audio system warning VRUs of oncoming trams in the study area. This poster focuses on challenges for video-based conflict studies between trams and VRUs identified before the warning system's installation.

Figure 1 Pictures depicting the study area (3-D and aerial views) where pedestrians, cyclists and urban rail share the route in Viikki, Helsinki. The blue line indicates the light rail route, while the yellow marks the crossing trajectory of VRUs. The left picture is a video recorded within the study, and the background picture on the right is from Google Maps.

Research Methodology

The intersection was filmed from August to September 2024, providing about 90 hours of footage from morning and evening peak traffic periods for analysis. A camera was installed on the roof of a nearby building at a height of approximately 20 meters from the road surface, which was the highest available spot with visibility toward the intersection.

To avoid the potentially error-prone process of manually detecting conflicts from the lengthy video material, we used the open-source Road User Behaviour Analysis (RUBA) software to detect tram crossings and potential conflicts. With RUBA, we detected trams crossing the entry and exit areas of the intersection so that the uninterrupted movement of a tram was captured from its entry into the intersection to its exit. Each event was stored as a series of images capturing the detailed movement of the light-rail across the intersection.

Results

The described research design helped us identify possible challenges for video-based tram-VRU conflict studies. The foremost challenge is finding a suitable camera location to record the precise movements. In this case, finding an unobstructed view where approaching VRUs would be fully visible on both sides of the intersection was more difficult than in e.g., a car-VRU conflict study due to the light rail's large size, since nearby filming locations such as rooftops were too low to fully avoid occlusion. We decided to compromise on visibility for VRUs approaching from the right, as they were occluded by the tram. Instead, we concentrated on capturing the direction featuring the potential blind spot issue.

Another challenge was the low reliability of identifying VRUs using RUBA. Due to the camera's placement at the highest possible location, VRUs appeared relatively small and were challenging to distinguish. However, because of their larger size, detecting tram crossings was more reliable. Therefore, we decided to capture each potential tram-VRU interaction by detecting and observing every tram crossing, instead of, e.g., simultaneous appearances of trams and VRUs.

In the next stage of the study, we will estimate time-to-collision in observed conflicts with t-analyst. After installing the real-time light and an audio warning system at the intersection, video analysis will be conducted again to evaluate the system's efficacy.

Discussion and conclusions

Based on our observations, improved opportunities to capture footage from a bird's-eye view, e.g., with drone technology, could improve conflict studies where observed vehicles are larger like trams. This would address both the occlusion issue and unreliable detection of VRUs if footage can be captured from a shorter distance directly above. In the cases where occlusion is unavoidable during tram-VRU conflict studies, researchers should be careful about how they choose to prioritise visibility to ensure all relevant issues are considered. While installing multiple cameras can also prevent the occlusion issue, this would pose a challenge regarding available resources, making it less feasible to perform a conflict study.

International Cooperation on Theories and Concepts in Traffic Safety

24. TIAS: A fine-grained traffic area dataset for AI-based segmentation to support large-scale road safety analysis

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Existing spatial datasets do not adequately represent Germany's traffic infrastructure: the available data is fragmented, varies in quality, and often lacks clear documentation on acquisition methods and spatial coverage. This limits its usefulness for traffic safety analyses, urban planning and related applications. Even in larger cities, where data availability is comparatively better, the interaction of different traffic participants within shared traffic spaces cannot be fully reconstructed. One example of the lack of nationwide data is the absence of a publicly available comprehensive and up-to-date dataset on bikeways. The challenge, especially in regard to road safety, is to map traffic areas used by vulnerable road users, as well as areas with interactions between different transport modes. Also, upcoming technologies such as autonomous driving rely on the representation of the traffic network through detailed high accuracy data.

To reduce the gap between currently available datasets on traffic areas and the demand for comprehensive, large-scale, high-resolution information, we introduce the TIAS dataset (Traffic Areas and Surroundings), which provides a detailed representation of urban traffic areas for training AI-based segmentation algorithms. TIAS includes fine-grained annotations from a transportation system perspective, supporting applications in traffic safety research. Alongside the dataset, a novel AI-based segmentation algorithm trained and validated on TIAS was developed, enabling the mapping of traffic areas for entire regions.

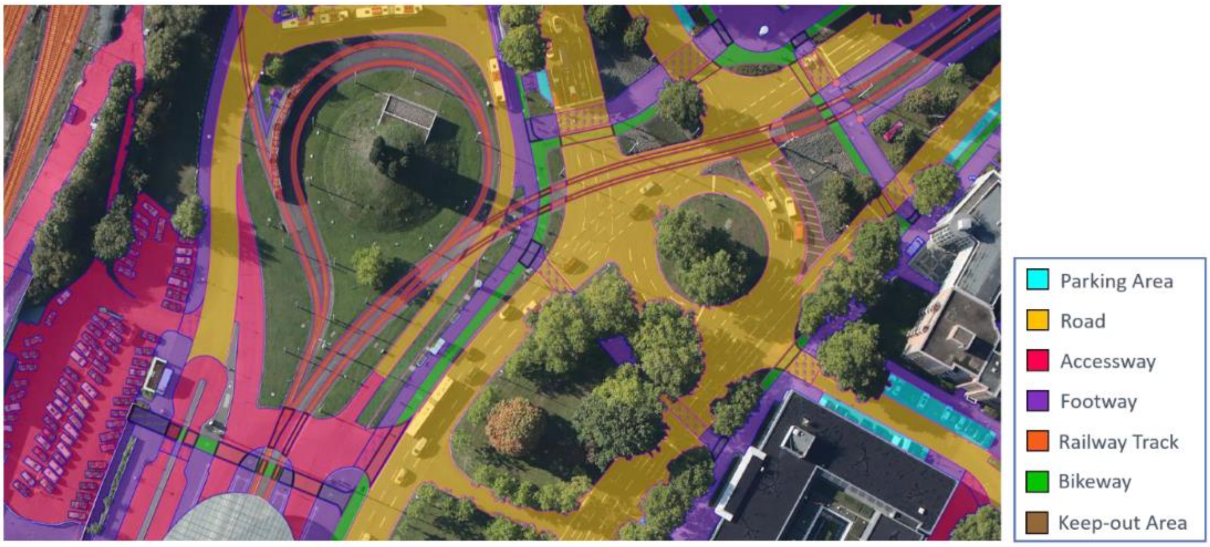

Figure 1: An urban scenario from the TIAS dataset showing a high density of different classes in a small area

The current version of the TIAS dataset consists of 51 manually annotated aerial images depicting urban traffic scenarios across Germany, covering areas in Berlin, Hamburg, Braunschweig, Landsberg, Kaufbeuren, and Munich. Of these, 45 images were acquired using DLR's 3K and 4K camera systems, while six are DOP10 aerial images taken on behalf of public authorities. The images have been selected to cover a wide range of situations, weather conditions, times of day, seasons, and viewing angles. Traffic areas are classified into nine classes: road, access way, bikeway, footway, keep-out area, parking area, railroad bed, road shoulder, and water. A key focus is on preserving the topological nature of the transportation network. To achieve this, TIAS implements a shared attribute, where overlapping areas between different transport modes are explicitly annotated. For example, at a crossing where a footway crosses the road, this shared area is annotated as road shared with footway. These shared areas indicate the use by multiple modes of transportation and therefore possible interactions between those. Additional attributes indicate whether a traffic area is under construction, located on a traffic island, or elevated above another area.

The TIAS dataset is used to train and validate a neural network-based segmentation algorithm capable of efficiently identifying and classifying traffic areas from aerial imagery. This approach allows for high levels of automation and enables large-scale segmentation, covering entire cities or even whole countries. A first case study, conducted for the city of Berlin, demonstrated the method's potential for the segmentation of roads bikeways and footways.

For traffic safety the segmentation results could open the door for further applications, particularly in large-scale road safety analysis and the identification of hazardous areas within the traffic network. By extracting centerlines from segmented traffic areas along with their shared attributes, a first step towards a routable network could be made. Given network highlights edges where different traffic participants, especially cyclists and pedestrians, interact with other road users and potentially dangerous interactions may occur. Additionally, the traffic island attribute indicates locations that may serve as refuges for pedestrians and cyclists when crossing roads, adding further value for safety assessments.

In conclusion, TIAS is a novel training dataset for AI-based algorithms that bridges the gap between existing incomplete traffic data and the demand for high-resolution, large-scale datasets on urban traffic areas. By integrating segmentation results, it opens the door to new possibilities for traffic safety analysis and the identification of hazardous areas within the transportation network for large areas.

25.Constrained motorway layout: does it lead to negative safety implications?

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Introduction

In Israel and other countries, road design guidelines define standard road layouts, with travel lane and shoulder widths, where motorways have the highest design standards. Due to steadily increasing congestion on the main road network, transport authorities apply strategies for increasing the capacity of existing roads, by means of part-time shoulder use, high-occupancy vehicle lanes or adding travel lanes within existing roadways, which implies a constrained road layout that may lead to negative safety implications. Previous research on the topic is scarce while evaluation examples from US states reported mixed safety impacts. Furthermore, when road infrastructure characteristics are used for predicting accidents on motorways, international research typically indicates lower accident frequencies for wider shoulders and lanes thus supporting the need for standard layouts.

In Israel, a redesign of motorway sections was recently introduced to increase capacity on Highway#1 which connects two major cities. It provided three travel lanes instead of two, in both travel directions, within the existing roadway, by means of narrowing shoulders' and lanes' widths; the speed limit was restricted to 90 kph. The redesign was intended to reduce transit times within the sections, especially during rush hours. Due to the constrained layout, safety concerns were raised and a follow-up evaluation was initiated.

Aim: This study aimed to examine the safety performance of motorway sections with the reduced design standards relatively to before the change period and other roads, to provide a basis for future use of similar measures.

Methodology

The follow-up evaluations included before-after analyses of road accidents and travel speeds, on the redesigned sections while accounting for changes in traffic volumes. For that, data were extracted from the national accident and traffic count files, for a three-year before and a six-year after period, enabling to consider initial and long-term effects. Changes in accident rates and types, between the periods, were examined using statistical tests. Data on transit speeds were collected for the pre-defined subsections, near and between the interchanges, using Google measurements. Over-time changes in average travel speeds and their correspondence with the speed limit were analyzed. In addition, from the entire road network, 34 motorway sections with standard and constrained layouts were selected, for which accident rates were estimated and compared for the same period. The latter should assist in generalizing the safety effects observed on Highway#1.

Results

On the redesigned sections of Highway#1, daily traffic volumes increased by 21% and by 31%, in the first and next three-year period, respectively, as opposed to previous years. In the initial after period, travel speeds improved substantially and became stable over day-hours, with an increase in rush hours in the range of 10-30 kph vs. the before period. After six years of operation, in one travel direction, in most subsections speeds decreased and became unstable in rush hours, while in the other direction they remained stable. Average transit speeds in day hours were in the range of 85-108 kph, mostly over the speed limit. In both after periods, a significant decrease was observed in accident numbers and rates relative to the before period, without changes in accident types. These findings were surprising in light of the expectation of deterioration in road safety performance following a reduced standard redesign.

The analysis of additional road sections revealed that on motorway sections with the constrained vs. standard layouts, generally, higher accident rates per road kilometer were found, both in total injury and severe accidents, while for sections with very high daily traffic volumes, over 150,000 vehicles, also higher rates per exposure were observed.

Conclusions

The case of Highway#1 showed that constrained standard redesign of motorway sections may not necessarily lead to negative safety impacts. Reasons for that may be related to the restricted speed limits and stricter surveillance applied on the road (to treat the events when vehicles stop on the shoulders). In general, motorway sections with constrained layouts were associated with lower safety levels compared to sections with a standard layout, but findings were not uniform, indicating sensitivity to road conditions and traffic volumes. The findings for Highway#1 cannot yet be generalized to changing road design guidelines.

26.Constructionist learning principles in driving lessons

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Background: Constructionism and learning

Driver training, as described in the GDE matrix, is based on a constructionist view of learning, which implies that communication and reflection are important for learning. However, research on which communication styles best facilitate this learning during driving lessons and hence improve safety is lacking.

Training can be defined as systematic activities to improve the knowledge, skills, and attitudes of the trainee. The purpose is to let the trainee practice the physical and mental skills needed. Constructionists understand learning as a cognitive process that builds on the trainee's experience. Learning is not a one-way street from the instructor to the student. Rather, both of them are active participants in the learning process, and the social and communicative interaction between them is important.

Driving lessons are situated learning in a context that differs a lot from other learning contexts: The instructor and the student sit together in a limited room (the car), and the social interaction is between the two, but at the same time they are interacting with other road users. The training also has two very specific goals. One of them is to pass the test to get a driver's license. The other is to develop higher-order driving skills. To achieve the latter, communication between the instructor and the student is essential.

The field of communication includes a wide range of ideas, and communication has been described as something impossible to avoid; it is impossible not to communicate. During a driving lesson, this includes communication between the instructor and the student; verbal, and non-verbal, hand signals, cues, and silence, and at the same time it involves communication with other road users.

Aim

The research question for this study is: How can constructionist learning ideals shape the way instructors communicate with their students during driving lessons?

Method

The data material consists of seven in-depth interviews with driving instructors in Norway. We followed a semi-structured interview guide with questions about what they say to the students before, under, and after driving, non-verbal communication, and how they feel the students respond to this communication.

Results

Preliminary analysis shows that the driving instructors usually start the lesson with a chat about what they did the previous lesson, and the student's thoughts on this, before they explain the plan for today's lesson. They also discuss what the students have been doing in between lessons, as most of them will test drive with their parents or other adults.

The first lesson typically starts with a longer chat where the instructor tries to get to know the student, and how he or she thinks they want the driving lessons to be. Some students prefer the instructor to be mostly quiet while they are driving because it lets them focus on driving and reading the traffic. The instructors said that they reached an informal agreement with each student on working methods and how they should cooperate, and that the working methods are often adjusted as they have several lessons with the same student and learn to know them better.

The instructors said that students often struggle with receiving positive feedback and would often just shrug it off without reflecting on what they did right. On negative feedback, the instructors said they would often try to get the students to say it themselves to see if they understand what they did wrong and if they are able to reflect on their own actions. The lesson concludes with a short conversation.

Conclusions

According to constructionist learning theory, the conversation at the end of the lesson should be longer to give time for the students to reflect on their own learning, which is necessary to achieve higher-order driving skills. Both pre-driving and post-driving communication are important to achieve higher learning. Getting to know the student is useful for being able to adapt the learning process to every individual, and for inviting the student to be an active participant, and not just a passive receiver of information.

27. The moderating influence of pedestrians' traffic beliefs and superstitions on their risk perception and safe walking practices

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Background

Pedestrian safety is a vital component of sustainable and inclusive mobility systems. As cities continue to grow and transportation networks expand, ensuring pedestrian safety has become a pressing challenge. According to global traffic safety reports, pedestrians represent a significant portion of road traffic fatalities and injuries, particularly in urban areas where vehicle-to-pedestrian interactions are common. The consequences of unsafe pedestrian environments go beyond individual harm, impacting public health, economic productivity, and urban liveability.

Beyond infrastructure and policy, pedestrian safety is also influenced by human factors, including individual traffic beliefs and cultural superstitions. Perceptions of road safety, risk-taking behaviours, and local customs shape how pedestrians navigate urban environments. Understanding these psychological and cultural dimensions is crucial for designing effective safety campaigns and behavioural interventions that resonate with public attitudes toward road safety.

Aim

This study investigates how pedestrians' traffic beliefs and superstitions influence their risk perception and safe walking practices. It, therefore, emphasises how cultural perspectives can enhance or hinder safe mobility practices.

Method

The study was conducted in Accra and Kumasi, Ghana's two most urbanised cities and leading hotspots for pedestrian crashes with high annual rates. Using an intercept sampling approach, the study surveyed 1,060 respondents in both cities' high-risk fatal crash corridors. The research instrument examined, among other factors, respondents' risk perception and acceptance, traffic beliefs and superstitions, safe walking practices, traffic crash experiences, and perceived causes of traffic crashes in their cities. The study employed a statistical moderation framework to analyse the influence of pedestrians' traffic beliefs and superstitions on their risk perception and safe walking practices. The model specification utilised the Hayes PROCESS v4.2 Model 1 in SPSS version 29.

Results

The study found that risk perception positively influences safe walking practices. Additionally, traffic beliefs and superstitions also positively affect safe walking practices. However, the interaction between risk perception and traffic beliefs and superstitions was negative and statistically significant, indicating that these beliefs and superstitions negatively moderated the effect of pedestrians' risk perception on safe walking practices.

Conclusions

This study highlights the complex relationship among risk perception, traffic beliefs and superstitions, and safe walking practices. The findings indicate that while risk perception positively influences pedestrian safety behaviour, traffic beliefs and superstitions contribute positively. However, their interaction presents a paradox. Specifically, the negative moderation effect suggests that stronger traffic beliefs and superstitions may diminish the impact of risk perception on safe walking practices. This implies that although such beliefs might encourage cautious behaviour, they could also lead to misconceptions, weakening pedestrians' ability to assess risks and respond appropriately. These insights underscore the need for targeted educational interventions and awareness campaigns that effectively address rational risk assessment and cultural beliefs to enhance pedestrian safety. Integrating behavioural research into mobility planning can help policymakers develop interventions that resonate with public perceptions and promote responsible pedestrian behaviour.

28.Bridging the Yielding Gap: Examining Drivers, Cyclists, and E-Scooter Riders at Pedestrian Crossings

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Background

Pedestrian safety at crossings remains a critical concern in traffic environments worldwide, particularly as multimodal travel expands with the increased use of bicycles, e-scooters, and other micromobility options. Despite measures that encourage drivers to reduce speed or come to a complete stop at crosswalks, comparatively little is known about how non-traditional road users interpret and execute yielding maneuvers. This shortfall in understanding is especially evident at unsignalized intersections and mid-block crossings, where inconsistent road user behavior can lead to unpredictable interactions and heightened risk. As road safety research places growing emphasis on vulnerable road users (VRUs) and the need for robust data on user interactions, an investigation into how different groups conceptualize and practice yielding is both timely and necessary.

A preliminary investigation using publicly available top-view drone footage (the inD dataset) in Aachen, Germany, highlights the complexity of cyclists' decision-making at pedestrian crossings. The footage was collected at the intersection of Bismarck Str. and Schloss Str., focusing on 107 interactions between cyclists and pedestrians at a zebra crossing. To ensure clear observations, only "leading cyclists", those not influenced by additional vehicles or cyclists, were considered. Analysis of this subset revealed that 41% of cyclists did not yield to pedestrians, while 63% reduced speed and 21% opted to swerve around pedestrians. These findings suggest that cyclists adapt their behavior, possibly in an effort to save time or manage perceived risk. This early evidence underscores the need for a broader examination of how various road users define and enact yielding in differing infrastructural and demographic contexts.

Aim

The overarching goal of this research is to assess how drivers, cyclists, and e-scooter riders conceptualize and perform yielding at pedestrian crossings. By encompassing a range of ages, genders, and cultural backgrounds, this study seeks to identify the key factors that shape compliance and uncover common misconceptions or misunderstandings. This approach includes multiple types of crossing infrastructure, such as marked versus unmarked crosswalks and the presence or absence of bike lanes, to provide a holistic perspective on yielding behaviors.

Method

A comprehensive survey will serve as the primary data collection method, designed to capture and compare yielding behaviors across diverse user groups. Scenario-based questions will be introduced through brief written or visual vignettes that vary in pedestrian volume, traffic controls, and crossing type. Participants will report on their likely actions, perceived barriers, and potential hesitations around yielding, offering insight into how demographic, cultural, and situational variables might interact to influence behaviors. Both quantitative and qualitative analysis techniques are planned. Descriptive statistics will highlight patterns and trends in self-reported behaviors, while open-ended responses will be systematically coded to expose deeper motivations and decision-making processes. This dual approach allows for a rich exploration of the attitudes and perceptions that underlie yielding decisions.

Results Expected

While results from the planned survey are not yet available, preliminary data indicate that cyclists sometimes prioritize personal goals, such as minimizing travel time, over yielding to pedestrians, even at clearly marked crosswalks. Extrapolating from these initial insights, the upcoming study is expected to show variability among user groups in terms of compliance and interpretation of yielding. The survey findings are anticipated to highlight the influence of infrastructure design, demographic factors, and cultural background, on yielding tendencies.

Conclusions

By contrasting different road users' interpretations of yielding and exploring how these perceptions translate into real crossing scenarios, this research aims to provide a more nuanced understanding of roadway interactions at pedestrian crosswalks. The results have the potential to inform targeted interventions, including educational initiatives and infrastructure improvements that better align with the behaviors and needs of all road users. Ultimately, the study seeks to reduce ambiguity around yielding practices, enhance compliance across a range of transportation modes, and support ongoing efforts to lower crash incidences and severity for vulnerable road users.

29. Safety issues with tram-trains in an urban environment: a before-after gaze behavior study

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Introduction

Szeged, a city in southeastern Hungary, has a long history of rail-based transportation, both in terms of mainline and light rail. As an overlap of these two modes of transportation, Hungary's first tram-train service was launched on November 29, 2021, connecting Szeged's main station with a regional center approximately 25 km away. In 2022, the number of accidents involving tram-trains was comparable to those involving trams on the same route. However, if we consider the number of trips, tram-trains have a proportionally worse accident record. Various theories have been proposed to explain this, but none has been professionally substantiated.

Tram-trains are an unusual mode of transportation in an urban environment due to their different form of design compared to regular trams. Our hypothesis was that the color and design of tramtrains affect their visibility and perception. The objective of our research was therefore to investigate the underlying causes of tram-train accidents using a before-after study.

Research Methodology

The research is divided into a before and after phase. In the before phase, we conducted a questionnaire survey and an eye-camera study. This will be followed by an after study to analyze the impact of the implemented recommendations.

The before phase of research began in the first quarter of 2023 with an analysis of accident statistics of 2022. The analysis revealed that human factors have the most significant impact on accidents. A questionnaire survey was conducted to assess residents' perceptions of the new mode of public transport. The questionnaire survey focused on the safety and visibility of the trams and was addressed to people actively involved in road traffic in Szeged. A total of 453 participants completed the survey.

In addition, an eye-tracking study was conducted using the Pupil Labs Pupil Core Eye Tracker. This study investigated how often test participants, who were car drivers, looked at the different parts of the tram-train in the rear-view mirror when making a left turn. An eye tracking study was conducted with 12 participants (6 males, 6 females) using the Pupil Labs Pupil Core Eye Tracker. The device recorded videos showing which parts of the tram-trains the participants looked at before turning left. These tests were conducted on the same road section in both directions, with regular trams and tram-trains.

Results

Our research clearly showed that participants were more likely to notice trams than tram-trains. The most significant difference was in the number of glances directed at the lower front elements of the tram-trains. The results of the questionnaire survey showed that road users ranked the color of tram-trains as the second cause of accidents after inattentiveness of car drivers. Therefore, it was recommended to the tram-train operator to test the application of yellow foil on the lower front elements of tram-trains, which was done in the first quarter of 2025 (Figure 1).

In the after phase, we intend to analyze the impact of the foil by the end of the third quarter of 2025 using the same 12 participants, routes, equipment, and evaluation methods to ensure the most accurate comparison.

Discussion and conclusions

The eye-tracking study in the after phase is expected to determine whether the yellow foil improved the visibility of tram-trains. In addition, the tram-train operator will evaluate the impact of the yellow foil over a one-year test period. If it proves effective in reducing accidents and repair costs, it will be permanently incorporated as a design element.

The research findings may be considered by operators, decision-makers, and urban planners when planning future tram-train developments.

Figure 1. Tram-train design before (right) and after (left) (photo credit: Ministry of Construction and Transport)

30.The effect of navigation modalities on driver performance

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Background

In 2023, Swedish emergency services responded to nearly 17,000 road accidents, with 200 fatalities. Young adults, particularly males aged 18–24, are disproportionately involved. Research highlights the role of Education, Enforcement, and Engineering in improving traffic safety. Simulator-based driving education in Sweden has been proposed to enhance training and assessment reliability, but these simulators rely on visual aids, which may not adequately prepare learners for real-world tests that use only auditory instructions.

Aim

This study aimed to examine how the modality of driving instructions (auditory vs. visual) affects driving performance and cognitive load. The research questions were as follows:

- How does the modality of driving instructions impact simulator driving performance?
- How is experienced cognitive load affected by navigational modality?

Method

Data was collected using a between-group design, with participants divided into two groups, each conducting the experiment on separate occasions. One group received visual navigation instructions, while the other received auditory instructions. Driving performance was measured based on speeding, failure to indicate turns, accidents, reckless driving, failure to adhere to stop signs, and failure to follow navigation instructions. Acceleration (both laterally and in the direction of travel) and distance to obstacles were combined into the variable 'careless driving.' These metrics were automatically recorded by the simulation software. Cognitive load was assessed using a post-drive NASA-TLX survey. Data analysis focused on comparing driving performance and cognitive load across the two modalities.

Participants

The study was conducted at a Swedish automotive-focused high school using nine simulators and involved 50 participants, all with prior simulator experience. Participants in both had a mean age of 17 and gender distribution was approximately 60% male and 40% female.

Equipment

High-fidelity driving simulators, equipped with software from Skillster (skillster.se), were used to collect the data. Each simulator featured a force-feedback steering wheel, a pedal set, and multiple screens for an immersive driving experience (figure 1). The simulation software created a realistic urban environment. Auditory navigation instructions were delivered via headphones, while the visual navigation system is shown in Figure 2.

Procedure

Participants were divided into smaller groups of nine, with three trials per group. Upon arrival, they were informed about the study and asked to sign a consent form, acknowledging that they were participating in a driving exam and the modality they would receive. They then completed a brief demographic survey. After the drive, participants completed a second survey to assess cognitive load.

Results

Driving performance significantly differed based on the modality received, t(43) = -2.31, p = .026. Participants who received auditory instructions performed significantly better than those who received visual instructions, see figure 3. However, there was no significant difference in perceived cognitive load between the two modalities. When comparing each NASA-TLX category independently (Mental load, physical strain, stress level, performance and frustration) no significant difference was indicated.

Discussion

In line with dual-process theory, visual tasks such as driving can be negatively affected by the presence of additional visual information. Consequently, auditory navigation may allow drivers to allocate more cognitive resources to the driving task, potentially leading to improved performance. The absence of significant differences in perceived cognitive load indicates that participants may not fully recognize the cognitive demands associated with each modality. This discrepancy underscores the complexity of cognitive resource allocation and highlights the need for further research into how these processes interact in real-world driving contexts. Additionally, this issue is further emphasized by the lack of significant differences in self-evaluated performance (as measured by one category of the NASA-TLX) between the groups, suggesting a tendency for inaccurate self-assessment, a phenomenon commonly observed in young adults.

Figure 1: Simulator setup at the automotive school.

Figure 2: The visual navigation system.

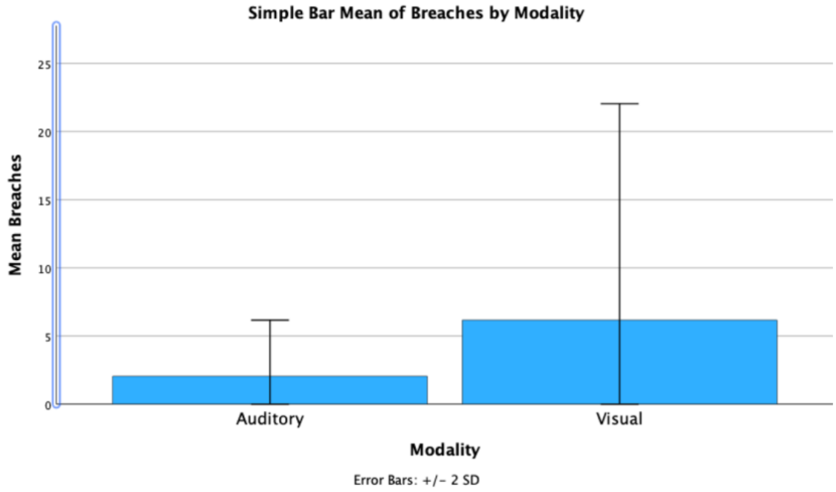

Figure 3: Standard deviation and means by modality.

Conclusion

This research is a step forward into creating realistic screening test for the Swedish driver education program. Based on the results; such screening tests should be implemented with auditory navigational instructions, as it is significantly better for driver performance while also being the modality used in the real-world driving exam.

31. Promoting safe and efficient pedestrian crossing behaviour using vehicle kinematics: an explainable machine learning approach

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Background

With vehicle automation technology evolving rapidly, highly automated vehicles (HAVs) without humans in control are expected to operate in complex environments together with human road users. The HAVs will present communication challenges on the road because (1) they cannot communicate with verbal cues, gestures, and eye contact like drivers do; (2) if not designed carefully, they may adopt kinematics patterns unfamiliar to other road users, which has the potential of causing crashes. These challenges are particularly serious for vulnerable road users, such as pedestrians.

A promising solution for both of these challenges is to have AVs learn from human kinematic patterns to effectively communicate their intentions to pedestrians. For example, in real driving conditions, human drivers adopt early and gentle deceleration, to communicate their yielding intentions, encouraging pedestrians to cross the road without hesitation. Previous studies have determined that vehicle kinematic features contribute to predicting pedestrians' crossing decisions (i.e., whether to cross before the vehicle), and high vehicle speed deviation can lead to prolonged pedestrians wait time during crossing.

However, previous studies neglected several key aspects: (1) vehicle kinematics encompass numerous interrelated features, including initial states (such as distance) and deceleration characteristics. These features likely influence each other—for example, shorter initial distances may correlate with lighter deceleration rates, jointly resulting in a pedestrian crossing after the vehicle. Examining these relationships could enhance our understanding of how human drivers communicate their intentions; (2) pedestrian crossing behaviour is a complex manoeuvre that cannot be described by a single metric, such as wait time. A more comprehensive description of pedestrian crossing behaviour, including whether and how they cross before vehicles, can help determine which vehicle kinematic combinations can lead to safe and efficient pedestrian crossing.

Aim

The aim of this study is to identify the types of vehicle behaviours that promote safe and efficient pedestrian crossing at zebra crossings. To address this aim, this study will answer two research questions:

1. How do vehicle initial kinematics correlate with the subsequent deceleration kinematics?
2. How do vehicle initial and deceleration kinematics jointly predict pedestrian crossing behaviours?

Method

The data used to answer the research questions were collected at two marked crossings in Leeds, UK. Multiple sensors were mounted on nearby streetlights and tracked vehicles and pedestrians' trajectories over discrete time stamps.

We introduced pre-cross zones to define interactions. A pre-cross zone is a half-circle with a 3-meter radius, centred at the pedestrian's zebra crossing entry point (Figure 1). The interaction begins when a pedestrian enters this zone, and pedestrian behaviour is classified based on their actions within this zone. Interaction data, vehicle kinematics and pedestrian crossing behaviour were then extracted using Python.

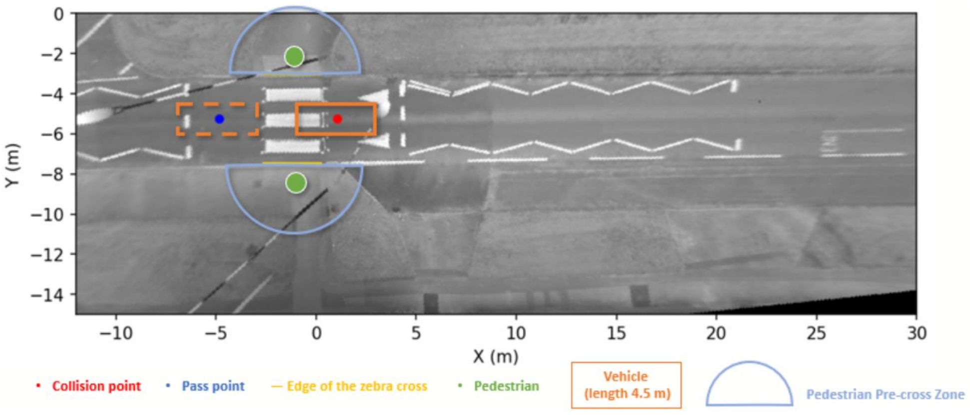

Figure 1 an example of vehicle-pedestrian interaction

Four algorithms, Random Forest (RF), Support Vector Machine (SVM), Gradient Boosting Machine (GBM), and Extreme Gradient Boosting (XGBoost), will be used to predict interaction outcomes and pedestrian crossing behaviour. Models with best performance will be further analysed. To address the machine learning's limitation on explainability, we will use two complementary methods to help us understand how the model makes decisions:

- SHAP (SHapley Additive exPlanations) uses a game-theoretic approach to quantify the contribution of each feature to individual predictions. It provides insights into the relative importance of features, how they affect predictions, and the interactions between features within the model.
- Supervised UMAP (Uniform Manifold Approximation and Projection) is a dimensionality reduction technique that incorporates class labels to enhance class separation in lower-dimensional space, making it useful for visualizing and understanding supervised learning model decisions.

Current and Expected Results

A total of 3064 interactions were extracted from the naturalistic data. We then classified pedestrian crossing behaviour into three categories: cross without hesitation; slow down to observe the road; and stop and wait for the vehicle to show clear yielding intention, allowing a more nuanced understanding of pedestrian decision-making. As our next step, we will use the mentioned machine learning algorithms to identify a model that can best predict, from vehicle kinematics, both whether the pedestrian crosses before or after the vehicle, and with which type of crossing behaviour. We will use SHAP analysis to identify the most influential vehicle kinematics features and reveal how initial kinematics interrelate with deceleration kinematics to determine the interaction outcome. We will use supervised UMAP to visualize how the different models separate different pedestrian crossing behaviours based on different vehicle kinematic combinations.

Conclusions

We will clarify how initial vehicle kinematics and subsequent deceleration kinematics are interrelated in driver-pedestrian interactions, and which vehicle behaviours facilitate safe and efficient pedestrian crossing. In future studies, we will test AVs with these kinematic behaviours in controlled experiments to investigate whether pedestrians comprehend the vehicles' intentions and cross the road as anticipated. The results from this study and follow-up studies can be used to inform user-centred AV design.

32. Trajectory Trace: A traffic and trajectory data management platform for storage, visualization and analysis of streaming sensor data and historical data sets

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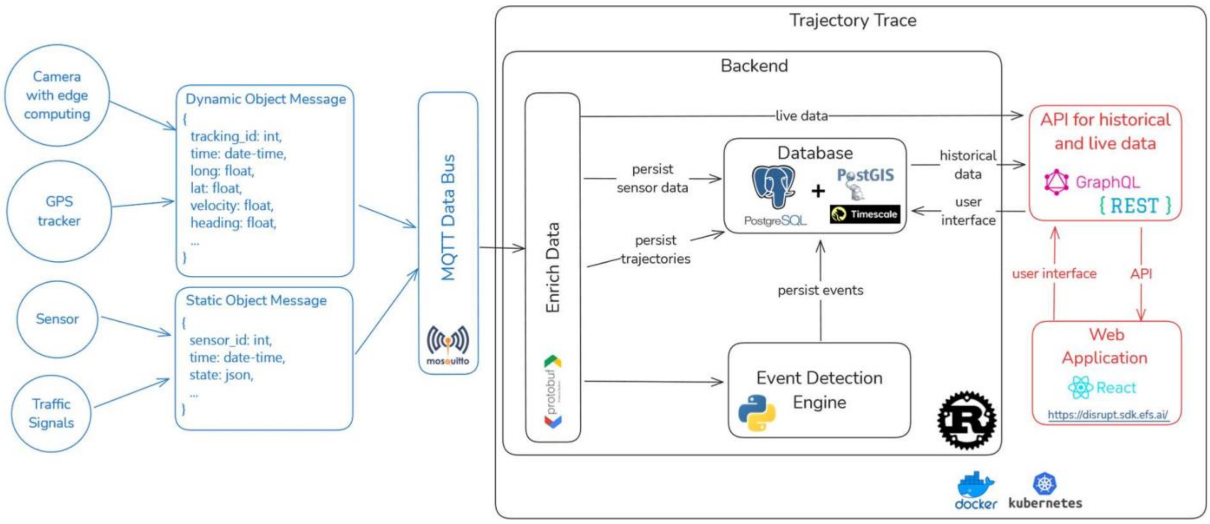
The vision of a traffic system without serious injuries and fatalities requires precise, data-based insights for effective safety measures. As technology advances, IoT devices and mobile and static sensor setups are becoming ever cheaper and more powerful. These new and extensive data sources open up entirely new possibilities for analyzing human behavior in road traffic, the interaction with existing infrastructure and the impact on road safety and the environment. In the DISRUPT research project, for example, mobile sensor boxes and corresponding algorithms are developed to determine the movement status of road users and thus predict their behavior in the near future. This will allow dangerous situations to be recognized at an early stage and vulnerable road users such as cyclists or pedestrians to be warned.

However, there is a lack of suitable data platforms to efficiently store the continuously streamed data volumes, make them easily accessible and draw insights from the data. On the one hand, there are big data technologies that make it possible to analyze large volumes of recorded data. On the other hand, there are IoT platforms that can store and, to a limited extent, visualize the input of live data. But there is currently no publicly available solution that combines both capabilities and also enables the simple connection of new sensors.

Therefore, Trajectory Trace has been and is being developed, which is a cloud-based traffic data platform with a special focus on accessibility, high-performance processing and easy distribution of road user and infrastructure data. The use case of DISRUPT as well as numerous other use cases from the field of traffic and accident research can be implemented.



The Figure shows an overview of the data flow, and the most relevant technologies used for Trajectory Trace. The basis is the open source solution Superb Data Kraken of e:fs TechHub GmbH, which enables deployment in the cloud with the help of Docker and Kubernetes. The other aspects Backend, API and Web Application are the extensions of Trajectory Trace that turn the general platform into a powerful traffic data platform. The database used is PostgreSQL with Timescale and PostGIS extensions to ensure performance and scalability. Nevertheless, the detection and tracking of road users generates enormous amounts of data at up to 30FPS, which can only be processed and made available again with a sophisticated database schema, extensive caching and the utilization of modern compression methods such as protobuf. The performance and stability of the backend is ensured by the use of the Rust programming language.

The results so far and those still expected are promising. Since July 2024, all trajectories of all road users at a busy intersection in Ingolstadt have been recorded at 25 frames per second. Together with the storage of GPS signals from Ingolstadt buses, which send one signal per second, around 13 million new data points are currently being processed every day. In addition, the published data sets TUMDOTMUC and DLR Urban Traffic dataset have been loaded into the platform and can be analyzed and visualized via the front end.

The performance of the platform is guaranteed by various methods. Firstly, all positions of an object are additionally summarized as trajectories in protobuf format and stored in an entity table. This greatly reduces the necessary accesses to the measurement table and reduces the query costs for the trajectory information by an average of 80%. Secondly, by using GraphQL as the interface between the backend and frontend, the necessary data queries and manipulations are only carried out at runtime and no unnecessary arithmetic operations are performed.

With Trajectory Trace, we present an innovative open source-based solution for end-to-end storage, individual queries and clear visualization of trajectories and traffic infrastructure data. The system combines modern technologies such as Rust, Timescale, GraphQL and protobuf with proven state-ofthe-art solutions such as PostgreSQL, PostGIS and MQTT. In current operation, the platform is stable and performs well. The modular code structure ensures further development for even greater scalability, new analysis options and, as the next major feature, the automated detection of interesting or critical traffic scenarios. The deployment of the platform with various public data sources is available here: https://disrupt.sdk.efs.ai/.

33. Predicting High-Risk Accident Locations with Floating Car Data: A Combined AI Analysis of Braking and Incident Patterns

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Background

Even today, road accidents remain one of the leading causes of death and disability worldwide. The WHO reports 1.19 million fatalities and approximately 50 million injuries from road crashes each year. The EU aims to halve the number of fatalities by 2030 and reduce it to zero by 2050. According to the Safe System approach, such an ambitious plan requires continuous and substantial improvements in road infrastructure, which serve as the space for traffic flows and interactions between various road users.

The extensive literature review conducted reveals a significant increase in the number of studies related to road safety from 2000 to the present, aligning with the ambitious goals set at the EU level.

Much of the research addresses the issue through quantitative and reactive methodologies, such as accident analysis or the evaluation of intervention effectiveness through various before/after methods. However, proactive analyses have recently emerged, which do not wait for accidents to occur but instead seek to prevent them by analysing driver's behaviour and how such incidents can be avoided, with a focus on road design and vehicle technology. These methodologies often require substantial effort to collect the necessary data for implementation. Today, data collection should no longer be a barrier, given the availability of data-driven resources, such as Floating Car Data (FCD). However, relatively few studies have harnessed this type of data, despite its great potential to adopt a data-driven approach that enables objective decision-making and enhances road safety.

Aim

In this context, research goal is to develop one of the first proactive screening tools designed to identify high-risk locations within the road network. This tool combines an analysis of harsh braking data, recorded by vehicles regularly driving through these areas, with ISTAT accident data. Additionally, the research aims to propose a simple and intuitive tool that is continuously updated, enabling the identification of high-risk sites and the creation of a prioritized intervention strategy based on Artificial Intelligence (AI) prediction.

Research Methodology

Managing large amounts of data requires the application of appropriate analytical methodologies to obtain reliable and consistent information for implementing road network screening procedures. The methodology used for data management leverages existing data to make predictions based on features that enable classification of the road network and identification of locations that, due to their characteristics, may or will represent high-risk sites. The analysis was conducted using AI supervised algorithms, Random Forest and Support Vector Machines, to perform the classification task. Through Ensemble Learning, an effort was made to combine these two mentioned algorithms to enhance prediction quality and identify high-risk accident sites. The procedure was tested on various road types within the road network of the province of Florence, after a segmentation process based on road homogeneity. It reveals both its potential and critical issues across the different implementations. Key road features influencing the classification of each site were also identified to provide a comprehensive understanding of the phenomenon.

Results

The proposed methodology enables the classification of each road segment and identifies the key road features most relevant to the process. The predictive performance of the models is both promising and encouraging. The accuracy achieved is consistent between the test and training sets, exceeding 60%. The importance of various road features (such as small-radius curves following long straight sections) was assessed, and the proposed model was designed to be simple, minimizing the risk of overfitting.

Conclusions

This paper addresses road safety by utilising Floating Car Data to extract information related to harsh braking and accidents, which are influenced by driver behaviour on the road network. An evaluation of road features was conducted at sites identified as high-risk. The proposed procedure, based on AI algorithms, analyses the database, classifies sites based on harsh braking data, accident information, and road layout features, and provides warnings for locations identified as critical. Increasing the dataset by including data from a larger area could ease model development and potentially enhance model performance in classification tasks, allowing for better differentiation between fatal accidents and injury-related crashes.

34. Dangerous Ground or Peaceful Coexistence? A Data-Driven Approach to Analyzing the Subjective Safety of Pedestrians and Cyclists on Shared Pathways

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In recent years, the collection of bicycle traffic trajectories via GPS has gained increasing importance, enabling new approaches in traffic safety research. On the one hand, provided that appropriate extrapolation methods are used, accident rates for intersections or road sections can be calculated, allowing for control of the Safety In Numbers (SIN) effect [1]. On the other hand, cyclists' behaviour concerning safety-related parameters such as speed can be assessed.

While objective safety, which can be measured effectively using accident data, is crucial, subjective safety is also of great importance in some planning scenarios. Both aspects need to be addressed to ensure a safe and comfortable riding experience.

One persistent point of conflict is the evaluation of shared pathways with pedestrians. Although shared-use paths should not be the preferred option, they are sometimes unavoidable when aiming to create an attractive cycling infrastructure. This applies particularly to routes in parks and gardens, pedestrian zones, traffic-calmed areas, and multi-use trails in scenic environments. In these settings, pedestrian complaints are common, yet they often do not align with actual accident data. Since many accidents involving cyclists and pedestrians—especially those without (serious) injuries—are not officially recorded by the police, a significant number of unreported cases is likely [2,3]. Furthermore, conflicts without direct accidents can still cause discomfort, particularly for pedestrians, leading to complaints.

The combination of existing complaints and a suspected number of unreported incidents generally results in the need for action by local authorities. Shared use paths and especially conflict areas with high counts of pedestrians are usually monitored using video technology, which allows for direct evaluation of interactions and estimation of cyclists' speeds as one main reason for pedestrians feeling unsafe. However, a major drawback of this method is the manual effort required for video analysis. Currently, no viable digital solution exists for analysing interactions in areas with high user density.

A useful preliminary step can be the analysis of (bicycle) traffic volumes and speeds, cross-referenced with typical pedestrian peak times. In this paper, we present analytical methods using GPS trajectories of cyclists, drawing on data from the 2024 STADTRADELN campaign. For selected study areas, we visualize both the spatial distribution of trajectories and the temporal patterns of speed and traffic volumes. Additionally, for several study areas in the city of Dresden, we compare this data with results from video analyses.

Our aim is to determine whether GPS trajectories from STADTRADELN can substantiate initial hypotheses regarding increased conflict levels, thereby justifying further investigation. The developed method is intended to be expanded into a scoring approach, which could be applied to additional network sections with shared-use paths, providing initial global indicators of potential problem areas.

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35. Enhancing Bicycle Safety in Hamburg: An Infrastructure-Based Approach by PrioBike-HH

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INTRODUCTION

Mobility plays a vital role in the quality of urban life, yet traditional car-centric transportation models contribute significantly to congestion, noise and air pollution. The Free and Hanseatic City of Hamburg in Germany strives for a sustainable mobility transition that prioritises environmentally friendly modes of transport. By 2030, the goal is to increase the share of cycling, walking and public transport to a total of 80% of all routes travelled, with cycling accounting for 25-30%. Cycling plays a key role in this transition as a cost- and space-efficient mode.

Within the framework of Hamburg's strategy of Intelligent Transport Systems (ITS) [1], the city has initiated multiple ITS-projects, including PrioBike-HH. This project seeks to enhance both cycling comfort and safety, acknowledging that safety concerns remain a key barrier to cycling adoption [e.g. 2]. A cycling infrastructure that ensures smooth and easy mobility within the city is vital for making cycling a competitive alternative to motorised private transport. This abstract focuses on the safety aspects of PrioBike-HH, specifically its infrastructure-based warning technology designed to reduce accidents at intersections.

OBJECTIVES

According to the Hamburg Police's traffic safety report, around 3,150 cyclists were involved in accidents in 2023. This is fewer than the previous year. Nevertheless, nine cyclists died; five of them were in turning accidents involving vehicles over 3.5 tons without turning assistance [3]. Enhancing the safety of cyclists in urban areas is a primary goal of PrioBike-HH. To reach this objective, applying an infrastructure-based warning technology and reducing the number of accidents involving cyclists is framed as one measure (see section 3). A comprehensive requirements analysis was conducted to ensure an effective solution involving key stakeholders, including cyclists, road users, motorised private transport, heavy goods vehicles, public transport, the police and further authorities within the Free and Hanseatic City of Hamburg. User stories developed during this phase emphasise the need for enhanced visibility and protection at intersections.

INFRASTRUCTURE-BASED WARNING TECHNOLOGY

One objective of PrioBike-HH is the implementation of an infrastructure-based warning technology at intersections to prevent accidents between vulnerable road users (VRUs, such as pedestrians and cyclists/e-scooter) and turning motorised traffic. The focus lies on the accident scenario with turning motor vehicle traffic crossing VRUs at inner-city intersections.

The warning message is triggered event-based when a cyclist is detected in a defined detection area, as shown exemplified in Figure 1. The goal is to avoid habituation effects by ensuring that the warning signals are activated only when necessary.

A feasibility study determined that radar sensors placed along the cycle paths and lanes provide the most effective detection mechanism. These sensors monitor the speed and position of cyclists and vehicles, activating white-flashing LED warning lights embedded in the cycle path when a collision risk is identified. The system was implemented at the beginning of 2024 and is currently in the testing and evaluation phase.

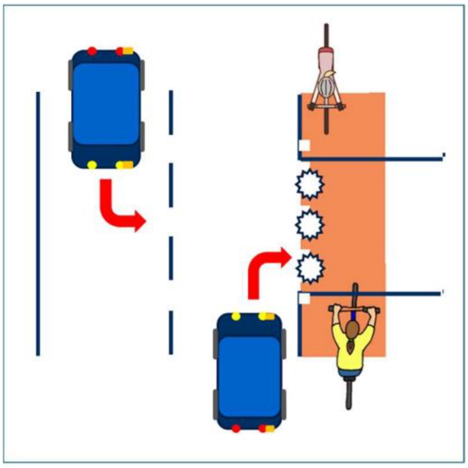

Figure 1: Example of a technology application to protect vulnerable road users © FHH

CONCLUSION AND OUTLOOK

Applying the measure described above within the project PrioBike-HH, the Free and Hanseatic City of Hamburg is eager to further improve cycling safety. As this measure is currently in the test and evaluation phase, it is expected to provide valuable insights into best practices for integrating technology into urban cycling infrastructure. The system has been running without any technical problems since its launch. Further data collection and analysis will determine its long-term effectiveness and potential for wider implementation.

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36. Calibrating the Exponential speed-crash model for different speed management and traffic calming measures

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Introduction

Driving speed has been recognised as the most influential traffic safety risk factor; various speed management and traffic calming measures (TCMs), which aimed at reducing the speed and thus decreasing the crash probability and severity, have been thus applied. In this context, several speed-crash models have been developed, allowing estimation of the expected crash change based on the measured speed change as a surrogate measure of safety change. Specifically, the Exponential model predicts a constant percentage change in the number of crashes or injured road users when the difference in speed is constant:

$$\frac{crashes_{after}}{crashes_{before}} = \exp\left(coefficient \cdot \left(speed_{after} - speed_{before}\right)\right)$$

Specific coefficient values for different crash severities were proposed and have been used internationally. But it is important to note that all the source data on which the Exponential models are based originated from macro scale studies (mostly on country or regional level), which focused on the high end of the speed limit range. Typically, these source studies evaluated of speed limit changes or enforcement activities. As the models gained popularity, they have been applied to estimate the safety impacts on a micro scale, such as single streets, intersections or schemes, to assess the crash changes due to the installation of TCMs. Further, the models have been frequently applied to the lower end of speed limit range. However, it is not clear if such practices are valid, due to several reasons:

- Different coverage of speed management. In contrast to the macro-scale, the micro-scale studies focus on the area level (e.g., a 30 km/h zone) or even a segment level (i.e., a specific road or street).
- Different categories of speed management measures. While the macro-scale studies evaluated the non-physical measures (speed limit changes or enforcement effects), the micro-scale focuses rather on physical TCMs.
- Different speed ranges. The macro-scale studies typically focused on the speed limit changes in the range above 50 km/h. On the other hand, for the micro-scale studies of local speed management, speed below 50 km/h is typical.

Some studies were aware of these potential differences and tried to calibrate the speed-crash models but found the coefficients quite varying. In addition, these attempts were based only on small local datasets and did not distinguish different speed management measures and TCMs. To fill these gaps, the presented study presents calibrating the Exponential model for several TCMs based on a review of an international speed-crash dataset.

Data and methods

The study was done in following steps:

1. Collecting past speed-crash evaluation studies around the world
   Based on literature review, as well as consultations with experts and our own unpublished data we collated 23 samples, covering 238 individual locations in total.

2. Extracting the data and contextual information on speed management and TCMs
   The data allowed extracting data on speed and crash changes before/after (or without/with).
3. Statistical analysis
   Descriptive analysis indicated the large variability in data, which biases the speed-crash relationship. We used linear regression modelling to identify the potential explanatory factors, which included also TCM categories.
4. Model calibration
   We estimated the model exponents for different TCM categories, such as horizontal TCMs, vertical TCMs, vehicle-activated signs, or 30 km/h zones.

Results

The calibrated coefficient in the Exponential model for most of the speed management measures analysed was found to be statistically significant. Therefore, the results can be used to assess the expected changes in crash rates more reliably for different speed management measures and TCMs.

Discussion and conclusions

The results enable more detailed consideration of different TCMs and comparison of their speed reduction impacts. However, the study may be limited by the source data characteristics (varying approaches to speed measurement or data aggregation) and other specific details (such as free-flow speed considerations, assignment of crashes to individual locations, various crash types, or TCM geometry characteristics). The sample size (although relatively big) is still limited, and did not allow more detailed categorization. Considering the data scarcity and lack of details, we used the simple evaluation approach without controlling for traffic volume changes and other potential confounding factors. Last but not least, while speed is an important risk factor, there are also other factors which are not reflected in speed-crash models.

37. The influence of attention to speed limits on driving behaviour: an analysis through simulation and Eye-Tracking

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Background

Correct perception and proper compliance to speed limits while driving play a crucial role in road safety. However, numerous studies suggest that drivers often do not focus their attention on speed limit signs, negatively affecting their driving behaviour and compliance with road regulations. Various factors, such as distraction or familiarity with the route, can impair the ability to detect these signs, making a thorough analysis of the phenomenon necessary.

Aim

This study aims to identify to which extent drivers consider speed limit signs along the road, if they comply with speed limits or if the speed limits have an influence on the speed held by the driver. Finally, the influence of familiarity has been also considered.

Research Methodology

The experiment has been carried out using the LaSIS driving simulator from the University of Florence, with six degrees of freedom, that recreates an immersive virtual reality, simulating the typical conditions of driving a real vehicle. The virtual scenario was constructed using 3D modelling software, allowing for the creation of realistic road environments. Using eye-tracking devices, capable of monitoring eye movements and fixation points, it was possible to analyse visual attention patterns and their impact on driving behaviour with great precision. The analysis considered both urban and rural scenarios, with a specific differentiation only for speed limits in urban areas, leaving the road geometry unchanged: in one case, the limit was 50 km/h (Group 1), while in another, it was 30 km/h (Group 2). The study assessed whether participants observed the speed limit signs and how this attention influenced their behavioural response in terms of acceleration or deceleration to adjust or not to the imposed limits. Furthermore, it was checked if, after fixating on the speed limit sign, participants shifted their gaze to the speedometer to verify the adjustment of their speed, thus evaluating the influence of this sequence of fixations on driving behaviour. This analysis was conducted by combining eye-tracking data with simulator data, aligning the moment the sign was fixated with the corresponding moment in the simulator data, which provided information on speed, acceleration and braking.

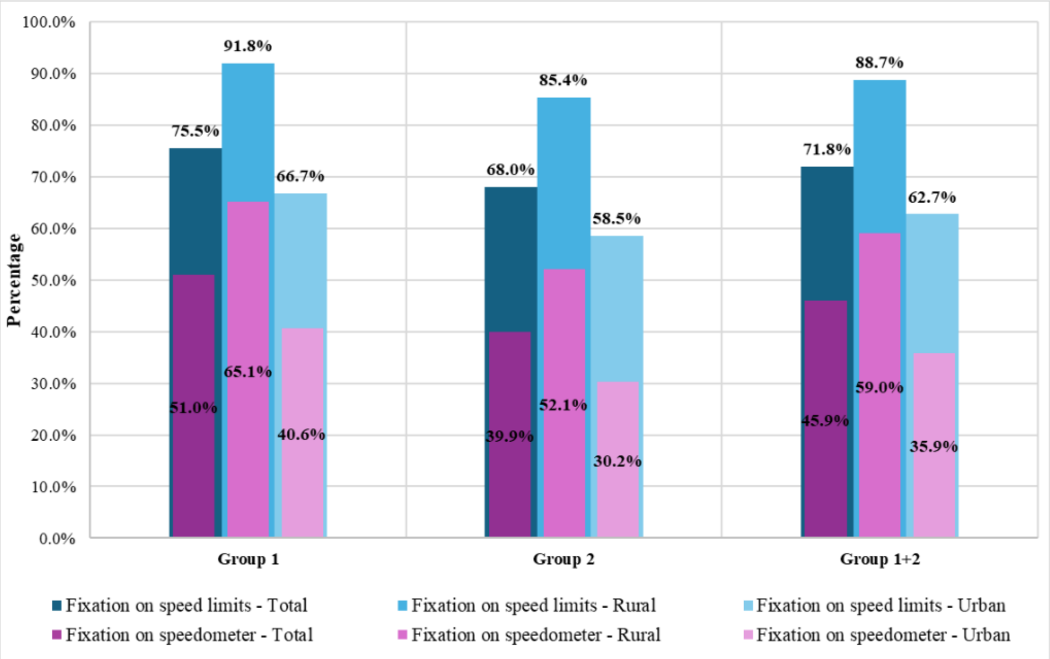
Results

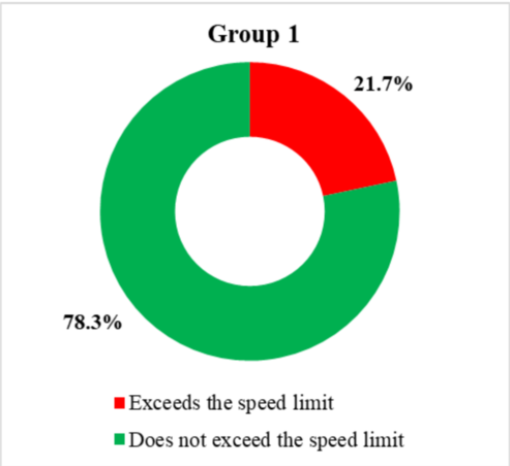
The results of the study indicate that participants who paid attention to the speed limit signs tended to regulate their speed more accurately, showing a greater tendency to slow down or accelerate in response to the posted limits, thus adhering to the road signs. Additionally, the study revealed that participants paid more attention to speed limit signs in rural areas (88.7%) compared to urban areas (62.7%), reflecting a heightened awareness in environments perceived as more hazardous or requiring greater caution.

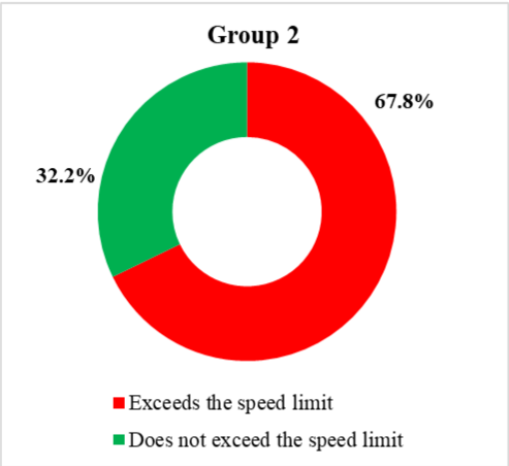
However, the credibility of the imposed limits also played a crucial role: when the speed limit was perceived as less credible, participants were more likely to exceed it. This was particularly evident in Group 2, where drivers encountered an urban road identical in characteristics to that of Group 1 but with a lower speed limit of 30 km/h instead of 50 km/h. The lower limit appeared less justified, leading to reduced compliance and higher instances of speeding. In fact, the percentage of participants who exceeded the limit in the urban area of Group 1 was 21.7%, while in Group 2, it rose significantly to 67.8%.

Conclusions

The analysis conducted highlighted how attention to speed limit signs plays a crucial role in regulating driving behaviour. These results emphasize the importance of strategies aimed at improving the visibility and effectiveness of road signage, as well as the need for educational interventions to raise drivers' awareness of the importance of paying attention to signs, with the goal of enhancing road safety. Furthermore, there is a need to introduce speed limits that are not only clearly visible but also perceived as credible, considering the road geometry, in order to encourage greater compliance with regulations by drivers.







38. Floating Car Data for road friction monitoring: an innovative approach to improve safety

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Background

Monitoring functional characteristics of road pavements is a key element in ensuring traffic safety and effectively managing road infrastructures. Among the most relevant parameters, tire-pavement friction plays a central role, as it directly affects a vehicle's ability to maintain stability and control, particularly during critical manoeuvres such as emergency braking, sudden acceleration or tight curves. However, friction can be significantly reduced due to adverse environmental conditions, surface contamination or pavement degradation, leading to an increased risk of vehicle instability and accidents. To prevent such situations, the adoption of systems capable to timely detecting critical surface conditions becomes essential. Traditional measurement techniques, such as the Runway Friction Tester (RFT), can provide accurate results, but they are often limited by economic, logistical and spatial constraints. In this context, the use of Floating Car Data (FCD), directly collected from onboard sensors, installed on moving vehicles, represents an innovative and efficient solution for friction monitoring, offering large-scale coverage for tailored maintenance actions to improve road safety.

Aim

The primary objective of this research is to assess the effectiveness of FCD as a tool for monitoring road friction conditions. The study aims to evaluate the ability of this technology to promptly identify critical segments of the road network, support preventive maintenance actions and contribute to the overall safety of road users.

Research Methodology

For the analysis, two road segments in Tuscany, with distinct infrastructural and functional features, were selected: a rural two-lane, two-way road and a freeway. The FCD analysed in this study were provided by NIRA Dynamics, a Swedish company specialising in automotive data processing systems, and were generated by the Volkswagen Group vehicle fleet starting in 2022. In the initial phase, the data were examined to assess internal consistency and their ability to capture spatial and temporal variations in road friction, with particular attention to the effects of weather conditions such as rainfall and temperature fluctuations.

Furthermore, changes in friction levels were evaluated before and after road maintenance interventions in order to assess the sensitivity of FCD to surface condition variations. The reliability of FCD was explored through comparison with on-site measurements obtained using the RFT, the technical standard for direct friction assessment. The analysis included both a qualitative trend comparison and a correlation analysis, aimed at defining the reliability and operational potential of FCD for continuous pavement condition monitoring.

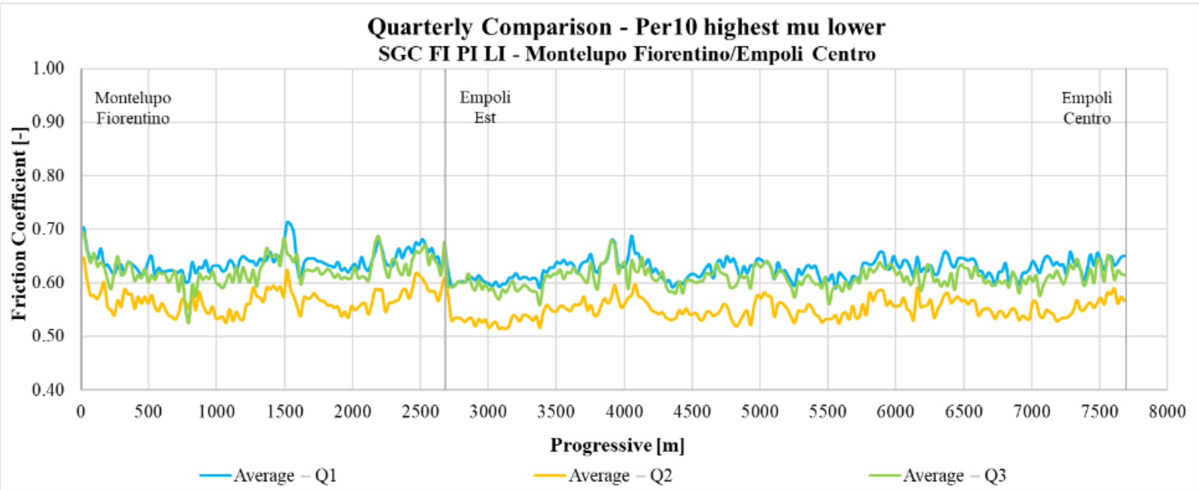
Results

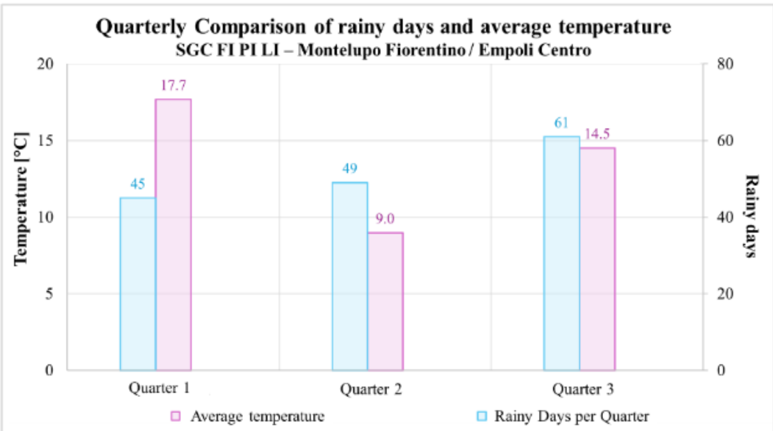
The experimental analysis showed that the data collected through the system developed by NIRA consistently represent the temporal evolution of road friction. FCD proved effective in capturing friction variations in response to changing environmental and operational conditions, confirming their potential for continuous pavement performance monitoring, particularly with respect to spatial–temporal dynamics. However, the comparison between FCD and the measurements obtained using the RFT in the two analysed scenarios highlights that the relationship between these two data sources cannot be evaluated through a simple comparison of absolute values. Although FCD values are generally higher than those obtained with the RFT, it is not necessarily to be intended as an overestimation of actual surface conditions. These discrepancies can be attributed to variations in measurement methodologies, vehicle operating conditions, or data processing algorithms.

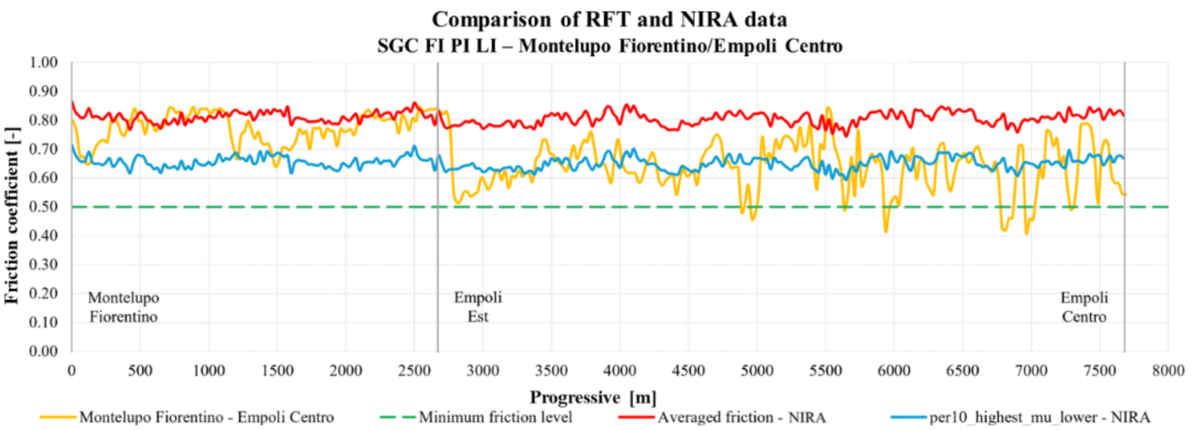
Conclusions

The results confirm that, the strength of Floating Car Data lies mainly in their consistent ability to track relative variations in road friction over time and space, although they may mismatch absolute values from traditional measurements. To improve the comparison with standard instruments, it will be essential to have a more extensive historical dataset, supported by regular measurement campaigns aligned with the temporal aggregation of FCD data.

Future research should aim to improve reliability by developing advanced predictive models that integrate weather data, vehicle dynamics, and tire conditions. The integration of this approach into road management practices may significantly support the transition toward predictive maintenance models, with measurable benefits in terms of safety and infrastructure performance.






Comparison of RFT and NIRA data
SGC FI PI LI – Montelupo Fiorentino/Empoli Centro
Friction coefficient [-]
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
Montelupo Fiorentino
Empoli Est
Empoli Centro
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
5500
6000
6500
7000
7500
8000
Progressive [m]
Montelupo Fiorentino - Empoli Centro
Minimum friction level
Averaged friction - NIRA
per10_highest_mu_lower - NIRA

39.Putting cyclists in boxes: an analysis of the bike box

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Background

The bike box has been hailed as a measure to reduce the risk of crashes between cyclists and right-turning vehicles and blind spot incidents. Despite some studies finding a positive effect, the safety effects of the bike box are inconclusive. A potential reason for the lack of conclusive results is the way cyclists position themselves in the bike box, which might not align with the intended use of the bike box. For the bike box to be effective, it is important that cyclists stand in front of the queue of cars. By doing so, they increase their visibility and encourage motorist to stay behind. Past studies have highlighted that while cyclists understand the purpose of the bike box, the actual use does not align with the design philosophy behind the bike box. As such, it is possible that the safety benefits will not materialize. This can be problematic as it causes planners, assuming a correct use, to unknowingly create a false sense of safety when committing to the implementation of the bike box at an intersection rather than providing a real safety benefit for cyclists.

Aim

Several studies in the past assessed the use of the bike box, but these studies come with limitations such as studying the use of the bike box shortly after the implementation (possibly measuring a novelty effect), studying the use of the bike box in conditions where cyclists have to make a staggered left turn, or using a questionnaire design that omits the presence of other cyclists in the bike box. This study aims to fill these gaps by making use of video observations and a questionnaire study in the Netherlands and Sweden. Two countries with a rich cycling culture and a history of applying the bike box at signalized intersections and where cyclists can make a left turn at intersections.

Method

We make use of questionnaire distributed in the Netherlands and Sweden and video observations. The questionnaire serves to understand where someone would wait when they turn left or go straight ahead, depending on the number of cyclists present in the bike box (none, one, or two) and their motivation for this choice. The video observations are used to study the real-world use of the bike box. The frequency of the use of the different zones was compared using a Fisher exact test.

Results

Figure 1 shows the position of cyclists based on the video observations and Figure 2 based on the questionnaire responses. We find a statistically significant effect of the turning manoeuvre on where cyclists position themselves. Cyclists going straight stand in the right-hand side or approach lane of the bike box, using it as a bike lane. Common reasons for this are to not block cars and follow the bike lane. Cyclists turning left do use the bike box correctly. Common reasons for their waiting choice are to show intention and have the shortest route to the left.

Conclusions

The study presented here focuses on the use of the bike box in the Netherlands and Sweden, two countries with a significant modal share of cyclists and history of applying the bike box at signalized intersections. For the bike box to work as intended and make cyclists more visible, reducing the risk of blind spot conflicts, it is important that cyclists make proper use of the bike box. The results presented here suggest that this is not the case. Although cyclists turning left do use the bike box as intended and the questionnaire responses revealed that the intention to do so is present, this group of cyclists is relatively uncommon across all measured intersections. A low volume of left-turning cyclists has been reported in other studies as well. The majority of the cyclists, those who continue straight ahead, tend to stay to the right-hand side. In doing so they block access to the bike box and cause later arriving cyclists to wait in the approach lane. As a result, the bike box is effectively used as a bike lane and blind spot conflicts are still possible to occur, meaning the intended safety benefits of the bike box are not realized.

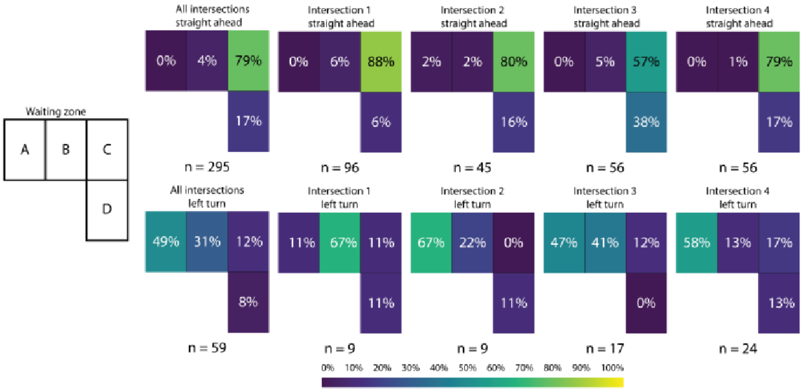

Figure 1: Results of video observations.

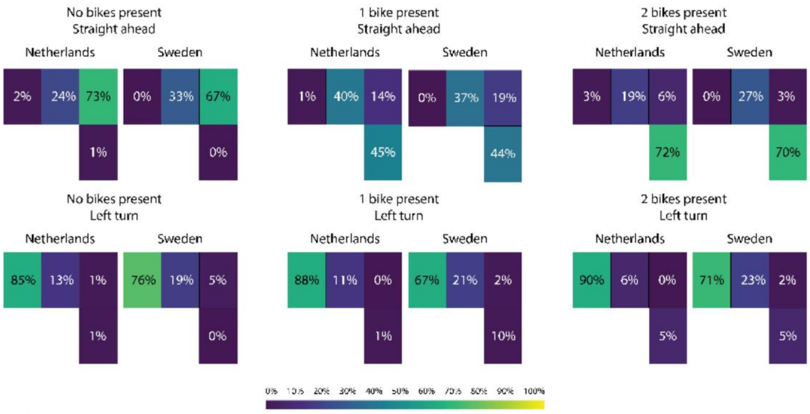

Figure 2: Results of questionnaire

40. Understanding organisations' responsibilities and engagement in occupational road safety – a necessity for saving lives beyond 2025

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Most organisations generate travel and transport and thereby influence traffic safety – by the employees' travel at the service and own transports or by the organisation's procurement of transport or of goods/services generating travel and transport (Wennberg & Hyllenius Mattisson, 2024; FIA, 2023). The roles and responsibilities of organisations are gaining increasing interest for advancing implementation of Vision Zero and reaching traffic safety objectives. Occupational road safety is highlighted in the expert recommendations that formed the basis for the Marrakech Declaration for the 4th Global Ministerial Conference on Road Safety in Marrakech in 2025 (STA, 2025). The concept of occupational road safety puts focus on organisations' formal responsibilities, and to the large share of work-related fatalities in road traffic that could be addressed through measures on organisational levels, rather than treating road safety as a concern for the individual road users (Murray, 2007; Lie & Tingvall, 2024; Kullgren et al., 2024; Nævestad et al., 2015).

Understanding organisations' responsibilities and engagement in traffic safety issues is a key for supporting and advancing traffic safety implementation on organisational levels. At the same time, there is only few studies yet providing such understanding. One example is Wennberg & Hyllenius Mattisson (2024) who examined companies' views on traffic safety as a part of sustainability practices, concluding that traffic safety is generally not viewed as a sustainability issue and is rarely included in sustainability reporting. Previous studies indicate that this may also be the case for the inclusion of traffic safety risks in occupational health and safety (OHS) practices where traffic safety in road traffic is often neglected or overseen (Lie & Tingvall, 2022; Swedish Work Environment Authority, 2017). Nævestad et al. (2021) have studied prevention of work-related accidents in different transport sectors in Norway and find several barriers to implementation of safety management systems in the road sector that must be handled. Understanding organisations' responsibilities and engagement in traffic safety is a necessity to involve these actors in the traffic safety work. Such understanding is related to strengthening traffic safety culture maturity and Safe System readiness in road safety authorities (c.f. Fosdick et al., 2024; ITF, 2022; Nævestad et al., 2024; 2025).

The aim of this study is to gain an understanding of organisations' responsibilities and engagement in traffic safety implementation by capturing organisations' views and efforts to improve traffic safety in their role as employers, i.e. concerning traffic safety when traveling at the service and for own transports, as well as transport buyers, i.e. concerning traffic safety requirements when purchasing transportation services or goods and services that generate transportation. More specifically, the aims are to: (a) indicate the level of engagement in traffic safety by private and public organisations and to present this engagement in the form of a summarising index (process indicator) to be used by follow ups of progress on the national traffic safety work in Sweden as well as to (b) examine whether there are differences in views and engagement between private and public organisations and (c) analyse whether the views on traffic safety (as an individual issue or responsibility for the organisation) influence the level of engagement in traffic safety.

The study is based on two surveys with similar questions, to ensure comparability: (1) a company survey involving both private companies with operations in Sweden and Swedish state-owned companies, and (2) a municipality survey involving local authorities in Sweden. The company survey was sent to 300 private companies with more than 200 employees operating in a strategic selection of relevant industries and the 30 largest state-owned companies. In total, 109 companies participated in the survey of which 57 of the respondents were from HR department and 65 from transport department. The survey was carried out from December 2024 to February 2025. The municipality survey was sent to 126 municipalities with over 20,000 inhabitants (there are in total 290 municipalities in Sweden) in March 2025 and is finalised in the end of April 2025. Analysis of data from the company survey is still in progress, and the comparison between these two surveys will be carried out as soon as the data from the municipality survey is available to address the specific aims a-c above.

The preliminary results from the company survey show that both private and state-owned companies recognise their roles and responsibilities in traffic safety implementation – with more focus on employees' travel at the service than on their transport suppliers or on other road users (third party). We find that state-owned companies to a larger extent than private companies set traffic safety requirements on employees' travel at the service, while it is the opposite for transport procurement where private companies set harder requirements than the state-owned companies. Thus, a lesson based on the study so far, is that the state-owned companies can learn from the private companies when it comes to setting traffic safety requirements in procurement. Whether there are any differences between public and private organisations is to be explored in the further analyses as well as on how the views on traffic safety (as an individual issue or responsibility for the organisation) influence the level of engagement in traffic safety. These findings will be presented at the conference, and in a paper, and discussed in relation to the overall aim of the study with the ambition to gain a better understanding of organisations' responsibilities and engagement in traffic safety implementation, and to move the field of occupational road safety forward.

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41. Assessing the statistical methods used to estimate the value of behavioral Safety Performance Indicators

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Introduction

In order to analyse the entire traffic system, it is necessary to consider all road safety data, as traffic accidents, being relatively rare events, may not provide a fully accurate or comprehensive representation of the overall traffic system. The limited occurrence of traffic accidents, along with potential underreporting or inconsistencies in accident data, limits their utility as the sole indicator of road safety performance. Therefore, Road Safety Performance Indicators (SPIs) provide a proactive and complementary option for assessing road safety. SPIs offer valuable insights into traffic behavior and safety-related practices, especially in cases where the direct consequences of risky behaviors (e.g. traffic accidents, injuries) are not immediately observable or measurable. In this study, we aimed to estimate behavioral SPIs, which are collected from roadside measurements. The primary objective of this study is to compare the performance of various estimation methodologies to derive an efficient and robust estimator. A critical aspect of this evaluation is the estimation of variance, which is essential for assessing the reliability of SPI values. To this end, confidence intervals will be calculated and analysed to evaluate the precision and statistical soundness of each method.

Methodology

In general, it is not feasible to evaluate the safety performance of every vehicle or road user within the entire traffic network due to practical and resource limitations. Instead, SPI values must be estimated using data collected from a representative sample of vehicles or road users through systematic traffic observations. This sampling is typically performed based on combination of key stratification factors such as road type, speed limit, time period, vehicle type and specific characteristics of road user (e.g., age, sex, private or professional driver, etc.). However, the behavior of road users may differ significantly across regions, even when similar road and traffic conditions are present. To correct this variability and ensure unbiased estimation of SPI values, individual observations are assigned with appropriate weights. These weights reflect the frequency and structure of the population represented by each observation within the overall dataset and count period data. By applying these weights, we can account for imbalances in the sample and improve the validity of SPI estimates.

Moreover, the SPI value is defined as the weighted expected value of positive counts depending on the specific definition of each SPI. For example, in the case of seatbelt usage, the SPI may represent the proportion of observed passengers wearing seatbelts, weighted according to the survey design. Complex survey analysis provides a suitable framework for estimating the expected value, particularly within the context of stratified sampling designs. These methods, based on complex sampling theory, ensure valid statistical inference. Estimation methodologies associated with survey design are traditionally centred on the design-based approach. However, in the context of SPI estimation, we extend our analysis to incorporate model-based inference, which is often used in applied statistics.

Results

The outcome of this study will be a comparison of the point estimates per stratum used in the Trendline project with alternative techniques, including generalised linear models (GLMs), applied with and without a weighting procedure. In addition to evaluating model quality through measures such as the adjusted coefficient of determination or Akaike information Criterion (AIC), we will also focus on the variability of estimates and the range of confidence intervals, which are key indicator of statistical precision and reliability. The comparison will highlight the practical implications of using methods in the context of SPI estimation.

Discussion and conclusion

In our study, we do not expect the estimates produced by GLMs to differ substantially from approach implemented in the Trendline project. The primary focus lies in demonstrating and comparing these methods using observed data and in exploring the potential of incorporating model-based approaches along traditional survey methods. A key question is whether the use of GLMs may gain more consistent or stable estimates. The finding and detailed comparison will be presented in our contribution.

42. Analysis of the safety of vulnerable road users at crossings without traffic signals across 2 or more lanes in one direction

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Background

In everyday life most of the time we are pedestrians, although we often don't realize it. Moving from home to work and school, we cross the road every day, and how a pedestrian crossing is arranged can make a huge difference to the safety of its users. In the 1950s and 1960s, there was a prevailing belief in the superiority of individual automobile transport over public transportation, walking, and bicycling. The aftermath of this in many eastern European countries, including Poland, is long pedestrian crossings in front of two or more lanes without the benefit of a dividing island or pedestrian asylum. Wider cross sections, on the other hand, encourage drivers to drive faster. Societies are aging and increasingly elderly or mobility-impaired people are using existing infrastructure. In the situation of using a long pedestrian crossing, such a user remains on the roadway for a very long time and is at risk of being hit. The above issues encouraged us to investigate whether a longer crossing increases the risk of an accident and how pedestrian and motorized users behave at such crossings.

Aim

This study aims to analyze pedestrian safety at multi-lane crossings, which is based on an analysis of footage at 5 selected training grounds and conducted speed measurements within the crossings using radar. Also included is an analysis of historical data on traffic incidents from 20 multi-lane crossings in Poland.

Method

The analyses were conducted in two stages. In the first stage, 20 pedestrian crossings without traffic lights located on a cross-section of 2 or more lanes in one direction were randomly selected, and accident data on these crossings from 2013-2023 were analyzed. The focus was on accidents involving pedestrians. The severity of the injuries and the pedestrian's age in the accident were analyzed.

In the second stage of the study, 5 pedestrian crossings with different characteristics and locations were selected, at which specto-recordings and radar studies of the speed of vehicles approaching the pedestrian crossing were conducted.

Results and conclusions

By analyzing historical accident data on a set of 20 crossings, it was possible to show how the type of cross-section can affect the risk of being hit at a pedestrian crossing, and whether age is correlated with a higher likelihood of being a victim of such an accident. Analyses of video-recording videos made it possible to analyze the behavior of users in various traffic situations at crossings. In turn, thanks to radar measurements, it was possible to determine the actual speed of vehicles and whether the location of the crossing and its characteristics had an impact on the behavior of both pedestrians and drivers.

43.Role of Driver Demographics and Road Geometry on Maximum Speed Reduction: Comparison of Day and Night Driving

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Introduction

Mountainous roads present unique driving challenges due to sharp curves, steep gradients, and limited visibility conditions that become more hazardous at night. Reduced visibility impairs driver perception, often leading to abrupt speed adjustments at critical points like tangent-to-curve transitions. While most speed behavior studies focus on daytime conditions, night-time effects remain underexplored. This study compares driver speed behavior under daytime and night-time conditions on a two-lane, undivided mountainous road. It examines the influence of driver demographics (age, experience) and geometric features on speed behavior, measured by the 85th percentile maximum speed reduction (85MSR), defined as the difference between maximum tangent and minimum curve speeds. Findings support visibility-sensitive design strategies for safer mountain roads.

Research Methodology

To investigate driver speed behavior under varying visibility conditions (i.e., daytime and night-time; Figure 1(c–d)), a motion-based, fully configured open-cockpit driving simulator was used (Figure 1(a)). A 21 km section of NH-7—a two-lane, two-way, undivided mountainous highway from Kaudiyala to Devprayag in Uttarakhand, India—was replicated using Unity3D (Figure 1(b)). Geometric data, including curve radius, gradient, segment length, and extra widening, were obtained from the Public Works Department (PWD), Uttarakhand.

(a) (b) (c) (d)

Figure 1: (a) Driving simulator setup (b) Replicated terrain view (c) Daytime driving scenario, and (d) Nighttime driving Scenario

The simulated stretch included 280 horizontal curves (145 left, 135 right) with a radius ranging from 20 m to 800 m, each preceded by tangent segments between 7 m and 153 m. The road was designed with a 40 km/h speed limit, 3.5 m lane width, 1.5 m shoulder, and gradients from −7.854% to +8.76%. The study involved 23 professional drivers from Uttarakhand, each with valid licenses and at least one year of mountainous driving experience. Each completed two ~21 km drives (both directions), totalling ~42 km. The study was conducted under dry, low-traffic conditions during both daytime (10 AM–3 PM) and night-time (7 PM–1 AM), and comprised three phases: (i) a pre-drive questionnaire and briefing, (ii) a 15-minute training session, and (iii) a ~21 km test drive. A post-drive evaluation was completed after the session.

Results

The present study evaluated the influence of driver demographics (age, experience) and road geometric characteristics on driving speed behavior using mixed-effects linear regression models under different lighting conditions. The primary performance metric was the 85th percentile maximum speed reduction (85MSR). Road geometry variables were categorized based on standard design classifications for two-lane undivided mountainous roads. Age was grouped into Young (21–26 years) and Middle-aged (27–

50 years), while experience was classified as 1–2, 2–5, 5–10, and >10 years. Roadway elements such as tangent/curve length, curve radius, deflection angle, direction, gradient, and superelevation were similarly classified.

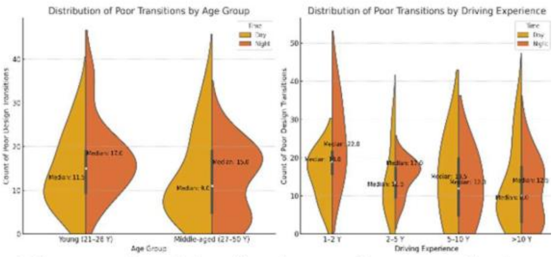

Figure 2: Distribution of poor design transitions by age and driving experience

Among the demographic variables, driving experience strongly influenced speed reduction. Drivers with more than 10 years of experience showed lower 85MSR values, particularly during daytime, indicating a more anticipatory and stable driving approach aided by better use of visual cues. Age had a modest effect, with middle-aged drivers slightly more cautious than younger ones. To assess the relationship between driver characteristics and roadway risk, poor design transitions were identified where 85MSR exceeded 17.27 km/h (day) and 18.58 km/h (night) —thresholds derived from the MSR. These transitions reflect abrupt inconsistencies. Night-time conditions consistently resulted in poor transitions, indicating greater difficulty in curve negotiation under low visibility. Violin plots showed that younger and less experienced drivers (1–2 Y, 2–5 Y) encountered higher and more variable numbers of poor transitions, especially at night (Figure 2). In contrast, experienced drivers (5–10 Y, >10 Y) exhibited lower and more concentrated distributions, though their exposure still increased slightly at night. Geometric variables showed stronger influence on 85MSR at night. For tangents of 151–200 m, 85MSR increased from +2.42 (day) to +3.04 (night), indicating sharper deceleration under limited visibility. Medium curves (51-100m) reduced speed more in daylight (−0.147) than at night (−0.083), while medium-long curves (101-150m) increased 85MSR at night (+0.210). Superelevation was more effective at night (−0.559). Curve radius showed a counterintuitive trend, with very large radii (>300 m) increasing deceleration (+0.435 day, +0.505 night), likely due to misjudgement. Right-hand curves, higher deflection angles, and night-time gradients also had stronger effects. Extra widening nearly doubled in impact at night (+1.353), reflecting increased pre-curve acceleration.

Discussion and Conclusions

The study highlights that night-time driving significantly increases safety risks on mountainous two-lane roads. Experienced drivers showed more stable speed control, while younger and less experienced drivers were more affected by poor transitions, particularly at night. Geometric features such as tangent length, superelevation, and gradient had significantly stronger effects on speed behavior under low-light conditions. These findings emphasize the need for night-time-specific design strategies, including better delineation, reflective signage, and consistent curve geometry. As most standards are daytime-focused, integrating night-time performance criteria is essential. Additionally, deploying ADAS—like curve warnings, lane assist, and downhill speed control—can help reduce risk for less experienced drivers especially during night driving.

44. The Prevalence of Drinking and Driving with Cars and Powered Two-Wheelers – Insights from a Survey-Based Measurement in Germany

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Background

Driving under the influence of alcohol is a significant road safety issue. A crucial characteristic of alcohol-related accidents is their severity, which disproportionately results in serious injuries or fatalities. Despite the decline in alcohol-related accidents in Europe and Germany, the further reduction of driving under the influence of alcohol remains a key objective of road safety work. Current road safety efforts aim to achieve a further reduction in alcohol-related accidents, for example, by establishing Safety Performance Indicators (SPIs) or Key Performance Indicators (KPIs), which aim to monitor the prevalence of driving above the legal alcohol limit in Germany (≥ 0.5‰ BAC).

Aim

A survey design was developed in order to record a trip-based prevalence of driving under the influence of alcohol among car drivers and riders of powered two-wheelers (PTWs) in the last seven days. This pilot-tested survey design has been used in a nationwide study in Germany. In addition to recording the trip-based prevalence, the collected data also provide trip-specific details such as the time or destination of the trip for further analysis.

Methods

The developed questionnaire records a randomly selected trip from the prior seven days. As only a small number of recorded trips under the influence of alcohol could be expected in the random selection, follow-up questions additionally record the last trip driven after drinking alcohol and serve as a solid basis for trip-specific analyses.

The study using this questionnaire was conducted as an online survey in May and June 2024. The target population consisted of individuals aged 18 to 74 who had driven a car or ridden a PTW in the 30 days prior to the survey. Recruitment was conducted through an online access panel, gathering data from 5,052 respondents to obtain a sufficient number of recorded trips.

To ensure representativeness, quotas were applied to match sex, age, and federal state with population statistics for individuals in Germany aged 18 and older. The data collected were weighted for sex, age, and federal state and an additional trip-based weight was applied to adjust for the oversampling of trips during the night.

Results

Among car drivers who had driven at least once in the last seven days, 1.3% reported alcohol consumption before the randomly selected trip. Together with drivers recorded in the follow-up questions, a total of 9.5% of those drivers stated they had undertaken at least one trip after consuming alcohol in the last seven days. Of the riders of PTWs with at least one ride in the last seven days, 5.1% reported the consumption of alcohol before the randomly selected trip. Combined with riders recorded in the follow-up questions, 17.1% of those PTW-riders indicated to having made at least one trip after drinking alcohol in the seven days prior.

This trip-based prevalence of drinking and driving builds the starting point for analyses that explore correlations between age and e.g., time of travel, vehicle type, or individual drinking habits. These analyses provide insights into patterns of alcohol-related driving highlighting specific profiles among car drivers and PTW-riders as well as young, middle-aged, and older drivers.

Conclusions

Despite the limitations of self-reported data, the presented survey design adds a new variant to measure the prevalence of drinking and driving. Moreover, the survey design makes it possible to analyse the occurrence of drinking and driving by combining trip-specific details with sociodemographic or attitude-based characteristics.

The results obtained provide, on the one hand, a trip-based prevalence for the last seven days on the basis of a random selection e.g., for use in the calculation of safety indicators and, on the other hand, a basis for detailed investigations. The analyses carried out provide insights into alcohol-related driving in Germany, where younger drivers stand out negatively.

Acknowledgement: This report is based on parts of the research project carried out at the request of the Federal Ministry for Digital and Transport, represented by the Federal Highway and Transport Research Institute, under research project FE 86.0099/2023/. The author is solely responsible for the content.

45.Deep Learning for Real-Time Detection of Vulnerable Pedestrians

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Background

In urban environments, child and elderly pedestrians represent particularly vulnerable groups due to distinct behavioral characteristics and physical limitations. Research has shown that children frequently exhibit unsafe crossing behaviors, including crossing outside designated crosswalks, running across roads, neglecting to verify the presence of oncoming vehicles, and crossing between parked cars. These behaviors are often influenced by visual obstructions, inadequate pedestrian infrastructure, and limited adult supervision [3]. According to the Israel Central Bureau of Statistics, children aged 5–9 are especially susceptible to road injuries due to insufficient awareness of safety practices and impulsive behaviors such as abruptly entering roads outside marked crossings [2]. As children age, injury patterns shift towards accidents involving bicycles and electric scooters, despite regulatory age restrictions.

Elderly pedestrians face increased risks primarily because of reduced mobility, slower walking speeds, and age-related declines in vision, hearing, cognitive processing, and reaction times. These limitations significantly reduce their ability to safely navigate complex urban environments with high traffic density and fast-moving vehicles [1]. Data from Israel emphasize these vulnerabilities, indicating pedestrians aged 85 and above have severe injury rates nearly six times higher than those aged 25–44, and individuals aged 65–74 face risks approximately four times greater [2]. Figure 2 below summarizes the main factors influencing pedestrian vulnerability in urban settings.

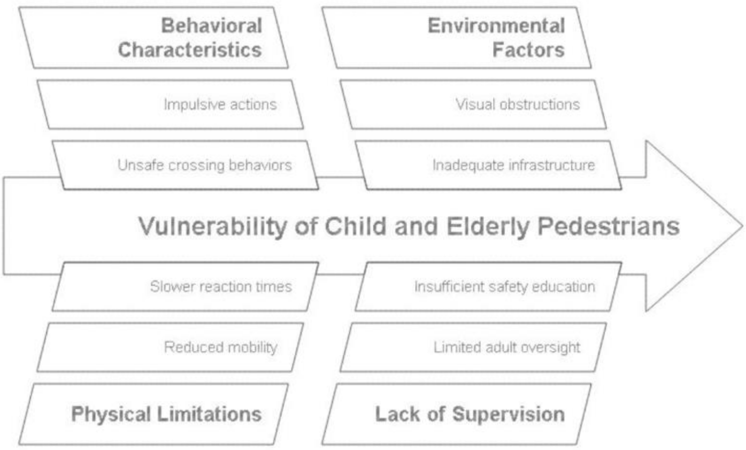

Figure 1: Vulnerability of Pedestrians in Urban Environments

Aim

This study aims to leverage advanced machine learning techniques to improve real-time pedestrian safety recognition systems. We present a novel deep learning model designed to accurately identify vulnerable pedestrian groups, such as children and elderly individuals, from surveillance footage, thus enhancing accident prevention strategies in varied urban environments. It is critical to differentiate pedestrian categories to enable timely and appropriate warnings. Specifically, vehicle safety systems must proactively identify children approaching curbs or crossing outside designated areas, anticipating their unpredictable behavior. Elderly pedestrians similarly require early detection and warnings due to their typically slower movements and prolonged crossing times.

Methodological Issues

We apply state-of-the-art machine learning methodologies, evaluating a variety of image pre-processing techniques alongside multiple deep learning architectures. While previous studies have explored CNN-based models, transformer-based models, and hybrid approaches for classifying pedestrian attributes, these efforts have primarily focused on tasks such as face recognition. In contrast, our study addresses a fundamentally different challenge: recognizing pedestrians from a distance, often before their facial features are visible or discernible. As a result, face-based identification methods may frequently be ineffective in our context. Moreover, prior benchmarks on pedestrian classification [4] have primarily focused on adult populations and aimed to infer a broad set of attributes. In contrast, our study specifically targets the classification of pedestrians into three critical age-based categories—children, adults, and elderly individuals—and assesses model performance directly in this focused context.

The primary objective of our approach is to enable autonomous vehicles to identify and respond to children and elderly individuals at an early enough stage to allow for safe and proactive driving decisions. The motivation is to enhance driver awareness in time to permit gradual deceleration in potentially hazardous situations. Our methodology involves fine-tuning and evaluating advanced deep learning models on datasets composed of unclear, anonymized, and low-resolution images captured from considerable distances—conditions that closely mirror real-world urban surveillance scenarios. Figure 2 illustrates our methodological framework in detail.

Figure 2: Advanced Methods to Improve Pedestrians' Safety

Results obtained or expected

To achieve our objectives, we compiled a dataset containing several hundred annotated images across various age categories. Through fine-tuning these advanced models, we anticipate achieving satisfiable accuracy levels, significantly enhancing drivers' and automated systems' capabilities to recognize pedestrians whose behaviors are either unpredictable (children) or characterized by limited mobility (elderly).

Conclusions

Integrating advanced machine learning techniques into pedestrian detection systems enhances early recognition capabilities, thereby enabling vehicles to proactively anticipate and respond to critical road situations. This research significantly contributes to road safety by assisting automated vehicle systems in recognizing and mitigating risks involving vulnerable pedestrian groups, ultimately reducing accidents and the severity of pedestrian injuries.

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46. Hybrid AI and Physics-Based Modeling for Large-Scale Car Accident Injury Estimation

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Background

Despite notable advancements in vehicle safety and road infrastructure design, road traffic crashes remain a leading cause of serious injuries and fatalities worldwide. Traditional crash analysis methods have relied heavily on historical data and deterministic models, offering valuable insights but often falling short in accurately capturing real-world crashes' complex dynamics and variability.

These limitations become increasingly evident with the growing integration of Advanced Driver Assistance Systems (ADAS) and other evolving vehicle safety technologies, which have introduced new patterns in crash severity and injury outcomes.

Furthermore, as crash rates decline in many regions due to improved safety measures, the ability of existing models to identify high-risk scenarios and emerging safety issues becomes less effective.

More sophisticated, flexible, and interpretable tools are required to sustain progress in injury prevention and road safety, particularly those capable of leveraging large, diverse datasets and modeling new types of vehicle-occupant interactions.

Aim

This study aims to develop and demonstrate a hybrid modeling approach that combines the predictive power of Artificial Intelligence (AI) with the explanatory clarity of physics-based crash simulations. By integrating these two paradigms, we seek to create a comprehensive tool for estimating injury risk in motor vehicle crashes that is both scalable and interpretable.

The broader objective is to support evidence-based road safety strategies, providing researchers, designers, and policymakers with actionable insights into injury causation and prevention.

Method or methodological issues

This research is built upon the integration of extensive crash data sources, including the U.S. National Highway Traffic Safety Administration (NHTSA) database and over 15 years of real-world crash reconstructions. These datasets are used to train and validate a hybrid injury prediction model. The AI component of the model processes large-scale image and trajectory data to extract key crash features.

Techniques such as image-based damage classification, 3D occupant modeling, and machine learning-driven trajectory prediction enable rapid assessment across a variety of crash scenarios.

However, as standalone tools, such AI models are very good at generalizing to unseen scenarios, but often lack transparency. To address these limitations, the AI model is coupled with physics-based simulations, which model the dynamics of vehicle impacts and occupant biomechanics.

These simulations ground the AI predictions in physical principles, enhancing interpretability and reliability. A key methodological innovation involves the refinement of traditional injury risk curves, particularly the Maximum Abbreviated Injury Scale (MAIS), by incorporating factors such as occupant age, position, restraint use, and ADAS availability.

Results obtained or expected

Initial results demonstrate that the hybrid model substantially improves injury prediction accuracy, particularly for injuries classified as MAIS 2 and above. By dynamically combining physics and data-driven reasoning, the model can provide detailed, scenario-specific predictions while remaining interpretable.

One notable application is the rapid estimation of injury risk from post-accident images, eliminating the need for time-consuming crash reconstructions in certain cases. The model has also shown strong generalization across a range of impact types (frontal, side, rear), vehicle categories, and occupant demographics. These capabilities make it a powerful tool not only for academic research but also for practical applications in emergency response planning, infrastructure evaluation, and vehicle safety design.

Conclusions

This study presents a novel methodological contribution to road safety research by merging the generalization capabilities of AI with the explanatory strengths of physics-based modeling. The resulting hybrid framework addresses key limitations in existing injury estimation methods, offering a scalable and interpretable solution for injury risk assessment.

In the context of ICTCT's mission to advance evidence-based approaches to traffic safety, this research provides a practical and innovative tool that can support data-driven decision-making across multiple domains, from infrastructure design and vehicle engineering to crash management and public policy.

By enabling a deeper understanding of injury mechanisms and risk factors, this approach contributes to the overarching goal of creating a safer, more resilient transportation system.

47. The potential of self-reported accidents for better site-specific road safety work

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Introduction

Most countries' official statistics on road accidents are based on police-reported accidents and have a large dark figure, especially among vulnerable road users. This is a particular problem in site-specific road safety work by road authorities – often called hazardous road location work. Road accidents in Denmark are not only recorded by the police, but also by hospitals and insurance companies, where far more accidents are recorded than by the police. In Denmark, for example, 10 times as many injuries after road crashes are registered at hospitals as with the police. The problem with hospital registrations, however, is that very little information is recorded about the individual accident and, for example, not the geographical location of the accident. This makes hospital registrations difficult to use in site-specific road safety work. But what about asking the injured parties themselves to talk about their accident? The Traffic Research Group has worked with this method in several research projects.

Method

We have developed a web-based tool for self-reporting road accidents. With this tool, accident victims can report where the accident took place and what happened, e.g. mode of transport, whether there was a second party, how the person was injured, contributing accident factors and what injuries the person sustained. To specify accident location we ask accident victims to mark on a map exactly where the accident took place. This is done through a specially developed map module where you can not only put a dot to indicate where the accident took place but also place arrows to indicate the route of you and any other party. The figure above shows an example. Data can be viewed in a display. Data are connected to an analysis tool for road authorities to analyse the reported accidents.

Results

The method has been used in a project where road accident involved customers of two Danish insurance companies, for a year were encouraged to self-report their accident. The project documented that the number of accidents on a national scale may be as high as 5,000 accidents per year per million inhabitants.

The method is also used in an ongoing project where a digital letter is sent every month to all patients treated at three hospitals in the Region of Northern Denmark via the patient's CPR number, encouraging them to self-report their accident using the web tool.

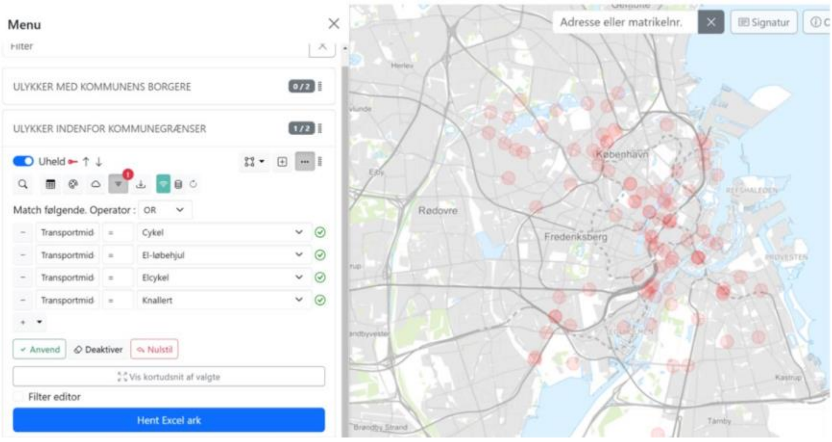
This project has been running since 1 August 2024 and by October 2025 we will have one year of results, but we can already see that 20% of the injured parties report their accident. This way of reporting results in around 3 times as many accidents as the police reports. A preliminary analysis of the response’s documents that in particular many bicycle accidents and falls involving pedestrians are registered. This contrasts with the accident picture based on police accident reports, where most accidents registered involve cars for the same period.

In the presentation, results from both projects will be presented and compared with police data, and the quality of both self-reported data and police data will be discussed based on interviews with injured parties, where their self-reported data will be compared with information given during the interview.

The road authorities’ experiences with the developed display and analysis tools as an aid to site-specific road safety work will also be discussed. The image below shows the analysis and presentation tool applied to data collected in the insurance project. The image shows one year of reported insurance accidents in the municipality of Copenhagen to the two insurance companies involving bicycles, scooters, e-bikes and mopeds.

Conclusion

The two projects show that accident victims are happy to report their road accidents, and that this information is extremely useful for road authorities, especially in site-specific road safety work.



48. Comparison of measurement models for acceptance of the driver monitoring systems (DMS)

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Background

Driver monitoring systems (DMS) offer substantial safety benefits for drivers, passengers, and traffic safety. With recent policy changes and technological advancements, all new vehicles are likely to be equipped with these technologies, making it important to understand the factors affecting users' acceptance of DMS. However, recent research (Chu et al., 2023; Smyth et al., 2021) has identified substantial variations in public attitudes, alongside significant concerns that warrant attention.

In studies examining the acceptance of new technologies, there is an ongoing debate regarding whether acceptance should be conceptualised as a single latent factor or as comprising multiple components (e.g., Aasvik et al., 2024; de Winter & Nordhoff, 2022). Although this issue has been explored in the context of automated vehicle systems, the acceptance of DMS technologies has not been investigated from this perspective.

Aim

In this study, we investigated the acceptance of driver monitoring systems among 9025 drivers across nine countries (i.e., Germany, Spain, France, Japan, Poland, Sweden, the United Kingdom, the United States, and China). The objective of this research is to examine various models conceptualising the acceptance of DMS and association of the constructs with the behavioural intention to utilise DMS in the near future.

Method

An online survey was conducted as part of the Hi-Drive project, which focuses on drivers' perceptions of automated driving systems and driving monitoring systems. The survey comprised multiple sections and took approximately eight minutes to complete. This paper will report only on the section concerning DMS acceptance.

We assessed the acceptance of DMS through a questionnaire that evaluated performance expectancy, perceived ease of use, trust, concerns regarding data collection, concerns about secondary use, perceived insecurity, and behavioural intention. This questionnaire was adapted from previous relevant studies (Smyth et al., 2021; Ghazizadeh et al., 2012; Chu et al., 2023).

To investigate the structural components of DMS acceptance, we compared four models: a single-factor model (model 1: acceptance), an oblique lower-order model with six correlated factors (model 2), a two high-order factors model (model 3: acceptance and concerns), and an oblique lower-order model with two factors (model 4: acceptance and concerns). We employed a series of structural equation modelling analyses to examine these model structures. Subsequently, we conducted a mixed-effects model to explore the relationships between the constructs and the behavioural intention to use DMS. A random coefficient for country variable was added to the model. Results were interpreted at the significance value of $p < .001$.

Results

Based on the model comparisons (Table 1), Model 2, characterised as an oblique lower-order model with six correlated factors, emerged as the most effective model.

Table 1. Fit indices for the four models.

	df	χ^2	CFI (robust)	TLI (robust)	SRMR (robust)	RMSEA (robust)
Model 1	119	61732.633	0.479	0.405	0.210	0.228
Model 2	104	1051.748	0.994	0.993	0.013	0.025
Model 3	92	2426.029	0.991	0.989	0.023	0.031
Model 4	118	3178.303	0.985	0.983	0.025	0.038

According to the mixed-effects model (Table 2), performance expectancy, perceived ease of use, and trust exhibited a positive relationship with behavioural intention, whereas age and concerns regarding data collection demonstrated a negative association.

Table 2. Fixed effects parameter estimates

	F	Estimate	SE	*t*	*p*
Gender (0: Man; 1: Woman)	0.292	-0.006	0.010	-0.540	0.589
Age	10.309	-0.001	0.000	-3.211	0.001
Performance expectancy	1895.146	0.420	0.010	43.533	<.001
Perceived ease of use	261.287	0.174	0.011	16.164	<.001
Trust	1865.059	0.406	0.009	43.186	<.001
Collection concerns	17.991	-0.043	0.010	-4.242	<.001
Secondary use concerns	0.142	-0.004	0.010	-0.377	0.706
Perceived insecurity	4.104	0.021	0.011	2.026	0.043

Conclusions

In this study, we examined the construct structure of factors associated with the acceptance of DMS and their relationship with behavioural intention. Consistent with research on the acceptance of shared fully automated vehicles (Aasvik et al., 2024), our findings support the multi-dimensional model of acceptance for driver monitoring systems. The findings further indicated distinct relationships between performance expectancy, perceived ease of use, trust, and collection concerns with respect to behavioural intention. Specifically, collection concerns were negatively associated with behavioural intention, whereas the other factors demonstrated positive associations.

The study is subject to certain limitations due to its reliance on self-reported online surveys and its restricted capacity for causal inference due to the use of cross-sectional data. In conclusion, the findings suggest that the acceptance of DMS is a multi-dimensional construct. It is imperative for research, industry, and policy to consider these diverse elements to enhance the adoption of DMS technologies among the general public.

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49.How Safe Are Zebra Crossings for Pedestrians and Cyclists? A Surrogate Safety Study of Two Urban Sites in Germany

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BACKGROUND

While zebra crossings are intended to provide safe crossing opportunities for pedestrians, actual safety levels can vary significantly depending on infrastructural design and surrounding traffic conditions. Vulnerable road users (VRUs) such as pedestrians depend on the consideration of drivers to assert their right of way – but are often denied it in practice. Since many traffic conflicts do not result in actual collisions, traditional crash-based safety assessments fail to capture the full picture of everyday risk. Surrogate measures of safety (SMoS), such as Time-to-Collision (TTC), offer a more detailed understanding of these interactions.

AIM

This study investigates how differences in road infrastructure and speed environment affect pedestrian and cyclist priority and interaction dynamics at zebra crossings. The goal is to identify whether design features such as speed limits, bottlenecks, and central refuge islands influence crossing behaviour, priority, and SMoS outcomes. Additionally, the study explores (i) how cyclists approach zebra crossings – whether they dismount and walk or remain mounted – and which strategy yields better safety and efficiency outcomes; and (ii) how pedestrians interact with cyclists who use the road and pass through zebra crossings, with a focus on cyclist compliance (e.g., yielding vs. swerving behaviour).

METHODS

Trajectory data were collected via a traffic observation system of DLR's Application Platform for Intelligent Mobility (AIM), consisting of a trailer-based pole with stereo camera systems at two zebra crossings in Braunschweig, Germany. The videos were recorded at 11 Hz and processed using an object detection and tracking algorithm to classify road users and extract two-dimensional positional data, from which velocity and acceleration were derived:

- Crossing A: Located in a 30 km/h zone with a physical bottleneck and low traffic volume (10 days with 24 hours each)
- Crossing B: Located in a 50 km/h zone with a central refuge island and high traffic volume (2 days with 10 hours each)

Potential pedestrian-vehicle, cyclist-vehicle and pedestrian-cyclist interactions were identified using Post-Encroachment Time (PET < 5 seconds) as the primary SMoS. The sequence of crossing was determined algorithmically by comparing the arrival times of road users at a predefined interaction-point near the crossing. Cyclist behaviour (mounted vs. dismounted) and yielding or avoidance manoeuvres in pedestrian-cyclist encounters were also extracted from the trajectory data and crosschecked by video annotation.

RESULTS

Preliminary analysis shows that pedestrians crossed first in 74% of cases (N = 110) at the 30 km/h bottleneck location, compared to only 59% at the 50 km/h site (N = 525), indicating a stronger assertion of pedestrian priority in lower-speed/bottleneck environments. When the interaction partner was a cyclist rather than a vehicle, however, the picture changed: at Crossing A, pedestrians were given priority in only 49% of cases (N = 110). This suggests that cyclists – compared to cars – more frequently pass through without yielding, often swerving around pedestrians instead of stopping – leading to closer and potentially hazardous interactions. While these encounters are often cooperative, the lack of clear yielding behaviour may reduce predictability and perceived safety for pedestrians. Ongoing work will explore whether mounted vs. dismounted cyclist behaviour influences these outcomes and how SMoS (e.g., TTC) describe the interaction dynamics and criticality.

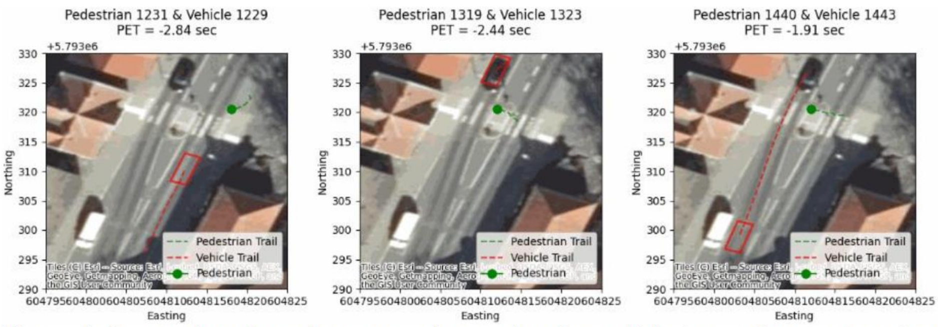

Figure 1: Screenshots from three exemplary pedestrian-vehicle interactions at Crossing B

CONCLUSIONS

Initial findings suggest that lower speed limits and bottleneck designs may better support pedestrian priority and safety. Cyclists, in contrast, are less often granted the right of way, which reflects their legal status at zebra crossings when riding. These insights point towards the need for infrastructure and policy measures that better accommodate the nuanced dynamics between different VRUs, particularly in mixed crossing environments. Ongoing work aims to further investigate how specific design elements and road user strategies (e.g., dismounting cyclists) contribute to safer and more efficient multimodal interactions.

50. Drowsy driving prediction based on biometric and dynamic driving parameters

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Introduction

The prevalence of human errors remains the main threat for road safety, contributing somehow to 95% of crashes. In this way, driver monitoring systems (DMS) have been promoted as a way to increase vehicle safety, aligned with the Vision Zero strategy of decreasing the number of serious injuries and deaths by halve, until 2030, and achieving zero deaths by 2050; specifically, "safe vehicles" is one the pillars of the Safe System Approach. In parallel, the quest for fully autonomous vehicles rests on the ability to drive without human intervention. But until that is possible, both advanced driving assistance systems (ADAS) and DMS will be further developed and integrated to assist drivers in the driving task and to monitor them during manual and automated driving, detecting risky behaviours and offering visual and audio warnings.

Drowsy driving, defined as the operation of a motor vehicle under impaired conditions such as sleepiness or fatigue, is one of the main causes of crashes. It especially affects specific groups of drivers (e.g., young and professional) and is associated with monotonous road environments and certain periods of the circadian circle (e.g., after lunch or during night time). Although drowsiness detection has been widely studied, the prediction of this phenomenon is still an evolving subject, as it is the performance of the models and the balance between identifying all the relevant occurrences without incurring in excessive warnings that reduce compliance.

The main objective of this research is to detect the first stages of drowsiness while driving, in order to be able to accurately and timely predict the occurrence of critical drowsiness levels from which the probability of crashing increases significantly. This approach aims to provide the driver with warnings and correct information about the current ability to drive given his state, and also with a prediction of when a critical drowsiness threshold can manifest.

Experimental setting

The data was collected in the light vehicle driver simulator of the University of Porto. Simulators are especially suitable for drowsy driving research, as drowsiness may be stimulated without incurring in safety risks. Each experiment lasted for 70-90 minutes in a monotonous highway environment. In total, 100 participants, balanced between age and gender groups, participated in the experiments. The data collected in the simulator included vehicle dynamics (e.g., speed, acceleration/deceleration, lane positioning), steering and pedal inputs, biometric data (eye tracking and heart rate monitoring), and self-reported drowsiness level based on the Karolinska Sleepiness Scale (KSS). The KSS was collected every five minutes in a touchscreen and its use as ground truth has been thoroughly discussed in the literature, since objectively defining a driver's tiredness level without any reference can be misleading.

Methods

An extensive literature review to understand the most important features contributing to drowsiness has been carried out beforehand. Therefore, the first step of this research is to perform data processing and exploration, leveraging features from previous research and combining them in a suitable way. The most important features, or a combination of them, must be normalized and integrated into a drowsiness index using dimension reduction techniques. The index should encompass different information that correlates with an individual's drowsiness level and his/her fitness-to-drive. To set ground for the predictions, a critical threshold to classify a pre-drowsy state will be established, based on the KSS.

Time series forecasting will be employed to predict the drowsiness index variability across time and implications to the driver. Artificial intelligence models work by training on data and finding meaningful patterns and trends that lead to the classification of each instance into a particular category. In this case, where the role of sequential information is key to predict risky behaviours, the literature shows that Recurrent Neural Networks (RNN), and specifically, Long Short-Term Memory (LSTM) models and subsequent variations are the most promising due to their high capability and performance in capturing essential temporal patterns, joined by the ability to learn long-term dependencies. Different algorithms could be combined to improve prediction accuracy, provided that the final model is simple enough to ensure low inference times. To prevent issues such as overfitting or bad generalization due to unseen or poor conditions, data augmentation techniques will be considered.

Expected results

This study is being developed under an ongoing MSc thesis (to be completed in July). In the end, the developed model should be able to accurately predict drowsiness according to the driver's behaviour, state and characteristics. The innovative aspect of this research is the use of sequential and combined features in order to improve prediction on the critical drowsiness states in real time, providing the user with more accurate assessments about his/her present and future state, increasing the compliance with drowsiness warnings.

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51. Towards Safer Roads: A Data-Driven Ground-Aerial Fusion Approach for Enhanced Ego-Localization

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Accurate localization is crucial for autonomous systems to ensure safe and effective operation on modern roadways. While consumer-grade GPS sensors are widely used, they often fall short due to limitations imposed by satellite geometry, atmospheric disturbances, and multipath interference. These factors can result in errors of several meters, a discrepancy that is unacceptable for the centimeter-level accuracy required for autonomous driving. Inaccurate positioning not only affects navigation, but also increases the risk of collisions, thus undermining road safety.

To overcome these challenges, autonomous vehicles are now integrating a variety of sensors such as inertial measurement units, LiDAR, radar, and computer vision to provide a more reliable picture of the environment. These systems combine data streams to improve overall accuracy and resilience to individual sensor failures. Filtering algorithms, including Kalman and particle filters, have been instrumental in refining localization estimates. Computer vision techniques such as visual odometry further mitigate scenarios. More recently, deep learning approaches have emerged as powerful tools capable of learning complex mappings between sensor inputs and precise location outputs. These advances not only enhance autonomous navigation, but also contribute to road safety by reducing the risk of accidents and promoting smoother interactions among all road users.

As research continues to evolve, the development of comprehensive, high-accuracy datasets remains critical to training adaptive models that can thrive in diverse driving conditions. Existing simulators and data collection platforms often lack the centimeter-level accuracy, environmental diversity, and temporal dynamics required to train robust models. Improving these datasets is also essential to fully exploit emerging methods and ultimately pave the way for safer, more reliable autonomous navigation systems.

In this work, we develop a robust solution for ego-localization. We propose to create a carefully curated dataset that overcomes current shortcomings by providing centimeter-level GPS annotations, diverse scenarios, and rich temporal dynamics. In addition, we design an innovative architecture that fuses ground-view images with rough GPS localization data to accurately predict true positions.

To generate the ego-localization dataset, we use the CARLA simulator. We equip each simulated vehicle with six RGB cameras, a Bird's Eye View (BEV) camera for semantic segmentation, and a GPS sensor. Vehicle data is captured from multiple perspectives and locations. In addition, we collect aerial imagery by moving a camera with a GPS sensor through different environments while obtaining fine-grained semantic segmentation annotations. Our localization correction approach consists of three modules: BEV mapping, aerial image segmentation, and localization error estimation.

A segmentation BEV map of the vehicle's environment is generated using six images from the vehicle's cameras. An aerial image centered on the vehicle's GPS position is processed to create an aerial segmentation map. The two segmentation maps are then matched to estimate the true location of the vehicle by determining the center of the BEV map on the aerial segmentation map. Assuming accurate georegistration of the aerial images, the geo-coordinates of the estimated point represent the true vehicle position. Finally, the distance between this estimated point and the GPS-derived center of the aerial image quantifies the localization error.

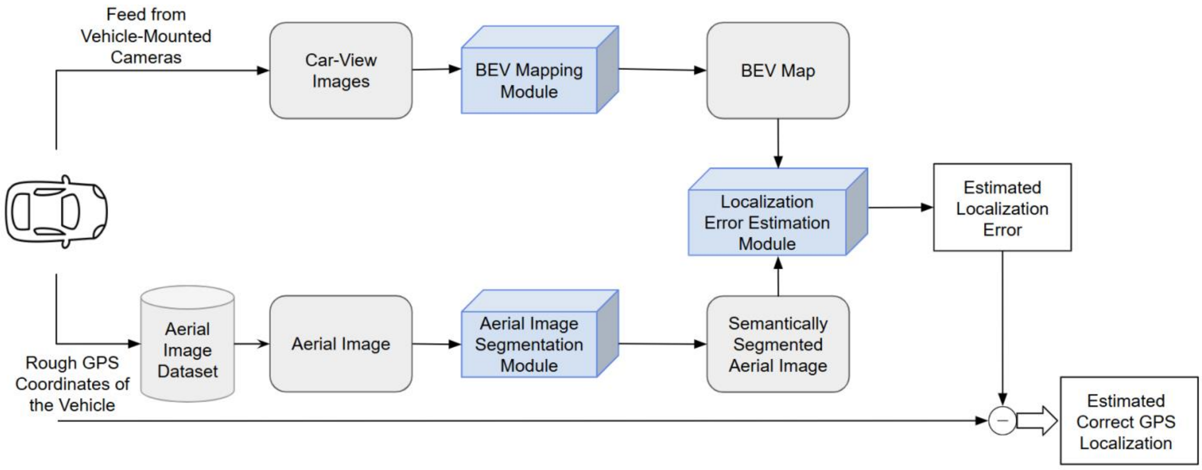

Figure 1 Overview of our localization correction approach

We expect the proposed approach to achieve high sub-meter localization accuracy under varied simulated urban conditions, providing a robust benchmark for evaluating safety-critical localization tasks. Initial experiments will be conducted on the synthetic dataset to validate performance across diverse environments. Subsequently, real-world samples will assess the model's ability to generalize beyond simulation. This sim-to-real evaluation will determine how effectively the system supports accurate and reliable localization under real driving conditions—a prerequisite for safer navigation and reduced collision risks.

This work presents a novel localization correction approach that fuses ground-view and aerial data to significantly improve positioning accuracy. By reducing GPS-related errors, especially in urban environments, the system enhances the reliability of autonomous navigation—a key enabler of traffic safety.

52. Pedestrian Interaction with Multiple Automated Vehicles: A Real-World Study on light-based eHMIs

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Background

Highly automated vehicles (HAVs) hold the promise of safer and more efficient road traffic. However, the absence of a human driver removes traditional communication cues such as eye contact and gestures, leaving pedestrians to rely solely on vehicle kinematics to interpret vehicle intent. Especially at low speeds, these implicit signals can be ambiguous, increasing the likelihood of misunderstandings. This challenge becomes even more pronounced in situations where pedestrians must interact safely with multiple HAVs simultaneously. Prior simulator studies suggest that external human-machine interfaces (eHMIs), particularly LED-based light signals, can help clarify an automated vehicle's intent by offering explicit cues to pedestrians.

Aim

This study aims, first, to validate and extend simulator-based findings into a real-world context by assessing the effectiveness of an LED-based eHMI in supporting pedestrian decision-making. Second, it specifically investigates whether such eHMIs improve subjective measures and behavioural responses during road-crossing scenarios involving multiple HAVs.

Method: A controlled test-track experiment was conducted using two automated research vehicles equipped with LED-based eHMIs. Fifty participants took the role of pedestrians and were asked to decide when to cross a street while two HAVs approached from opposite directions. The experiment manipulated two factors: (1) eHMI presence (no eHMI vs. LED light band) and (2) yielding behavior of the automated vehicles (left HAV, right HAV, both, or neither vehicle yielding). Key dependent measures included crossing initiation time, subjective safety ratings, and perceived usefulness of the eHMI.

Results

The presence of the LED eHMI significantly reduced crossing initiation times, indicating quicker decision-making. Participants also reported higher levels of perceived safety and greater confidence when the eHMI was active. The eHMI effectively complemented the vehicles' kinematics by providing explicit signals of intent, thereby reducing confusion, especially in more complex, multivehicle interactions. Overall, the LED-based communication strategy improved the predictability of pedestrian-HAV interaction.

Conclusion

This study demonstrates the feasibility and value of eHMIs in real-world environments. By extending prior simulator findings to a realistic setting with real automated vehicles in an urban environment, the results highlight the importance of combining explicit communication via eHMIs with the implicit cues of vehicle motion. These findings support the scalability and robustness of LED-based eHMI strategies, reinforcing their potential to enhance safety and understandability regarding future automated mixed road traffic systems.

53. Proactive identification of high-risk locations in road networks using crowdsourced reports and vehicle kinematic data

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Introduction

Globally, with sustainable transportation on the rise, walking and cycling are increasingly promoted, yet ensuring the safety of Vulnerable Road Users (VRU) remains challenging due to road infrastructures primarily designed for motorized traffic. For example, in Germany, the number of cycling crashes with personal injury has increased 19.5 % over the last ten years. Traditional crash-based safety analyses suffer from the low incidence and underreporting of incidents, limiting their effectiveness in timely identifying critical locations.

To overcome these limitations, Surrogate Safety Measures (SSM) that do not rely on crash data have been developed. Advances in vehicle telematics have enabled the analysis of vehicle kinematics; however, validating these measures remains challenging due to underreported crashes and mismatches in observation periods, particularly for VRU incidents. As another complementary method, crowdsourcing allows road users to report unrecorded crashes and infrastructure deficiencies via online platforms, offering valuable insights. However, the objectivity and reliability of this data can be questioned as each individual user report underlies an inherent subjective bias.

In light of these challenges, this study investigates the relationship between the two novel data sources, namely, safety-critical driving manoeuvres from motor vehicles and crowdsourced user reports, and actual safety deficits in road infrastructure. This approach aims to support proactive safety assessments and more effective and resource-efficient safety interventions for VRU.

Methodology

User reports on dangerous locations were collected via an online platform featuring an interactive map (www.gefahrenstellen.de). Users could submit danger spots by selecting predefined categories modelled after German crash report form and had the option to endorse existing reports created by other users.

Anonymized kinematic data were obtained from the telematics solution of Germany's largest motor insurance company, HUK-COBURG, to capture hard braking events, which were defined as decelerations of at least -4.5 m/s². In addition, crash data were sourced from the German Federal Statistical Office. Annual average daily trips provided by HUK-COBURG were used to normalise incident numbers for traffic volume.

To validate the relationship between the incidences and actual safety deficits, on-site audits were conducted at randomly chosen locations across two major German cities. Using a deficit checklist adapted from German road safety audits, 50 safety deficits across 10 categories were evaluated. Each location was classified as "risk observed" or "risk not observed" (with "uncertain" cases omitted). In total, 160 locations in Aachen and 74 in Bonn were audited. The relationship to the SSM and crash data was analysed using logistic regression, with the safety rating being the dependent variable. Model performance was evaluated through Receiver Operating Characteristic (ROC) curve and the Matthews Correlation Coefficient to determine the optimal threshold for classifying locations as high risk.

Results

The final regression model successfully predicted locations with objective safety deficits: Increases in the number of user reports at one location, the number of endorsements of user-reported danger spots, and clusters of hard-braking events significantly raised the probability of observing safety deficits during on-site audits. In both Aachen and Bonn, the model exhibited robust discriminatory power, with an ROC-AUC of around 0.92 and 0.72 respectively.

However, the results show that the majority of predicted high-risk locations did not yet show conspicuously high crash rates. This suggests that the model can detect locations with a high potential for unreported or future crashes. Furthermore, although official crash records largely involve car drivers, most user reports emphasise risks faced by cyclists (82 %) and pedestrians (44%). In line with previous studies, this discrepancy also indicates that crashes involving VRU are likely underreported in official crash statistics.

Discussion and conclusions

This study highlights the potential of combining crowdsourced user reports with vehicle kinematic data for proactive road safety assessments. This proactive approach not only uncovers areas with unreported or future crash potential but also provides timely feedback on the effectiveness of safety interventions. Although resource constraints limited the number of audited sites and the kinematic data only covered passenger cars without detailed deceleration profiles, the results underscore the potential application of this methodology. Future research within the research project HarMobi will further explore the relationships between SSM obtained through kinematic data and road infrastructure by obtaining critical manoeuvres from other road users (bicycles, e-scooters, trucks, delivery vans).

54. Surrogate indicators for bicycle falls

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Background

Single bicycle accidents represent a significant traffic safety issue in Sweden. Studies indicate that over 70% of all bicyclist injuries occur in single-bicycle incidents, where the cyclist falls or collides with an obstacle without involving other vehicles. These accidents often lead to severe injuries. However, we lack an effective method to proactively evaluate the safety of bicycle infrastructure in terms of single accidents risks.

Aim

The aim of this study is to establish a SMoS framework for analyzing the single bicycle accidents caused by instability. The framework consists of the identification of SMoS indicator for bicycle instability and incorporate extreme value theory to proactively evaluate bicycle safety.

Methodological issues

Extreme value theory (EVT) has received much attention in its application on surrogate measures of safety (SMoS) to estimate expected accident frequency. Its basic idea is that by observing events of moderate extremity (e.g. near-misses), it is possible to estimate the frequency of the truly extreme events (accidents). EVT has been applied on single car accidents (e.g. drive-off-road scenarios), but never on bicyclists.

There are two major challenges: (1) bicycle stability is a complex phenomenon, and there is no one single indicator that can reflect it all—a combination of indicators is necessary; (2) the boundary conditions for a fall become 'dynamic', since it is a certain combination of parameters, and not a single threshold for each of them, that leads to a fall. In this study we explore the potential for estimating bicycle falls frequency (which are a significant sub-set of the single bicycle accidents) using such an approach. First, we are developing a theoretical model for bicycle stability based on the literature review and physics, then we will extract the indicator from naturalistic video footage and apply extreme value theory to calculate the risk.

The cycling trajectory data have been collected by Viscando AB, using stereo vision algorithms for data extraction. The data was collected in two setups: (i) in a controlled experiment where cyclists were asked to pass several 'kissing gates' with different geometric parameters (overlap, passing width, etc.); (ii) naturalistic observations in real traffic at several locations with 'challenging' geometry for cyclists (e.g. combination of a curve, downhill, and sudden reduction of the paths width).

Lastly, the approach will be validated by repeating the analysis on an experimental dataset, where subjective feedback from the participants will be used to compare with the risk calculated from extreme value theory. Finally, we attempt to apply the EVT on our dataset to estimate the feasibility of the approach.

Results

- A list of SMoS indicators for single bicycle falls
- The distributions of these indicators and their safety implications according to extreme value theory
- Comparison between the measured risk level and the perceived risk level.

Conclusion

We expect the result to answer the following research question:

1. Is it possible to find a simple set of indicators, extractable through unobtrusive data collection methods such as video analysis, that can reliably distinguish between stable/unstably bicycle conditions, given various fall scenarios (side skidding, turnover, etc.)
2. Explore whether EVT modelling is feasible when being applied on a dataset with no actual falls observed to estimate the fall frequency.

55.Navigating Urban Stressors: Using VR to Assess Cognitive Load and Visual Attention in Cargo Bike Riding

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Introduction

As cities increasingly adopt cargo bikes as a sustainable alternative for urban transportation, new challenges emerge in understanding their interaction with complex urban environments. While cargo bikes reduce emissions and traffic congestion, their unique physical characteristics—such as larger form factor and heavier weight—present new risks that differ from conventional bicycles. Despite their rise in popularity, there remains limited empirical research on how external environmental stressors, particularly traffic density and adverse weather conditions, impact cognitive load, visual attention, and perceived safety during cargo bike usage.

This study researches the use of Virtual Reality (VR) as a tool for assessing cognitive and physiological responses to urban stressors during cargo bike riding. Specifically, it investigates whether variations in traffic density and weather conditions result in significant changes in cognitive load, gaze behaviour, and subjective safety perception. Similar methods have been used when studying regular bikes and we aim to find out whether such techniques can be adapted in cargo bike research.

Research methodology

A high-fidelity VR environment of the city of Weimar, Germany was created at a 1:1 scale using Unity. 12 participants were instructed to follow a 2.2 km long route with left and right turns, traffic lights and varying types of bike infrastructure (no bike lane, bike lane, protected bike lane). The environment incorporated immersive features such as traffic, buildings, pedestrians, rain, lighting, and ambient city sounds. As input method a real Long John cargo bike was mounted on a bike trainer. Velocity and steering were captured with a custom sensor setup and controlled a physics-based 3D model of a cargo bike.

We employed a 2x2 repeated measures design with the independent variables „Visual Condition" (clear/rainy) and „Navigational Complexity" (off-peak / peak traffic), resulting in a total of four scenarios. The scenarios were completed by all participants in a counterbalanced order. Data collection included eye-based metrics (pupil diameter, gaze entropy, saccade frequency), self-reported cognitive load via the simulation task load index (SIM-TLX) after each scenario, and a final survey assessing perceived realism, safety, and user experience. Pre-processing involved establishing baselines and calculating derived gaze metrics to quantify attention and workload.

Results

Scenarios with higher traffic density and adverse weather conditions both increased SIM-TLX scores. Eye-tracking analysis revealed reduced saccade frequency and changes in gaze entropy in these conditions. Participant feedback showed that while the simulation evoked moderate stress in complex conditions, perceived danger was reduced due to the absence of collision dynamics.

Table 1: Selected results of the four experimental scenarios.

	Clear/Off-peak	Rainy/Off-peak	Clear/Peak	Rainy/Peak
SIM-TLX	29.72%	33.47%	39.72%	37.64%
Situational Stress	25.00%	23.61%	33.33%	36.11%
Saccade Frequency	62.93%	61.03%	60.02%	58.71%
No. of Gaze Points	47,252.83	47,183.67	47,657.68	47,455.50

Discussion and conclusions

The preliminary findings indicate that cognitive load increases in more challenging riding scenarios, reflected by the higher SIM-TLX scores. The corresponding changes in gaze entropy and the decrease in saccade frequency suggest a more focused or strained visual attention.

The use of a real cargo bike helped ensure spatial realism in VR, though the study did not compare effects to riding a standard bike. Instead, the results show that the influence of environmental variables on behaviour and perception can also be measured for cargo bike riders in controlled VR environments. This study confirms that immersive VR is a useful research tool for replicating and analysing environmental stressors. The integration of real-time eye-tracking and subjective workload measures enables a multi-dimensional analysis of cognitive and visual responses to dynamic urban conditions. Though the absence of physical collision feedback and limitations in sensory realism remain challenges, the approach can inform infrastructure planning, policy development, and future research into sustainable transportation systems, specific to cargo bikes.

By demonstrating that key variables such as traffic density and weather conditions measurably affect rider responses, the study lays a foundation for using VR in ongoing cargo bike research. Future goals include the validation of the set-up in a combined lab and field test, comparisons to standard bikes and researching the influence of specific cargo bike dynamics.

56.Two directions, one goal: enhance cycling in one-way streets

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Cycling has become increasingly popular in many urban areas in recent years and is an important form of mobility. Particularly in densely populated cities, traffic planning design must ensure the safety of both, cyclists and other road users. One such traffic planning measure is the introduction of an additional traffic sign, which allows cyclists to ride in the opposite direction in one-way streets in Germany, in 1997. This measure aims to improve urban cycling infrastructure and increase accessibility for cyclists. However, it also causes new interaction and conflict situations in these streets. Since the implementation of two-way cycling in oneway streets, numerous scientific studies have examined accident data and road user surveys.

However, this study is the first to investigate cyclists' riding and gaze behavior in contexts of one-way streets open to cycle in both directions. To identify and mitigate risk situations, it is essential to understand how perception and interaction patterns between motorized and nonmotorized road users change in these environments, and what safety risks may arise. In particular, the visual attention and related decision-making behavior of cyclists and drivers in one-way streets that are open to two-way cycle traffic have not yet been sufficiently examined. This challenge is compounded by the growing demand for space due to increasingly large vehicles such as SUVs, cargo bikes, and bicycles with trailers - while the available space in one-way streets remains limited.

This study systematically analyzes the gaze behavior and situational awareness of road users in one-way streets open to two-way cycle traffic, in order to identify potential safety deficits and develop measures to improve the safety of vulnerable road users (VRUs). Central questions include how critical situations influence visual attention, what factors contribute to uncertainty or conflict, and how road users behave and respond in real encounter situations.

The methodology is divided into two phases. In the first phase, an online survey was conducted with n = 183 exploitable participants, including cyclists, drivers, and individuals who use both modes of transport. The survey recorded subjective experiences, perceptions, and safety assessments related to two-way cycling in one-way streets. It also covered typical traffic situations, previous conflicts, rule comprehension, and suggestions for improving safety. Initial results show significant differences in awareness: nearly half of all surveyed drivers were unaware that they were using one-way streets open to two-way bicycle traffic. In contrast, cyclists were considerably more aware of the regulatory situation. Both groups reported a low sense of safety on such roads, particularly in encounter situations involving oncoming cyclists and vehicles. Commonly cited concerns include narrow carriageways, parked cars that restrict visibility and movement, and the lack of clear spatial separation between cyclists and motor vehicles. In the second phase, drivers' behavior is examined in these simulated environments under controlled conditions in a driving simulator. The development of realistic and representative scenarios, which are implemented in a driving simulator using specialized simulation software is based on the survey results. Eye-tracking glasses record participants' gaze patterns to analyze how visual attention is distributed in critical scenarios - such as at bottlenecks, near parked vehicles, or at intersections when encountering cyclists. The analysis focuses on attention distribution, reaction times, and the duration and frequency of fixations on predefined Areas of Interest (AOIs). At the same time, behavioral data - such as speed, steering angle, and braking - are recorded to provide a comprehensive assessment of driving behaviour together with visual processing. This approach also allows for comparisons between subjective perceptions and objectively measured behavior patterns. Preliminary expectations suggest a distinct shift in attention and perception in one-way streets with two-way cycling compared to conventional one-way streets.

The aim of this study is to use these insights to develop targeted strategies and recommendations for urban traffic planning. These will focus on improving the safety of vulnerable road users and optimizing the design of urban infrastructure to better accommodate the realities of shared traffic spaces.

57. Intelligent traffic detection for pedestrian-sensitive traffic light control and other safety applications

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Improving road safety and optimizing the traffic flow for all road users are major challenges for the future transportation system. In this context DLR and VITRONIC have entered into a cooperation. The starting point were VITRONICs enforcement systems, which have been contributing to safety for many years, e.g. by detecting speed and red-light violations at traffic lights [1]. The basic idea is that this technology can be expanded and used in parallel for additional functions. With the Local Traffic Safety Analyzer (LTSA), an initial safety-focused traffic control and information system was jointly developed and prototypically implemented at a test intersection in the city of Potsdam [2]. The system is based on a sensor platform that detects traffic objects. The data are processed in real time using AI approaches to interpret the traffic situation. The traffic objects are classified and their trajectories determined. With these data, the LTSA serves two use cases: It detects safety-critical situations and broadcasts warning messages via V2X communication. Furthermore, it enables adaptive signal control by providing the data to the local traffic light system (TLS). The approach is designed to be modular and can be expanded to include additional use cases, particularly those relevant to safety (e.g. long-term tracking of dangerous spots, providing data for traffic data platforms and traffic models, supporting automated and connected vehicles to determine operational designs (OD) or to accomplish operational design domains (ODD)).

This abstract focuses on the optimization of DLR's signal control modules for considering pedestrians automatically and adaptively at traffic lights (compared to the initial LTSA prototype). TLS are essentially safety and efficiency systems for intersections. They separate the traffic flows from each other to ensure safe crossing. Thus, a rule-compliant behaviour already offers a very high safety level. However, especially pedestrians do not always observe the "safe" signals, which can lead to a significant number of pedestrian accidents [3]. In this context, it is assumed that the inefficiency of traffic lights for pedestrians particularly triggers the incorrect behavior, as the signal controls are usually geared towards motor vehicle traffic. A pedestrian-sensitive signal control that adaptively integrates vehicles and pedestrians should improve efficiency for all road users. The aim is to achieve a more rule-compliant and less aggressive traffic behaviour, which indirectly increases safety. For this, DLR's modules determine relevant pedestrian parameters in real time from the recorded object data:

- whether and by how many pedestrians a signal group is requested
- the actual pedestrian waiting times
- whether a pedestrian crossing is currently being crossed and by how many pedestrians
- how long pedestrians are likely to need to reach or cross the pedestrian crossing

This opens up new functional possibilities in signal control with regard to pedestrians:

- automated and demand-based request (no manual actuation of request buttons needed)
- consideration of actually measured pedestrian waiting times instead of assumed values
- dynamic control of the green time depending on the actual approach or crossing time

In combination with a differentiated phase design, in order to be able to react more flexibly to the respective situation, various control strategies can be implemented. The DLR is striving for a multimodal optimum, where the traffic light controls the overall traffic flow in an aligned and safe manner. Therefore, different approaches were identified with regard to the new possibilities for pedestrian-sensitive signal control. For example:

- Switching to a phase without pedestrian signals, if all pedestrians have crossed or no pedestrian wants to cross the intersection.
- Pedestrians are given green directly after an automatically detected request or at the latest when they actually reach a maximum waiting time value.
- The tracked waiting time is used to decide the order of phases.
- Green times are extended as required for “latecomers”, a large number of and especially slower pedestrians.
- Switching to special pedestrian phases, especially if no other road users require green, e.g. pedestrian-all/diagonal-green.
- Conditionally compatible flows are divided into different phases, each is only switched when required (direct safety aspect).

Methodologically, a conceptual phase was carried out. On the basis of the initial LTSA prototype, objectives and expectations were refined and the system design was revised. The modules for data processing have already been developed and coupled with a SUMO simulation. Several control strategies are currently tested in this simulation. Afterwards the components will be integrated into the LTSA system at the test intersection and tested in real traffic. Regarding the mentioned assumption “safety by efficiency”, the analyses focus on efficiency parameters of traffic light control, e.g. waiting times and the number of stops. Depending on the availability, further traffic behavior and safety related data should also be evaluated (e.g. number of jaywalkers).

It is expected that particularly skipping the pedestrian signals when no pedestrians (or no longer) request them, although this sounds contradictory to the actual aim of promoting pedestrian traffic, has a positive effect on overall and also on pedestrian traffic. This generally allows other road users to cross more quickly and/or shortens the phase transitions. The remaining time can be used for other road users and pedestrians that annouce a need at this time or subsequently. At the conference, the optimized traffic light functions, the testbed implementation and initial test results will be presented in more detail.

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58. Transportation Utilization Patterns Among Youth Aged 10-18 and Their Parents During Routine Days and an Emergency Period: A Case Study of Haifa, Israel's Third-Largest City

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Background

Investment in public transport system (PTS) is essential for addressing the mobility needs of growing populations and ensuring safe, efficient transportation. This system reduces the risk of traffic-related injuries and fatalities, serving as a key strategy for improving road safety. During most of its existence, the state of Israel did not sufficiently develop the supply of PTS. As a result, a significant gap has been created between the level of service provided by PTS and that provided by road infrastructure. Haifa is the main city in the northern region of Israel and the third largest in the country. The main available mode of PTS in Haifa is the bus systems. To the best of our knowledge, no studies have been conducted examining transportation usage patterns among youth people in Haifa and their parents, nor addressing both routine periods and times of emergency.

The aims of this study were: 1) to describe the main modes of transportation used daily by youth and their parents in Haifa; 2) to assess the utilization of PTS among youth in their daily lives during routine days and the war (resulting from the 2023-2024 Israel-Hezbollah conflict) in Haifa; 3) to identify barriers to using PT among youth in Haifa.

Methods

The study was conducted in 2024-2025 using a survey distributed via social media, employing snowball sampling through social networks. A total of 163 Israeli parents of youth aged 10-18 living in Haifa completed an online self-report questionnaire. The study variables were presented as means (m), standard deviations(std.), and percentages. Chi-square tests were used to examine differences between independent proportions. Data analysis was performed using SPSS software (version 29), with statistical significance set at $p<0.05$.

Results

The 163 parents of youth aged 10-18 living in Haifa ranged in age from 32 to 60 years (m=46.3; std.=5.5) and were predominantly female (89.6%), married (82.2%), university graduates (85.9%), and employed/self-employed (96.3%). Almost all parents (97.5%) held a driver's license and owned at least one vehicle in their household. The most common daily mode of transportation for youth traveling to school was the bus (37.4%), followed by walking (17.8%) and being driven by their parents in a private car (15.3%). Notably, 14.7% of youth reported using a combination of transportation modes involving a private car (such as 'bus & car'), bringing the total proportion of car-based transportation to 30.0%. The primary mode of transportation for parents commuting to work was a private car (85.3%), with a notable gap to bus use (3.1%) and walking (2.5%).

Approximately 75% of youth used PTS, mainly buses, for traveling to leisure activities. During the war period, 43.6% of parents reported limiting their children's use of PTS. However, nearly all parents (95.1%) indicated they would allow their children to use PTS again after the war. No significant difference ($p>0.05$) was found between self-reported anxious and non-anxious parents regarding permission for their children to use PTS during routine days and the war.

Around half of the parents reported at least one barrier to bus use among their children. The most commonly reported barrier was fear of violent events due to the war (13.6%), followed by a lack of available buses in the residential area (5.6%) and fear of sexual harassment (3.7%).

Conclusions

Scientific evidence shows that using PTS can reduce road accidents and improve overall transportation safety. However, a significant portion of Israeli youth (around one-third) and their parents (about 85%) in Haifa rely on car-based transportation in their daily lives. Nearly half of the parents identified barriers to their children's use of buses. These findings highlight the need to improve the accessibility and availability of PTS, along with educating both youth and parents on its safety benefits to encourage greater usage. In the long term, parents can serve as rolemodels for their children, promoting the use of PTS over private cars. Almost all parents (about 95%) indicated that they would allow their children to resume using PTS after the war. Therefore, it appears that the impact of parental restrictions on their children's use of PTS during the war is expected to be short-term.

59. Width labels as Safety Performance Indicator for Cycle Tracks: a national study at Dutch urban cycle tracks

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Introduction

Each year, around 5,000 cyclists in the Netherlands sustain severe injuries in crashes without motor vehicles, most commonly in single-bicycle crashes such as falls or collisions between cyclists. The Dutch Strategic Road Safety Plan 2030 promotes a risk-based approach to road safety, encouraging road authorities to identify risks based on Safety Performance Indicators (SPIs) and to take preventative measures before crashes occur.

Design guidelines suggest that sufficient cycle track width is essential to reduce the risk of single-bicycle crashes such as riding off the pavement or colliding with another cyclist. This assumption is grounded in the idea that a cyclist's lateral position depends on available space. Previous studies have shown that cyclists maintain more distance from the verge and from oncoming cyclists on wider tracks.

To support road authorities with the risks-based approach, Fietsberaad developed a Width Label indicator to assess whether cycle tracks are sufficiently wide for the volume and direction (oneway or two-way) of bicycle traffic. This indicator includes six categories, ranging from A (sufficient width) to F (insufficient width). It could also serve as an SPI for cycle tracks.

However, there is a lack of crash-based research to support the hypothesis that sufficient width reduces the likelihood of cycle crashes. This study addresses this gap by investigating whether cycle tracks classified as insufficiently wide according to the Width Label indicator are associated with a higher likelihood of crashes not involving motor vehicles.

Research methodology

To support safety research on infrastructure, the National Road Traffic Data Portal (NDW) compiled a comprehensive dataset on Dutch cycle tracks by integrating multiple data sources. Cycle track width was derived from the Large-Scale Topography Registry; directionality (oneway or two-way) was identified using the Cyclists' Union route database; and cycling volumes were estimated by mapping all bicycle trips from national travel survey to this route database. This fusion of infrastructure data, travel behavior data, and spatial routing information enabled a detailed characterization of each cycle track section (defined as stretches between intersections). Width Labels were assigned to each section using the Fietsberaad method, which is based on cycle track width, one-way or two-way direction of cycle traffic, and cyclist volume during peak hours.

To test the hypothesis that insufficiently wide cycle tracks are linked to an increased likelihood of non-motor vehicle crashes, two types of crash data were used:

- Self-reported crashes, collected via panel members of research firm Kantar, supplemented by a survey of members of the Royal Dutch Touring Club (ANWB), which has over 5 million members.
- Police-reported crashes, obtained from the national crash database.

The analysis focused on urban areas, where cyclist volume estimates are most reliable due to higher numbers of cyclists and a greater share of utilitarian cycling. In contrast, recreational roundtrips with the same origin and destination could not be mapped to the network by the Cyclists' Union. A Negative Binomial regression model was used to assess the relationship between Width Labels and crashes without motor vehicles, controlling for the average daily cyclist volume per cycle track.

Results

The model based on self-reported crashes indicates that the likelihood of non-motor vehicle crashes increases for tracks labelled E or F. In contrast, the model using police-reported crashes suggests that crash likelihood already increases from label C onward. This second model also shows a larger risk increase for labels E and F compared to the self-reported crash model. Both models reveal a safety-in-numbers effect: the likelihood of bicycle crashes increases less than proportionally with higher cyclist volumes.

Conclusions and discussion

Cycle tracks classified as insufficiently wide based on the Width Label indicator are associated with a higher likelihood of crashes not involving motor vehicles. This supports the label's value for road authorities as a valid SPI for a risk-based road safety policy. Additionally, a safety-in-numbers effect is observed: higher cyclist volumes are related to a less-than-proportional increase in crash likelihood.

60. Enhancing traffic safety with thermal monocular 3D detection: Traffic conflict analysis through a digital shadow

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Introduction

Classical road safety research has concentrated on studying accidents, but there is growing interest in analyzing traffic conflicts and near-miss incidents. The increasing availability of big data and enhanced computational power have revolutionized various fields, based on big data traffic conflict analysis road safety research potentially is one of the next fields. This requests traffic sensors which build up accurate 3D traffic digital shadows. Traditional traffic monitoring systems often rely on optical cameras, stereo cameras, or LiDARs, which face challenges in adverse weather conditions and privacy concerns, as well as high costs. Thermal roadside cameras present a promising alternative, offering greater robustness in diverse conditions while ensuring privacy compliance. However, accurately detecting 3D object positions with monocular (thermal) cameras presents challenges due to ambiguity between 2D image coordinates and 3D world coordinates. This study focuses on leveraging monocular 3D detection with thermal imagery to create a 'digital shadow' for real-time traffic safety analysis.

Methodology

The system combines monocular 3D detection with thermal imagery and object tracking using a Kalman filter. The Kalman filter smooths noisy trajectory data, enhancing long-term tracking accuracy. To address the depth estimation challenge, the system employs a projection-based method that maps 2D image coordinates to 3D world coordinates, accounting for road surface and camera calibration. Additionally, object dimensions and orientations are estimated based on a neural network. This delivers a digital shadow of the traffic situation. Exemplary, based on a Post Encroachment Time (PET) prefiltering, near-miss situations are analyzed more detail in regard to minimum distance between objects to further filter for true near misses. Combining this the proposed system demonstrate the capabilities of the digital shadow for traffic conflict detection.

Results expected

Initial trials of the system have demonstrated its ability to detect near-misses with significant improvements over traditional 2D systems. The 3D representation reduces false positives by offering a more accurate observation of object behavior, particularly in complex traffic scenarios where 2D systems struggle with perspective effects. Figure 1 shows an example of a traffic conflict, illustrating how the system captures the entire trajectory and closest distance between objects, providing a clearer understanding of potential risks. This digital shadow provides a deeper insight into interactions between road users, presenting a more accurate representation of traffic conditions than traditional methods.

In future tests, the system will analyze a week's worth of data from a signalized intersection. The trajectory data will be made public available and a detailed 3D heatmap of traffic conflicts will be constructed. This heatmap will offer insights into the distribution of risks across different times of day and help identify the most hazardous intersections. By visualizing traffic conflicts over time, the system will inform the development of more effective traffic safety strategies.

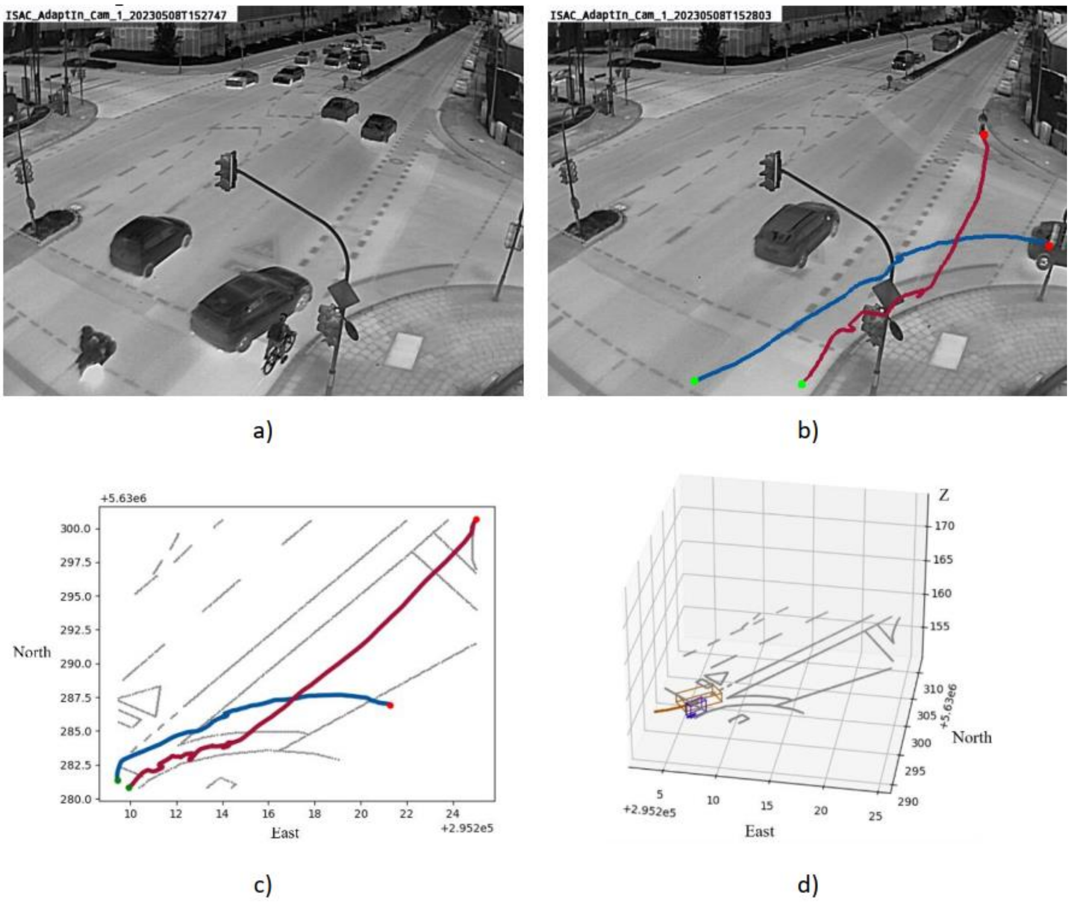

Figure 1. a) The most critical moment shown in the thermal image b) displaying the trajectories in pixel coordinates c) displaying the trajectories as single center points in Birds-Eye-View d) Showing the proposed method delivering a complete digital shadow of the scene

Conclusions

This study demonstrates the potential of using thermal monocular 3D detection to improve traffic safety analysis through the creation of a digital shadow, which offers a more accurate and comprehensive representation of traffic conditions than traditional 2D methods. By integrating advanced technologies such as thermal imaging, monocular 3D detection, and object tracking with Kalman filters, the proposed system effectively identifies near-misses and traffic conflicts. The ability to capture the full trajectory and proximity between objects enables better understanding of potential risks, particularly in complex traffic scenarios and adverse conditions where conventional systems struggle.

Future work will focus on analyzing extended datasets to generate detailed 3D heatmaps of traffic conflicts, providing deeper insights into risk patterns over time.

61.A Quantitative Study of Weather Effects on Cyclist Traffic Violations

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Introduction

Albeit classified as vulnerable road users, the German Federal Statistical Office reported that in 2023 cyclists and pedelec riders caused roughly 18% of traffic accidents involving personal injury in Germany. These cyclist-caused accidents (CCA) are not always the result of a traffic violation or directly attributable to one. However, accident records from the city of Munich link 60% of CCA in 2023 to specific traffic violations such as cycling on sidewalks, running red lights, or disregarding right-of-way. Among other factors, unfavourable weather conditions might act as situational triggers for certain types of traffic violations committed by cyclists. Low temperatures or rainfall may increase cyclists' tendency to run red lights to reduce travel time and minimize their exposure to discomfort. Wet surfaces and reduced visibility may lead cyclists to choose sidewalks over roadways in pursuit of a greater sense of safety. While adverse weather conditions are frequently considered in general traffic safety research, their specific connection to cyclist traffic violations has received comparatively little empirical attention. This study examines the effect of precipitation and temperature on the type and frequency of cyclist traffic violations that result in accidents. For this purpose, accident data from approximately 40,000 CCA recorded from 2021 to 2024 are matched with corresponding precipitation and temperature data.

Data

Accident records were obtained from local authorities of 11 federal states in Germany. These records typically include statutory offence codes and categorized accident causes, which are specified by the attending police officers and allow inferences about an accident's underlying traffic violation. Each accident is spatially and temporally matched to open precipitation and temperature data provided by the German Meteorological Office. High-resolution precipitation data is obtained through the RADOLAN (Radar Online Adjustment) dataset. The data is provided in 5-minute intervals at a 1 km² spatial resolution across Germany. Temperature data, being less volatile over time and space than precipitation, is based on hourly measurements from approximately 400 climate stations nationwide and is spatially interpolated to a 1 km² grid across the study area.

Methods

In the first step, relevant cyclist traffic violations are identified and descriptively analysed. Statutory offence codes and categorized accident causes are systematically examined to determine the underlying traffic violations associated with each CCA. The identified violation types are then grouped into broader categories for further analysis.

In a second step, the influence of temperature and precipitation on the occurrence of cyclist traffic violations is analysed using regression models. To account for fluctuations in cycling activity during different weather conditions, the analysis focuses on proportional differences in violation types. Cluster analysis is further applied to identify recurring patterns in cyclist behaviour across varying environmental contexts.

Results

The expected outcomes of the study are:

- A methodological approach to derive the effects of precipitation and temperature on cyclist traffic violations

- Empirical evidence on if and how precipitation and temperature affect different types of cyclist traffic violations
- Ideas for designing safer infrastructure for cyclists

Conclusions

The findings are expected to contribute to data-driven strategies aimed at reducing CCA, aligning with the broader objective of eliminating severe injuries and fatalities on the road. By demonstrating the nuanced ways weather conditions interact with cyclist behaviour, the results inform the design of targeted safety interventions and strengthen the understanding of traffic risk factors.

62.Traffic Safety Intelligence – A Surrogate Measure of Safety Toolchain (Streetscope Collision Hazard Measure Software Platform)

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Background

Trailing indicators, such as collision statistics, are a poor methodology for improving safety. In addition, the use of trailing indicators incurs pain and loss on society, and is not an ethically acceptable approach. An effective and consistent surrogate measure of traffic safety that can replace collision statistics as a means of assessing the safety of traffic infrastructure, vehicle behavior, or mobility system operations - must have a number of essential characteristics, including monotonicity and scalability.

Aim

Introduce an effective and consistent surrogate measure of traffic safety: Streetscope Collision Hazard Measure (SHM) and the associated software platform output data that forms a general Intelligence of Traffic Safety applicable to various stakeholders.

Method

The Streetscope Collision Hazard Measure (SHM) is a sensor agnostic software platform that analyzes traffic movement data to objectively measure the safety of operation and behavior of traffic objects (vehicles, VRUs, etc.). SHM generates a dense stream of output data which forms a general Intelligence of Traffic Safety applicable for a wide variety of use-cases. SHM can ingest traffic movement data generated from video sensors such as monocular cameras, LiDAR, Radar or movement data generated by Sensor Fusion of multiple sensors (AD/ADAS developers). This collision hazard measure is a kinematic measure that overcomes the limitations of existing measures and provides an independent leading quantitative measurement of safety.

SHM is an objective surrogate measure of safety that measures non-collision pairwise traffic object interactions to produce a quantitative score reflecting the riskiness or safeness of the behavior of vehicles in traffic. This collision hazard measure has the essential characteristics to provide an effective measurement of safety that will be useful to AV developers, traffic infrastructure developers and managers, regulators, and the public.

The platform records and analyzes pairwise traffic object interactions (TOI) from an egocentric (one-to-many) or poly-centric (many-to-many) approach and generates a SHM score of each Traffic Object Interaction and classifies these interactions into 14 different types.

Results Obtained and Expected

The detailed TOI output data with SHM values can be aggregated and analyzed to form the basis of traffic safety intelligence that can be used as safety baselines for traffic infrastructure, assessing mitigation measures and critical to the deployment and public acceptance of future automated mobility systems. Traffic Safety Intelligence Outcomes and examples from recent projects:

- Driving circumstance-based Safety Performance Indicators (SPIs) generated by platforms output data:
  - Time of day
  - Roadway Type
  - Traffic Object Interaction Type
    - Traffic Objects involved

    - Traffic Object Interaction Classification (rear-end, head-on)
- Geography based aggregation in 3 meter or 25 meter UTM grids summarizing the severity and frequency of high hazard Traffic Object Interactions – Hotspot Analysis
- High Hazard Scenario extraction based on SHM and TOI thresholds

Conclusion

Traffic safety intelligence extracted from the SHM Software Platform and the resultant Safety Performance Indicators (SPIs) have the potential to set safety baselines that can be applied to various stakeholders for addressing important safety questions:

- Risk assessment of driving behavior (human / AV / ADAS Drivers)
- Provide credible evidence to support AV / ADAS Safety Cases
- Effectively evaluate safety and risk mitigation in traffic infrastructure using leading indicators

63. The influence of (bicycle) road design on cyclists' and car drivers' perceptions

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Introduction

The benefits of cycling as a sustainable mode of transportation are well-documented. It promotes health (Oja et al., 2011) and serves as an eco-friendly alternative to motorized transport (Pucher & Buehler, 2017). In urban areas, it is efficient and reliable, gaining increasing policy support. However, expanding cycling's modal share presents challenges, particularly regarding safety and limited space (Gössling & McRae, 2022; Stülpnagel & Binnig, 2022). Creating a safe cycling environment is complex, as infrastructure must accommodate various road users. To improve cycling safety and appeal, measures like bicycle roads have been introduced globally (Fraser & Lock, 2011). These roads prioritize cyclists and aim to enhance safety (Schwarzkopf et al., 2024). In Germany, they allow bidirectional cycling and side-by-side riding, with a 30 km/h speed limit for cars (if motor vehicle traffic is allowed). However, the lack of standardized design leads to varied implementations—from fully redpaved roads to simple pictograms—potentially influencing user experience (Rivera Olsson & Elldér, 2023). Beyond design, broader infrastructural factors shape road user behaviour. The dominant transport mode (bicycles vs. cars) and potential conflicts impact traffic dynamics (Blitz et al., 2020; Schwarzkopf et al., 2024).

Against this background, two simulator experiments—a car simulator (CS) and a bicycle simulator (BS)—examined how bicycle road designs affect cyclists' and drivers' experiences. Additionally, the studies explored the impact of traffic composition (cyclist- vs. car-dominated) and roadside environments (car- vs. bicycle-/nature-oriented).

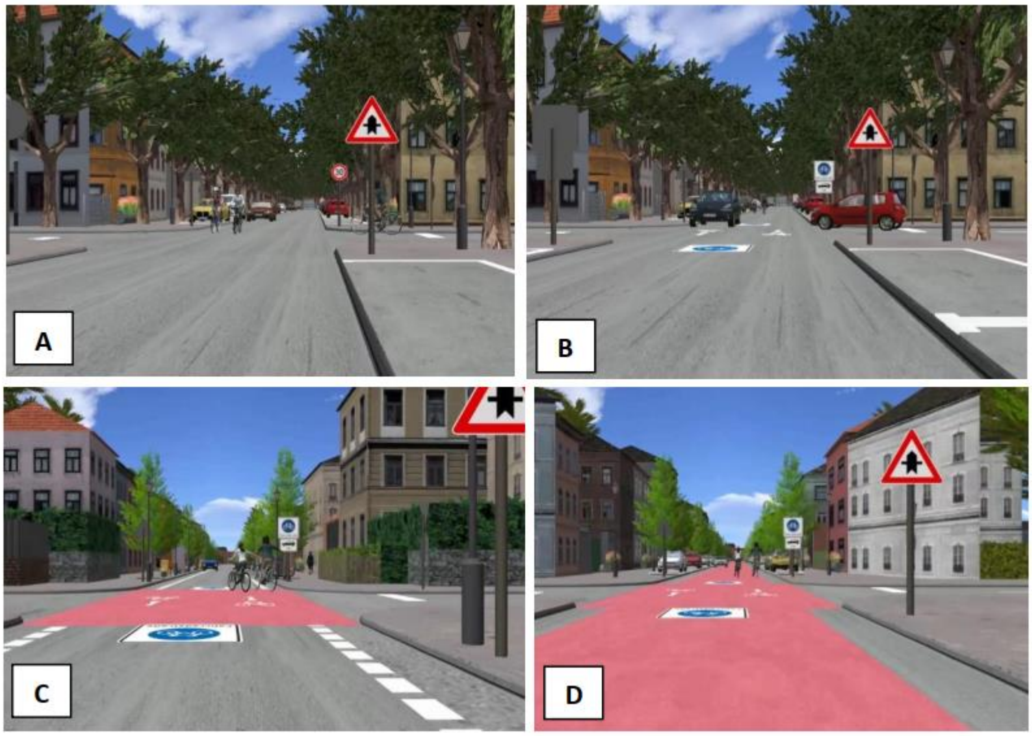

Figure 1. Visualization of the different road designs in the CSS and BSS. A = basis road; B = low-level bicycle road; C = mid-level bicycle road; D = high-level bicycle road

Methods

Sample & Design: The car simulator study (CSS) included 35 participants (23 female, 12 male; $M = 37.29$, $SD = 14.65$), while the bicycle simulator study (BSS) included 40 participants (18 female, 22 male; $M = 47.69$, $SD = 17.41$). In both studies, "road design" was varied across four conditions (see Figure 1): (1) Baseline road (30 km/h, no bicycle road markings), (2) Low-level bicycle road (signs and road pictograms), (3) Mid-level bicycle road (red-marked intersections, edge protection strip), and (4) High-level bicycle road (fully red-coloured). Additional independent variables were manipulated: In CSS, "roadside environment" (car-oriented vs. bicycle-/nature-oriented) and "interaction with cyclists" (one vs. two cyclists; Figure 2); in BSS, "traffic composition" (car- vs. bicycle-dominated; Figure 3).

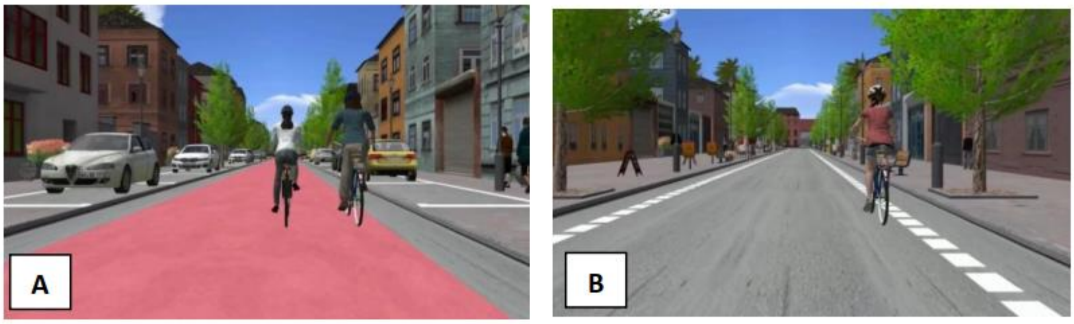

Figure 2. Visualization of the independent variables "interaction with cyclists" and "road-side environment" in the CSS. A = interacting with two cyclists in a car-oriented road-side environment. B = interacting with one cyclists in a nature-oriented road-side environment.

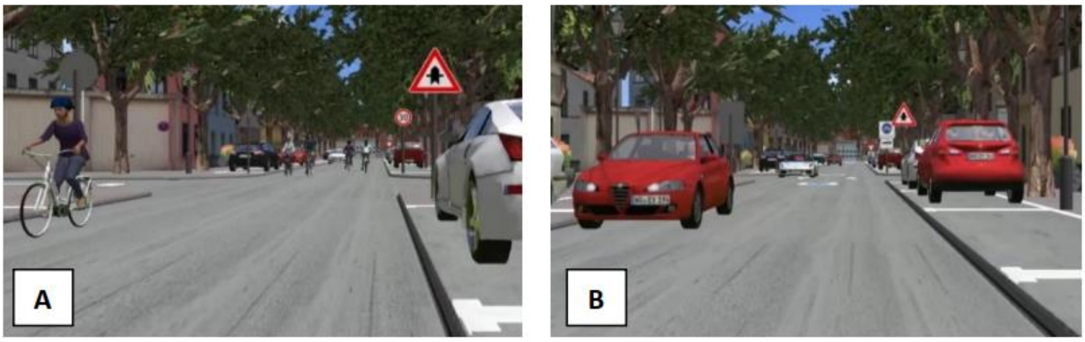

Figure 3. Visualization of the independent variable "traffic composition". A = cyclist-dominated; B = car-dominated.

Procedure & Measures: Participants completed all conditions (within-subjects design) in pseudorandomized order. After each ride, CSS participants rated cyclists' behaviour (assessment of disturbance; assessment of appropriateness) and mental load on 7-point Likert scales, while BSS participants evaluated perceived safety, mental load, and acceptance on 9-point Likert scales. Objective driving and cycling data (e.g., speed, overtaking, distance to the road edge) were recorded but are not included in this abstract.

Results

Car-Simulator-Study. Means and standard deviations are presented in Table 1. Statistical analyses showed significant effects of bicycle road design on disturbance ($F(1.68, 55.56) = 20.56$, $p < .001$, $\eta^2 = .049$), appropriateness ($F(1.64, 54.09) = 17.90$, $p < .001$, $\eta^2 = .039$), and mental load assessments ($F(2.44, 80.36) = 2.96$, $p = .048$, $\eta^2 = .012$). The baseline road was rated less favourably than designated bicycle roads across all measures, though post-hoc tests did not confirm this for mental load. The number of cyclists also influenced emotional ($F(1,33) = 16.71$, $p < .001$, $\eta^2 = .055$) and rational assessments ($F(1, 33) = 18.26$, $p < .001$, $\eta^2 = .108$): Two cyclists riding side by side were perceived as more disturbing and less appropriate than a single cyclist, regardless of road design. A significant interaction between road design and the number of cyclists was found for emotional ($F(2.08, 68.50) = 10.71$, $p < .001$, $\eta^2 = .014$) and rational assessments ($F(2.71, 89.56) = 12.00$, $p < .001$, $\eta^2 = .018$). In the baseline condition, two cyclists were perceived as significantly more disturbing than one, whereas in the high-level bicycle road, this difference diminished in the car-dominated roadside environment. Effects on emotional and rational assessments are visualized in Figure 4 and Figure 5.

Table 1

Means and Standard Deviations for car drivers' assessments divided after the independent variables

Independent variables		Disturbance assessment		Appropriateness assessment		Mental load	
		M	SD	M	SD	M	SD
Bicycle road	basis	3.47	2.00	4.41	2.12	2.8	1.46
	low	2.49	1.69	5.16	1.90	2.51	1.3
	mid	2.59	1.77	5.25	1.83	2.44	1.41
	high	2.57	1.76	5.19	1.82	2.44	1.34
Edge design	Car-centred	2.80	1.85	4.97	1.95	2.54	1.34
	Nature-centred	2.76	1.85	5.04	1.95	2.56	1.43
Number of cyclists	1	2.33	1.55	5.62	1.6	.	.
	2	3.23	2.01	4.39	2.07	.	.

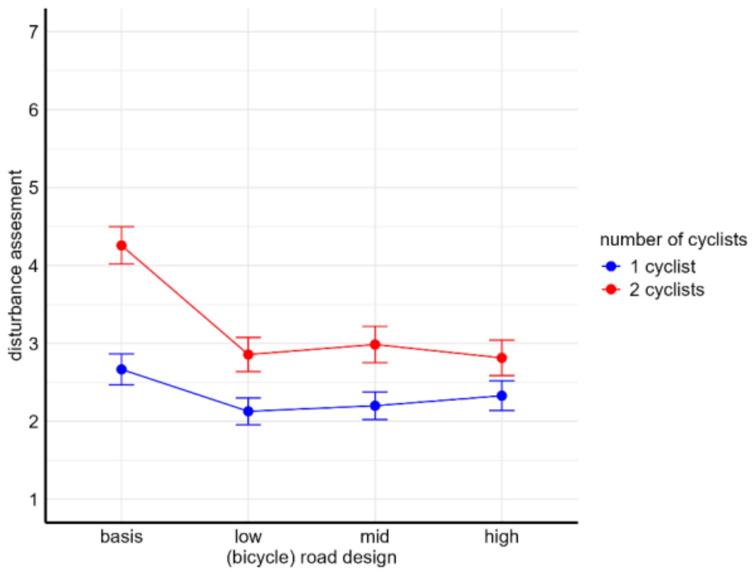

Figure 4. Visualization of the two-way interaction effect between "street-design" and "number of cyclists" regarding car drivers' emotional assessment ("How disturbing did you find the cyclists' behaviour?"). Likert scale ranged from 1 (*not disturbing*) to 7 (*very disturbing*).

Bicyclist-Simulator-Study. Means and standard deviations are presented in Table 2. Statistical analyses revealed significant effects of bicycle road design on subjective safety ($F(2.41, 84.48) = 9.01$, $p < .001$, $\eta^2 = .075$), mental load ($F(2.81, 101.29) = 6.40$, $p < .001$, $\eta^2 = .040$), and acceptance ($F(2.76, 99.26) = 4.63$, $p = .006$, $\eta^2 = .031$). Traffic composition also influenced subjective safety ($F(1,35) = 16.03$, $p < .001$, $\eta^2 = .042$), mental load ($F(1, 36) = 16.43$, $p < .001$, $\eta^2 = .044$), and acceptance ($F(1, 36) = 14.58$, $p < .001$, $\eta^2 = .032$). Post-hoc analyses indicate that cycling in the high-level bicycle road was perceived as significantly safer and less mentally demanding than in the different designed roads. A bicycle-dominated traffic composition also increased perceived safety. Cycling in a bicycle-dominated traffic composition was perceived as safer and less mentally demanding. An interaction effect was found for acceptance ($F(2.90, 104.33) = 3.20$, $p = .028$, $\eta^2 = .014$). In the baseline and low-level roads, acceptance was lower in the car-dominated traffic composition than in the bicycle-dominated traffic composition. However, this effect disappeared in the mid- and high-level bicycle roads. Effects are visualized in Figure 6, Figure 7 and Figure 8.

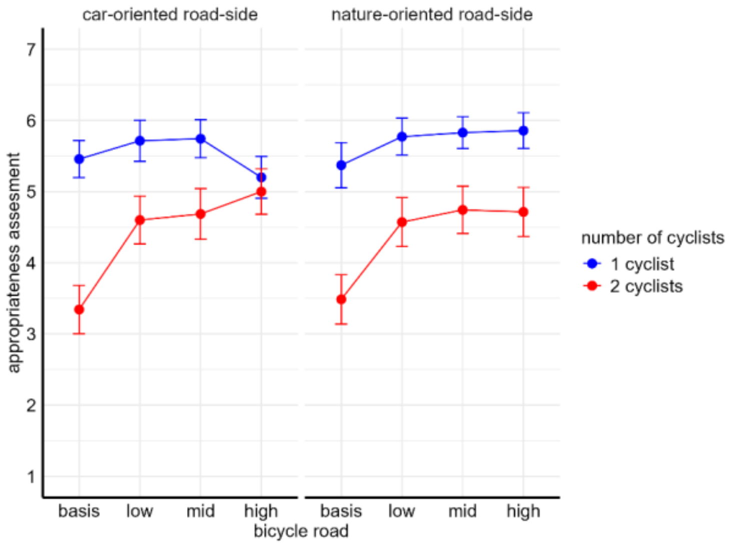

Figure 5. Visualization of the three-way interaction effect between "street design", "number of cyclists", and "road-side environment" regarding car drivers' rational assessment ("How appropriate did you find the cyclists' behavior?"). Likert scale ranged from 1 (not appropriate) to 7 (very appropriate).

Table 2

Means and Standard Deviations for cyclists' assessments divided after the independent variables

Independent variables		Subjective safety		Mental load		Acceptance	
		M	SD	M	SD	M	SD
Bicycle road	basis	8.08	1.39	7.77	1.49	7.69	1.50
	low	8.39	1.21	8.06	1.40	8.03	1.41
	mid	8.54	1.08	8.24	1.31	8.16	1.35
	high	8.89	0.57	8.45	1.22	8.36	1.23
traffic	Car-dominated	8.25	1.30	7.85	1.46	7.80	1.48
	cyclist-dominated	8.70	0.90	8.41	1.22	8.32	1.26

Discussion and Conclusion

The results indicate that road design significantly influences the experiences of both cyclists and car drivers. Drivers generally perceive cyclists as less disruptive and their behaviour as more appropriate when riding in bicycle roads, regardless of the specific design. However, in a car-dominated roadside environment, drivers rate the behaviour of two cyclists riding side by side in the high-level bicycle road as equally appropriate as that of a single cyclist—an effect not observed in other (bicycle) road designs. Furthermore, cyclists feel safest and experience the least mental strain when riding in a high-level bicycle road and within a bicycle-dominated traffic composition. When considering everyday cycling, they prefer a bicycle-dominated environment. However, when more cars are present, the high-level bicycle road design can enhance acceptance compared to other (bicycle) roads.

In summary, the findings from both studies suggest that the fully red-marked bicycle road can improve acceptance and experience in interactions between car-drivers and bicyclists, particularly in car-dominated contexts, compared to other design variations. This is especially relevant for bicycle roads that allow motor vehicle traffic. In cases where motor vehicle access is restricted, less salient bicycle road designs may also be sufficient. The results require further validation through analysis of the recorded behavioural data (e.g., driving dynamics). Additionally, findings from the laboratory should be corroborated in real-world field studies.

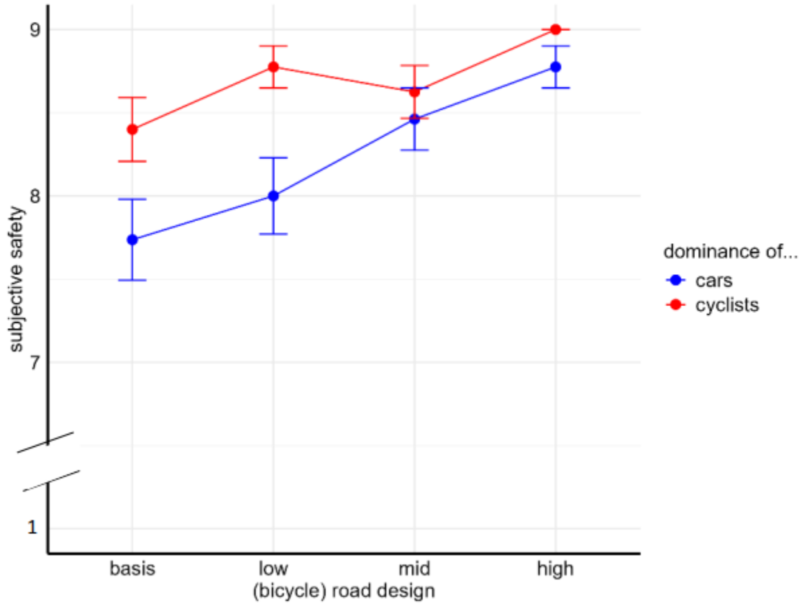

Figure 6. Visualization of the two-way interaction effect between "street-design" and "traffic composition" regarding cyclists' subjective safety ("I felt safe while cycling on this road"). Likert scale ranged from 1 (low agreement) to 9 (high agreement).

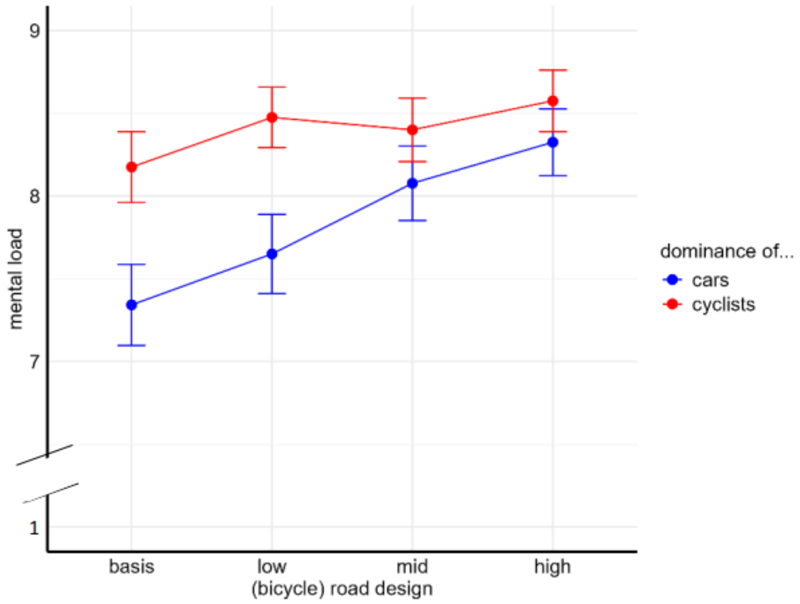

Figure 7. Visualization of the two-way interaction effect between "street-design" and "traffic composition" regarding cyclists' mental load ("The traffic situation was not mentally demanding for me"). Likert scale ranged from 1 (*low agreement*) to 9 (*high agreement*).

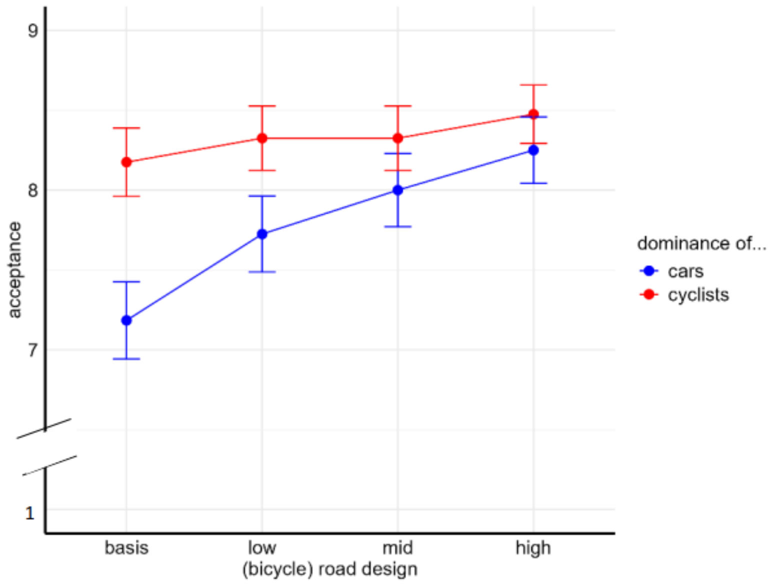

Figure 8. Visualization of the two-way interaction effect between "street-design" and "traffic composition" regarding cyclists' acceptance ("I would like to use this road for everyday cycling"). Likert scale ranged from 1 (*low agreement*) to 9 (*high agreement*).

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64. Can You Hear the Collision Risk? A VR Study on Beamforming Warnings for Cyclists at Urban Intersections

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Background

Urban intersections are among the most dangerous areas in road networks, particularly due to conflicts between motor vehicles turning right and cyclists travelling straight ahead. Although collision warning systems have been mandatory for new buses and trucks since July 2022, a significant safety risk remains, mainly because older vehicles are not covered by these regulations. Existing infrastructure-based warning systems, which primarily rely on visual signals, often generate high false alarm rates. This can lead to acceptance problems (e.g., "cry-wolf effect"), where frequent false warnings lead to real danger signals being ignored. Such systems are typically too unspecific and tend to address not only the road users at risk but also uninvolved persons, thereby reducing their overall effectiveness. Previous studies have shown that more targeted, user-centred warning concepts can improve reaction times and reduce the risk of accidents. These findings emphasise the need for more specific and less intrusive solutions. Beamforming technology, which directs acoustic signals precisely to those at risk, offers a promising advancement in traffic safety. By using speaker arrays for spatial control of sound beams, only endangered road users can be warned while uninvolved persons remain undisturbed.

Aim

The aim of the VR-based perception study[1] is to assess the subjective effectiveness, comprehensibility, and acceptance of directed acoustic warnings at urban intersections. The central research question is whether warnings generated by beamforming, which are directed exclusively at cyclists at collision risk, are reliably perceived as relevant in a realistic acoustic environment without disturbing uninvolved persons or unnecessarily increasing the urban background noise. Study participants are placed in different roles and positions within the virtual environment, such as cyclists approaching the intersection, pedestrians in the crossing area, or residents in the immediate vicinity. The study investigates how clearly directional warnings differ from background noise, whether they trigger behavioural adaptation, and what extent they may disturb others such as pedestrians or nearby residents.

Method

A fully immersive test environment was developed for the VR-based study. A detailed 3D model of an intersection was integrated with spatial audio simulations. Using beamforming algorithms, the sound immissions were simulated for the various user positions, e.g. on the cycle path, the pavement or in neighbouring buildings.

In addition, real traffic sounds were recorded on site and embedded in the virtual acoustic scene to evaluate the perception of the warning signals in a realistic urban soundscape. The audio signals are presented via headphones with head tracking, which enables dynamic acoustic feedback based on head orientation. The virtual 3D world is presented via a VR headset to support spatial orientation and create an immersive multi-sensory environment. This allows participants to experience the targeted warnings

[1] This study is conducted as part of the research project SOUNDWARN, funded by the mFUND innovation initiative of the German Federal Ministry for Digital and Transport (BMDV).

from different real-world perspectives and evaluate them accordingly. Participants will be instructed beforehand that the acoustic signals presented during the simulation may represent a warning related to a potentially hazardous situation for the cyclist.

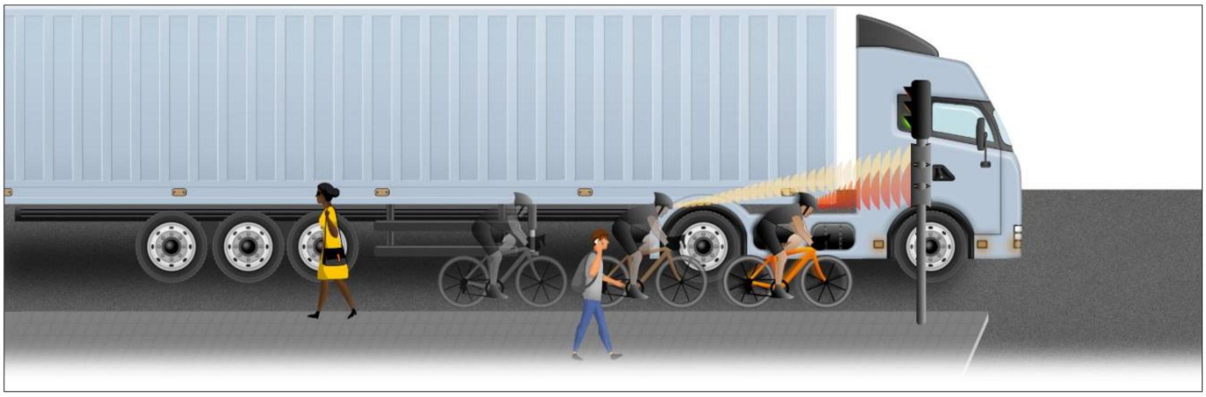

Figure 1: Person-specific acoustic warnings through electronic beamforming

Expected Results

The study aims to show that acoustic directional warnings generated by beamforming are perceived by cyclists as clear, localisable and relevant - even in a complex urban noise environment. The signals should clearly be distinguishable from the background noise without being perceived as disturbing by bystanders. It is assumed that early acoustic warnings increase the attention of cyclists and promote adaptive behaviour, e.g. braking before entering a conflict zone. In addition, individual perception is expected to vary depending on the role and location of the user, providing valuable insights for optimising signal design and speaker placement. Feedback from participants on acceptance and perceived disruption - particularly from the perspective of residents – will contribute to further technical and perceptual refinement of the system.

Conclusion

The VR-based perception study provides valuable insights into the effectiveness, specificity and user acceptance of beamforming-based acoustic warnings in urban traffic scenarios. The results provide a solid basis for further development and potential real-world deployment of such systems at intersections. By combining spatial precision and low disturbance potential, this approach could improve existing infrastructure-based warning technologies while significantly reducing false alarms. The study thus contributes to improving the safety of vulnerable cyclists. Furthermore, the study underlines the methodological potential of combining VR and acoustic simulation for the user-centred evaluation of complex safety technologies.

65. Influence of Traffic Flow and Merging/Diverging Ramp Design on Take-Over performance: A Cross-Country Comparison of Conditionally Automated Vehicles

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Introduction

The rapid progress towards autonomous vehicle technology is being driven by the improvement of Conditionally Automated Driving (CAD) system. Being classified as level 3 automation under SAE standards it requires drivers to take over control (TOC) when the automated system reaches its operational limits or encounters unsafe conditions. In the TOC process, take-over time is the time between the system alerting the driver and the driver taking control, while take-over quality is how smoothly and safely the driver regains control, aiming for minimal disruption and continued safe vehicle operation.

Previous research has shown that takeover time and quality are influenced by several factors such as time budget, take-over request modalities, type of the TOC scenario, the action taken to regain control (i.e., pressing a button, turning the wheel or pressing the pedals), traffic conditions and the driver's responsiveness, skills and reactions. However, there is a lack of knowledge about the effect of specific road geometry parameters connected to various driving manoeuvres and traffic levels. Therefore, this study chose to focus on the effect of ramp terminal type and length under different traffic conditions on TOC performance (i.e., TOC time and quality) when the driver must take over the control to perform merging and diverging manoeuvres on motorways.

Research Methodology

This study used two fixed-base driving simulators: one in NORD University (Norway) and one in Politecnico di Torino (Italy). The two simulators share the same software (SCANeRStudio® ver. 2023.3) and hardware. Eighty participants (40 in Norway and 40 in Italy), aged between 20 and 60 and holding a class B driving licence, were asked to drive the scenario, which was designed to (i) include variations in traffic flow rate under stable conditions, (ii) merging/diverging ramp type and (iii) length. The scenarios were the same except for the vertical signs and horizontal markings, which were adapted to national regulations. Table 1 summarises the experimental factors adopted in this study. In addition to driving in CAD mode, participants also drove in manual mode to establish a baseline for comparison. The participants were selected to have the same balanced male/female ratio and age distribution in both laboratories.

Table 1: Experiment factors and levels

Terminal ramp length in diverging	75 m	155 m
Terminal ramp length in merging	100 m	375 m
Terminal ramp type	Tapered	Parallel
Traffic flow rate in the motorway lanes	400 pc/h/ln	1500 pc/h/ln

The same protocol required participants to follow instructions to takeover control when necessary (CAD mode) or to drive in manual mode. All participants completed a total of 8 driving runs, 4 in CAD mode and 4 in manual mode, in two separate sessions for each mode.

All parameters were randomised in the experimental design to avoid any bias in the dataset. In addition, eye-tracking technology was used to record the participants' visual attention and to identify visual patterns. At the end of each driving session, post-drive questionnaires were administered to assess (i) mental workload using the NASA TLX model, (ii) driving simulator sickness, and (iii) participants' perceptions of the driving tasks and their overall engagement with the self-driving technology.

Results

At the time of submitting this abstract, the data collection was successfully completed, and some preliminary results are already available about:

- driving performance measurements such as vehicle speed and acceleration, lateral position in the lane, actions on the pedals and steering wheel (i.e., forces and reaction times), TOC time;
- drivers' gaze behaviour; and
- drivers' qualitative feedback on workload, simulator sickness and perceived fidelity of the simulated scenarios.

Preliminary results suggest that drivers were more prepared and attentive in manual control than in automated control. Some of the key findings include (a) higher mental demands and frustration levels during automated driving in dense traffic conditions, (b) lower physical demands and consistent temporal demands across different driving modes, and (c) a significant difference in driver performance and effort between manual and automated driving, with manual driving showing higher engagement and satisfaction.

Discussion and conclusions

Expected results might suggest that traffic flow rate and ramp design could have a significant effect on takeover performance during merging/diverging manoeuvres to/from a motorway in conditionally automated driving mode (CAD). At high traffic flow rates, participants might experience longer TOC time and exhibit lower quality control with respect to the low traffic flow rate condition. Likewise, shorter ramp lengths might narrow the merging or diverging window, which could lead to less stable control transitions. Tapered ramps could demand faster situational assessment, leading to faster TOC and better TOC quality. These patterns could be consistent across Norway and Italy, although subtle differences in driver behaviours may emerge due to cultural and driving styles differences. Eye tracking data may show increased visual scanning in heavier traffic, which is associated with increased cognitive workload. Subjective data could suggest lower physical demand in CAD mode but increased mental effort during take-overs. Overall, these hypothetical results suggest that road design, traffic conditions, and their interactions can significantly affect the time, smoothness, and safety of transitions from automated to manual control. This highlights the importance of re-evaluating current road configurations for conditionally automated vehicles or mitigate their effects by technological interventions that enhance the time and quality of TOC. However, all these hypotheses will be subject to careful scrutiny after data analysis, both of which are in progress.

66.Left-turn Gap Acceptance Behavior of Pedestrians under Time Pressure: A Signalised Intersection Study

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Introduction and Objective

A gap is the time interval between two consecutive vehicles that a pedestrian uses to cross the intersection. At signalized intersections, especially, the free left-turning vehicles (left side driving conditions) provide a feeling of unsignalized movements, which causes pedestrians to have to accept a gap between them to cross the entire intersection, especially at channelized intersections. In addition, many studies have presented a significant effect of time pressure on pedestrians' decision to accept a gap at midblock locations. However, to the author's knowledge, none of the studies examined the gap acceptance behavior of pedestrians at signalized intersections under time pressure conditions. Therefore, the aim of the current study was to understand the gap acceptance behavior of pedestrians at a channelized intersection

Methodology

The pedestrian behaviours were tested using a projector-based pedestrian simulator setup (Figure 1). Figure 2 displays the intersection layout, which includes the crossing locations the near-end (NE) and far-end (FE) sides of the approach were used to analyze gap-acceptance behavior. Pedestrians' experiments were conducted under three conditions. The first is the baseline condition, which has no time pressure (NTP) induced. The other two time pressure levels, which are Low Time Pressure (LTP) and High Time Pressure (HTP), were induced using hypothetical situations. A timer showing the amount of time left to cross the junction was also used (Figure 3). Each participant crossed the intersection nine times from A to B (Figure 2). Finally, in total, 1116 observations were obtained from 62 participants.

Figure 1: Projector-Based Pedestrian Simulator Setup

Results

The dependent variable, a gap acceptance size, was an ordered categorical variable with gap size varying from 1 to 8 seconds. In addition, multiple observations of each pedestrian were taken, therefore mixed effect ordinal logit model was used. Independent variables considered were experimental conditions (NTP, LTP and HTP), approach side (NE and FE), crossing speed of pedestrian, waiting time, spatial compliance behavior, head turns of the pedestrian while waiting and crossing, age and gender. The results found that under LTP and HTP conditions, the likelihood of accepting the larger gaps decreased by 55% and 60% as compared to NTP. Further, pedestrians were nearly 61% less likely to accept larger gaps in FE side as compared to NE side. Higher crossing speed was found to decrease the likelihood of accepting a larger gap by 79%. Whereas an increase in waiting time the likelihood of accepting a larger gap size increased by 15%. Further, pedestrians who looked for approaching vehicles while waiting but not while crossing accepted the 8.81 times larger gap as compared to those who did not look around at all. Similarly, those checking vehicles while both waiting and crossing accepted a 7.7 times larger gap. Further, with increasing age, pedestrians were 1.04 times more likely to accept larger gaps.

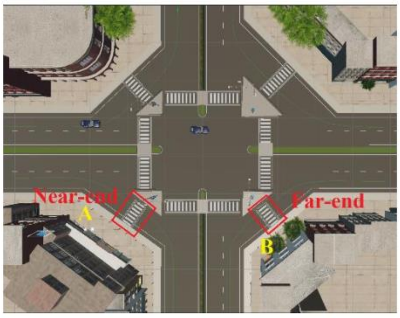

Figure 2: Intersection Layout with Crossing Locations

Figure 3: Stopwatch Timer for Inducing Time Pressure

Discussion and Conclusion

The current study shows the impact of various experimental conditions, demographic and behavioral on the gap size accepted by the pedestrians. An increased time pressure forces the pedestrians to accept smaller gaps. When there is NTP the pedestrians seem to be more relaxed and address the risk of gaps more cautiously, ultimately selecting a larger gap size. Under LTP or HTP pedestrians were in hurry to reach the destination, therefore taking a smaller gap to reduce the time spent waiting. Basically, this study can be a valuable input for traffic engineers to plan and design safer and more responsive crossing environments for the pedestrians under different conditions to increase pedestrian safety. For vehicles turning freely to the left, speed breakers can be placed immediately before the crosswalk to give pedestrians a larger vehicle gap size. Additionally, the approach can be narrowed at the crosswalk area to reduce the number of cars accessing the crosswalk simultaneously and to shorten the pedestrian crossing distance.

67.Enhancing Severe Traffic Crash Prediction through Data Balancing and Ensemble Learning: Case Study of England

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Aim

This research addresses the challenge of predicting the severity of traffic crashes, with a particular focus on severe and fatal incidents. It contributes by implementing a machine learning framework that applies data balancing techniques, particularly random undersampling majority class (RUMC) method, and explores the effectiveness of various machine learning models. By comparing ensemble methods such as voting and stacking, the study advances the understanding of managing imbalanced datasets, directly relating to ICTCT 2025 topics on road safety prediction, machine learning in traffic safety, and data imbalance issues.

Background

Traffic crashes remain a critical public health issue worldwide, with a notable percentage resulting in severe injuries or fatalities. Predicting crash severity is vital for designing effective interventions. However, the imbalance in crash datasets—where severe crashes are significantly rarer than minor ones—complicates prediction tasks. Machine learning models often favor the majority class, failing to accurately detect severe cases. Therefore, developing models that maintain strong sensitivity to severe crashes, without significantly sacrificing overall performance, is essential.

Method

The methodology involves pre-processing the dataset using the RUMC technique to balance the proportion of severe and minor accidents. The models were trained and tested on the English STATS19 dataset, a comprehensive and reliable national database of police-reported traffic accidents. Using such a high-quality dataset contributes to producing more accurate and trustworthy prediction results. Multiple machine learning models, including Random Forest (RF), Support Vector Machine (SVM), K-Nearest Neighbors (KNN), and Multi-Layer Perceptron (MLP), are employed to evaluate crash severity prediction. Additionally, ensemble methods such as Voting and Stacking are explored to enhance predictive performance. The primary evaluation metric is the Area Under the Curve (AUC), providing a comprehensive measure of model discrimination between severity classes.

Results

The results demonstrate that applying RUMC significantly enhances the models' sensitivity and F1-Score for severe crashes compared to models trained on imbalanced data. Although RUMC models show a slight reduction in overall accuracy, their ability to reliably predict severe and fatal accidents improves markedly. The Voting ensemble of RF and MLP achieved an AUC of 68.91%, while the Stacking ensemble, combining Decision Tree (DT), SVM, KNN, and MLP, slightly outperformed it with an AUC of 69.08%. These findings underscore the advantage of ensemble methods, particularly in handling imbalanced datasets, improving prediction stability, and achieving better sensitivity for rare but critical crash types.

Conclusion

Balancing the dataset using RUMC substantially improves machine learning models' performance in predicting severe traffic crashes. While accuracy marginally decreases, the improved sensitivity and F1-

Score, particularly in severe cases, justify this trade-off. Ensemble methods, though computationally more intensive, consistently outperform individual models, with Stacking providing the best balance between accuracy and sensitivity. Importantly, these results highlight the practical utility of ensemble approaches in real-world traffic safety applications, where accurately identifying severe crashes can significantly enhance prevention efforts. This study also confirms that focusing purely on accuracy can be misleading when dealing with imbalanced datasets in critical domains like traffic safety. A more nuanced evaluation that prioritizes sensitivity for rare, high-impact outcomes is essential.

Furthermore, the research demonstrates that incorporating balanced datasets into machine learning pipelines is crucial for developing reliable traffic crash prediction systems. Policymakers and traffic safety experts can leverage these findings to implement machine learning models that support proactive interventions, resource allocation, and risk mitigation strategies, ultimately leading to safer road environments.

68.TUMDOT-ING: Multimodal Trajectory Dataset from Aerial Observation

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Accurate and comprehensive trajectory data can be used for a variety of applications, particularly including road safety analysis. Interactions can be evaluated retrospectively and assessed in terms of safety, using surrogate safety measures, for example. However, this highly accurate database is rarely available, owing to several challenges. These include obstructions, perspective distortions or the falsification of results by the observation itself. Furthermore, installing such a sensor setup is often accompanied by high costs. To counteract this lack of data, we introduce the TUMDOT-ING dataset in this work. This dataset comprises multimodal trajectories of all types of road users across three intersections in Ingolstadt, Germany. The data was gathered during afternoon and evening peak hours on three successive weekdays utilizing multiple aerial, camera-equipped drones.

The survey was conducted in Ingolstadt at an intersection triangle, selected for its concurrent deployment of LiDAR sensors and thermal cameras. Specifically, the locations included:

- Location 1: Intersection of Friedrich-Ebert-Strasse and Goethestrasse
- Location 2: Intersection of Goethestrasse and Schillerstrasse
- Location 3: Intersection of Schillerstrasse and Friedrich-Ebert-Strasse, as illustrated in Figure 1A.

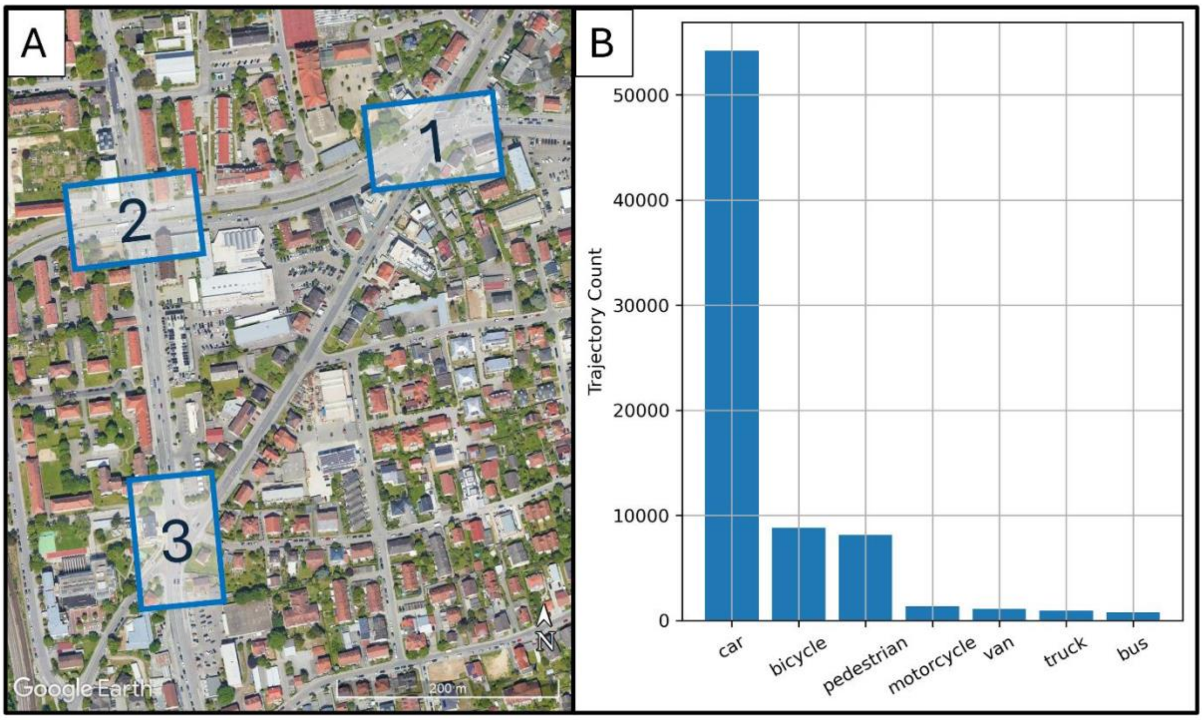

Figure 1: (A) Recorded intersections in the city of Ingolstadt, Germany (based on Google Earth) and the total amount of trajectories collected during the recording days (B)

The surveys were conducted over three consecutive days (Tuesday, July 4 to Thursday, July 6, 2023) avoiding holidays and public events to ensure typical traffic patterns. The weather conditions were consistently sunny. Data collection occurred daily during a roughly three-hour period between 16:00 and

19:00 to capture peak traffic volumes. Across the three days, a total of 75,000 trajectories were recorded, comprising around 8,000 from cyclists and pedestrians each, visualized in Figure 1B.

Due to the drones' limited flight time (caused by the battery capacity constraints), two drones were deployed at each location. The drones were each supposed to perform a transition with a temporal overlap in order to obtain a continuous image of the trajectories. Unfortunately, due to technical problems at the beginning of each video, as well as sometimes missing reference objects to connect the videos and meta data loss regarding the time stamps, it was not always possible to generate continuous timelines. The available, individual recordings of the drones per location and day, as along with the coherent timelines based on them, are shown as an overview in Figure 2.

The videos were recorded and analysed at a frame rate of 30 fps. For each frame, detailed information is available for each road user encompassing:

- Object type classification
- Global position as x and y coordinates in the UTM 32N system
- Bounding box dimensions
- Orientation
- Speed in the global reference system.

Validation exercises involving random checks against LiDAR data and observations from test vehicles during collection confirmed positional and bounding box inaccuracies generally fell within a ± 30 cm tolerance.

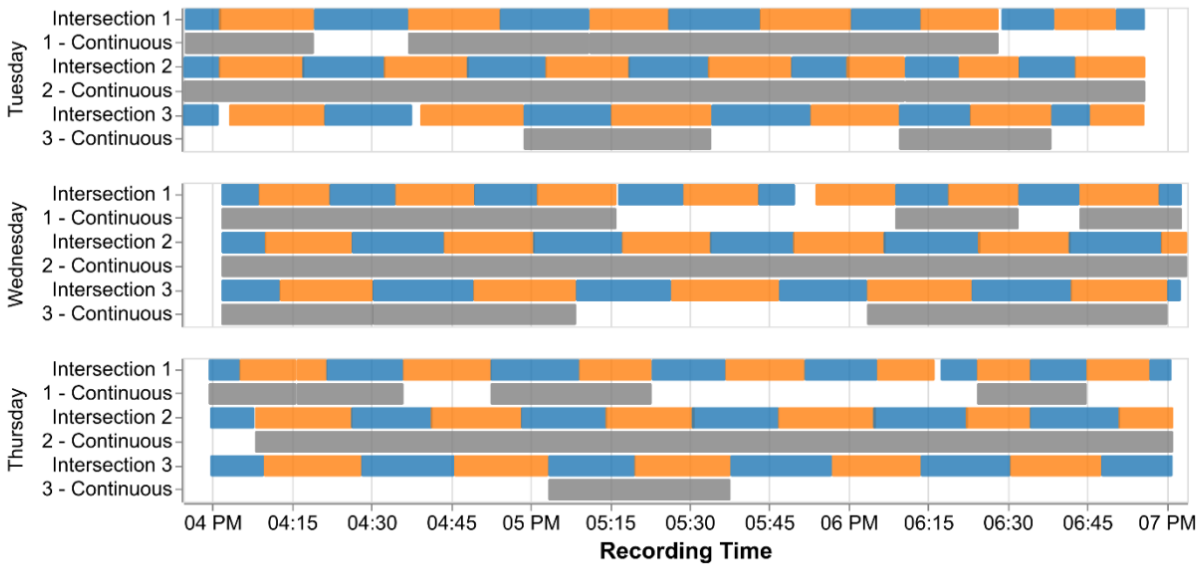

Figure 2: Recorded times during the afternoon peak hours from July 4 to July 6, 2023. Besides the individual drone flights (depicted in blue and orange for the alternating drones respectively), whenever possible a temporal concatenation was carried out (illustrated in grey).

This dataset is published open source for non-commercial research purposes under the Creative Commons CC BY-NC 4.0 license. Access the full dataset, accompanied by a step-by-step loading and processing guide, via: https://www.mos.ed.tum.de/vt/forschung/datensaetze/tumdot-ing/

Acknowledgements: The drone data were gathered with the help of Automatum Data GmbH (Trajectory Generation).

69.Modelling improvement of pedestrian road safety in Poland with time-series models

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Background

Over the last 20 years there has been a significant improvement in the general road safety situation in Poland. The fatality rate expressing the number of road deaths per million inhabitants has decreased from 150 in the year 2004 to 52 in the year 2024. The safety improvement was even greater for pedestrians whose situation in Poland in 2004 was quite alarming: they constituted 30.7% of road fatalities – one of the highest such proportions in Europe. This proportion has since decreased to 22.6% in 2024.

Aim

The objective of the paper is to investigate the time trends and identify factors which contributed most to the improvement of traffic safety situation of pedestrians in Poland.

Method

In order to assess the improvement of the safety of pedestrians in Poland, a time-series model of a monthly number of killed and seriously injured (KSI) pedestrians was formulated using data for the six-year period 2018-2023. The data comes from the Polish nationwide road accident database, maintained by the National Police Headquarters. For the period selected the database contains records of 33 674 vehicle-pedestrian injury accidents. Two modelling methods were used: a non-linear multiple regression model and an ARIMA model. As a proxy for exposure, average traffic volume index from eight Continuous Traffic Measurement Stations was used.

Results

During the six-year period investigated, several changes and events occurred which had an impact on road safety. One such event was the Covid-19 pandemic which caused a big drop in personal mobility during the lockdown periods and consequently a big drop in road accidents. The second important change was the new Road Traffic Law giving pedestrians full priority at unsignalized marked zebra crossings. According to the calibrated model, the monthly KSI number was dependent on the average traffic volume index, which was a proxy measure of exposure, presence of Covid restrictions, new traffic law as well as seasonality factors. KSI was significantly higher during autumn and winter months due mostly to longer periods of darkness during the day. For example, the KSI number per month for December was 2.56 times higher than during the reference May-August period. Covid restrictions caused a drop of the monthly KSI number by 22%. In addition, during the lockdown periods, there was a 28.6% drop in the average reference traffic volumes, which translated into an additional decrease in pedestrian casualties of 31.7%. Therefore, the overall impact of Covid restrictions could have amounted to as much as 46.8%. Although during the Covid restriction periods the overall number of accidents decreased, there was a marked increase in the proportion of fatalities. The effect of change in Road Traffic Law initially caused an increase in vehicle-pedestrian accidents but in the long run resulted in a 29% reduction in the number of KSI pedestrians.

Conclusions

In summary, vehicular traffic exerts the strongest positive (i.e. increasing) impact on the number of KSI pedestrian victims which is expected as the traffic volume is a measure of exposure to risk for pedestrians crossing roads. The overall trend is decreasing the number of killed pedestrians by around 8% per year on average. At the same time the seasonal variations are getting smaller. A new safety indicator, called "Monthly Average Daily Deaths" (MADD) is proposed which can express the overall safety trend as well as seasonal variations of the safety situation of pedestrians.

70.Eyes on the Road, Mind on the Move: Understanding Cyclist Workload through Sensors and Surveys

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[3]Gdansk University of Technology, Poland

INTRODUCTION

Cyclists' behaviour is a growing area of interest in road safety research. Understanding how cyclists perceive and interact with their environment is key to improving infrastructure and reducing accidents. This study explores cyclists' visual behaviour and mental workload by integrating sensor data (eye-tracking and electroencephalogram) with subjective evaluations (NASA Task Load Index questionnaire). The core question addressed in this paper is: How do subjective perceptions align with sensor-based measurements of mental workload and visual behaviour?

METHODOLOGY

This study adopts an integrated, multi-dimensional approach to examine how urban road environments influence cyclists' mental workload and visual behaviour under real-traffic conditions. The methodology integrates and compares eye-tracking data, EEG mental workload measurements, and subjective assessments, with data analysis performed using both statistical methods and machine learning tools. The experiment was conducted in Gdansk, Poland, along a 3-kilometer urban cycling track that featured a variety of traffic scenarios. After data cleaning and validation, the final dataset relates to ten of the 15 participants of diverse ages and cycling experiences. Each participant rode an instrumented bicycle equipped with GNSS for positional tracking while wearing eye-tracker glasses and EEG sensors. Data was collected in daylight and good weather to ensure the quality and reliability of both EEG and visual data. The eye-tracking glasses record gaze using two internal cameras focused on the eyes and a front-facing scene camera to capture the cyclist's view. Gaze points were sampled at 30–60 Hz, with data classified into saccades (shorter than 150 milliseconds), fixations (between 150 and 700 milliseconds), and long fixations (longer than 700 milliseconds). Fixations indicated periods when the cyclist's gaze was on a specific object, suggesting cognitive processing or attention. EEG data were collected using NeuroSky algorithms to derive Attention and Meditation metrics. The Attention metric is supposed to reflect the intensity of mental "focus", increasing when the cyclist concentrated and decreasing when distracted. The Meditation metric is supposed to indicate the mental "calmness" level, rising when the cyclist is relaxed and dropping under stress and tension. Both values are measured on a scale from 0 to 100. The subjective workload evaluations were collected using the NASA Task Load Index (NASA-TLX) questionnaire to complement the sensor data. After each ride, participants were asked to classify different bike lane zones based on their perceived workload and to rate them across dimensions: mental demand, physical demand, temporal demand, performance quality, effort level, and frustration level. These dimensions are rated on a scale, and the overall workload score is calculated using a weighted average of these ratings. These responses were then normalized into a single workload score between 0 and 1.

DATA ANALYSIS

The first step in the analysis explored the variability in sensor-based measurements across the different users and along the road path divided into six sections, aiming to determine whether differences could be attributed to individual characteristics or specific road traffic conditions. Subsequently, the correlation between sensors and subjective measures was analyzed to evaluate the consistency and role of the different sensor measures with the subjective evaluation of workload. A Chi-square test was conducted to examine gaze behaviour and compare the distribution of gaze categories (saccades, fixations, and long fixations) among participants and road sections. This was complemented by Bonferroni-adjusted post-hoc pairwise comparisons, which allowed the identification of specific differences in visual strategies across users. For the numerical data derived from EEG sensors, specifically the Attention and Meditation metrics, a Univariate Analysis of Variance (UNIANOVA) was employed to assess whether these cognitive indicators varied significantly by user or route segment. This statistical technique also enabled the analysis of potential interactions between users and route conditions. After the statistical analyses of variance, the k-Nearest Neighbors (k-NN) machine learning algorithm was applied to evaluate the relationship between sensor data and subjective workload ratings reported via the NASA-TLX questionnaire. It provided insight into how local variations in gaze patterns, attention, and meditation levels could predict subjective perceptions of mental workload.

RESULTS

The statistical analysis revealed several significant ($p < 0.05$) findings regarding cyclists' visual behaviour and mental workload. The Chi-square test on gaze behaviour showed statistically significant differences in the distribution of glance types across users and route sections. These results confirmed that cyclists employed distinct visual strategies depending on individual traits and encountered road environmental conditions. Similar and consistent insights were gained through the UNIANOVA tests conducted on EEG data. The results indicated that both the identity of the cyclist and the particular road section significantly affected attention and meditation levels. Moreover, the interaction between the user and the section was significant, meaning that cyclists responded differently to the same segment depending on their individual characteristics. To investigate the predictive relationship between objective sensor data and subjective workload, the k-Nearest Neighbors (k-NN) algorithm was applied. The model achieved moderate to strong predictive performance with a classification accuracy ranging from 46% to 75%. Despite differences in individual measurements, the relative variations in sensor data across route segments were consistently aligned with participants' perceived workload scores. Feature importance analysis within the k-NN model highlighted the relevance of the different features and the need for multi-sensor integration to achieve the highest accuracy. Glance type was the most influential predictor of subjective workload, followed by Meditation. While still relevant, Attention contributed the least to predicting how cyclists perceived mental demand.

CONCLUSIONS

This study offers valuable insights into how cyclists perceive and respond to the cognitive demands of navigating urban road environments by combining objective sensor data with subjective workload assessments. Despite individual differences, common patterns have been identified. Objective indicators of gaze behaviour and EEG levels closely align with how cyclists evaluate mental effort and environmental complexity. Results suggest that visual engagement and mental relaxation are central to shaping the perception of effort and stress while cycling, especially in environments with lower cognitive complexity.

ACKNOWLEDGEMENT

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71.Camera-based bike infrastructure and cyclist gesture recognition for trajectory prediction of cyclists

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Introduction

Cyclists are still among the most vulnerable road users. Camera-based approaches that recognize cars and their lanes already exist today, whereas cyclists and especially their infrastructure are often overlooked. Cyclists have to share the road with motor vehicles frequently, e.g. when bicycle infrastructure ends or is blocked, creating potentially dangerous situations. These may be anticipated by experienced human motorists. I work on enabling autonomous vehicles or lesser experienced motorists with a driver assistance system to have a similar situational awareness. Modern vehicles are equipped with a large number of sensors, among them cameras, that allow to perceive the surroundings. Trained computer vision (CV) algorithms to recognize bicycle infrastructures and cyclists' gestures are yet missing though.

Research methodology

In order to overcome this, a field study in form of a traffic observation took place. It aimed at identifying cyclist gestures in different traffic situations, such as merging and turning scenarios (Gross and Mueller, 2024). The gestures that were found to be meaningful, in particular hand signs and shoulder checks, are to be classified by the CV algorithm. In addition, bike paths (and signs for one), as well as cyclists and their distance should be found.

A literature study was performed to identify the most prevalent CV approaches for lane and object detection in traffic research as well as datasets that include traffic. I used publicly available datasets that include images and videos of different traffic scenarios, such as e.g. Cityscapes (Cordts et al., 2016), and merged and labelled them with additional features. These features include bike lanes, cyclists and their gestures. For the latter, additional data from the cyclist arm sign recognition dataset (CASR) from Fang and Lopez (2019) were used. Six CV models are then trained and tested with adjusted hyper parameters on this dataset and compared to each other.

Results

The models used are compared with respect to mean average precision, based on mean average precision calculated based on intersection over union (IoU) with two different confidence thresholds for each class, and inference speed metrics. When weighing these two metrics uniformly, CV approaches from the you only look once (YOLO) family (Redmon et al., 2016) performed best on the described dataset. Yolov8 reached a mean average precision with a threshold of 50% (mAP50) and 95% (mAP95) of 0.731 and 0.635 respectively. The metric for the inference speed largely depends on the used hardware and is thus only qualitatively comparable. The inference for all classes and segmented bike paths took 129ms. The following figure shows the annotated image.

The results of the CV algorithm presented here are used in turn to calculate cyclist position and the route of the lane of the ego vehicle as well as the route of the bike path.

Discussion and Conclusion

Real world data with annotated bike paths and cyclists proved to be difficult to find, a mix of different datasets therefore had to be created. CV algorithms that are prevalent, such as the YOLO model, provide good performance when applied to cyclist and bike path recognition. The results generated by the CV algorithm are used to model future actions of cyclists, so that motor vehicles can anticipate them. This is to be done in future works.

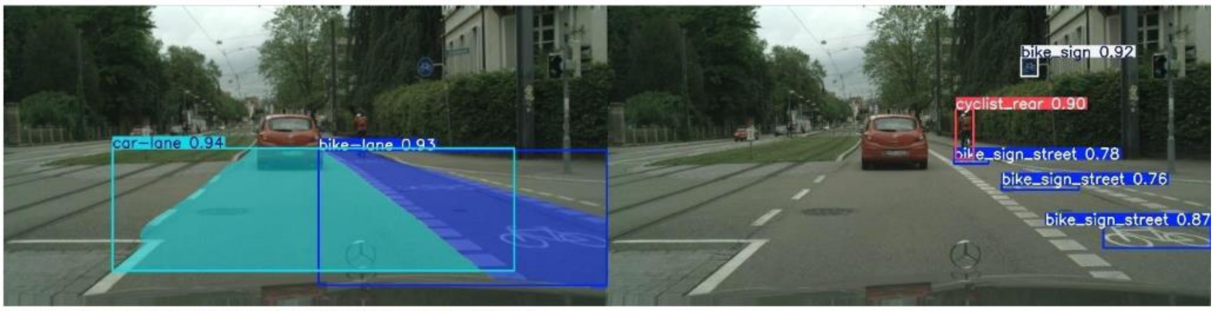

Figure 1: Annotated image from the Cityscapes dataset

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72. Comparison of Human and ADAS perception of lane markings in different road and environmental conditions

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INTRODUCTION

Road markings are recognized as essential road infrastructure elements, and they now serve a dual role in supporting human drivers and Advanced Driver Assistance Systems (ADAS) in automated driving vehicles. The markings' perception contributes significantly to road safety by providing visual guidance for lane keeping, navigation, and situational awareness. Human drivers interpret road markings through a complex interplay of visual perception, learned driving behaviours, and cognitive processing. This interpretation is influenced by human factors and external conditions such as ambient lighting, visibility (e.g., night driving, rain), road geometry, and the quality of the markings themselves. In contrast, ADAS systems rely on computer vision algorithms and sensor fusion (e.g., cameras & LiDAR) to identify and interpret road markings. While these systems can offer consistent and fatigue-free performance, they remain sensitive to several limitations—particularly in edge cases involving poor lighting, occlusions, worn-out markings, or adverse weather conditions. The potential divergence between human and machine interpretation of road markings raises critical questions regarding the robustness of current infrastructure and the readiness of roads for human and automated driving. This research aims to explore these disparities by analyzing field-collected data on road marking visibility and quality and comparing objective sensor-based evaluations with subjective human perception. Key areas of investigation include detection range, response to environmental variability, and the ability to interpret degraded markings.

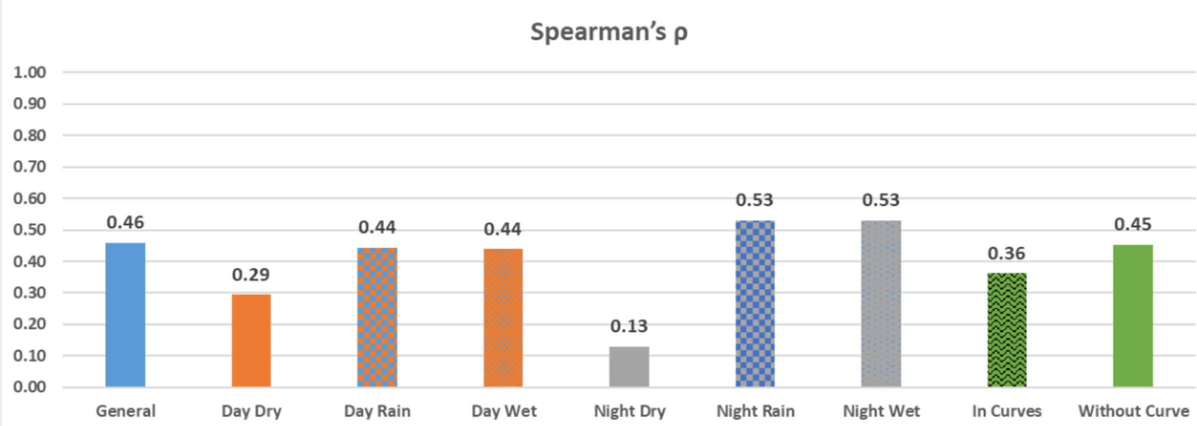
METHODOLOGY

The experimental approach integrates ADAS and subjective in-field assessments of road marking quality. The data collection campaign was conducted on approximately 450 km of two-lane rural roads with repeated measures under various lighting (daytime, night-time) and weather conditions (dry, wet, rain). The road segments covered various geometric configurations and marking conditions to ensure a comprehensive dataset. Road features include horizontal alignment, lane and shoulder widths, lane marking retro-reflectivity coefficient (RL) in [mcd/lx/m²].

ADAS data is obtained through a state-of-the-art vision-based Lane Assistance System (Mobileye 6.0). Lane marking quality was classified using a three-level quality scoring system (1 = low, 2 = medium, 3 = high quality) based on Mobileye's proprietary detection algorithms. Human subjective evaluations were collected from the driver, who provided real-time judgments during the survey. The driver (trained in road safety inspection) provided real-time subjective assessments of road marking quality using the same 3-point scale (1 = poor, 2 = acceptable, 3 = good). These judgments were synchronized with the sensor data and GNSS positioning through a specifically developed data logger, allowing direct comparison between human perception, automated detection, and road characteristics.

RESULTS

Overall, comparing the judgments between ADAS and Humans shows a higher frequency of poor and lower frequency of good classifications of marking quality given by the driver compared to the ADAS. That could be associated with a better performance of ADAS in detecting road marking. Spearman correlation is a no-parametric test we applied to assess the monotonic relationship between the ranks provided by human driver and ADAS. The Spearman correlation showed a moderate but significantly different from zero (P-value < 0.001) correlation between machine and human vision's ranks of marking perception. Therefore, we can assume a general agreement between the rank position of the two quality scores. The figure illustrates that the general Spearman's ρ value is 0.46, indicating moderate agreement. However, the level of correlation varies across specific conditions. The lowest correlation is observed under Night Dry conditions (ρ = 0.13), suggesting limited consistency between ADAS and human judgments in this context. On the other hand, the highest correlations are found during Night Rain and Night Wet scenarios (ρ = 0.53), where agreement appears stronger. Daytime conditions show moderate correlations, with Day Rain and Day Wet at 0.44 and a lower value under Day Dry (ρ = 0.29). Geometric conditions also influence the correlation, with a higher value on Straight segments (ρ = 0.45) than Curves (ρ = 0.36). These variations suggest that environmental and geometric factors play a significant role in the consistency of marking perception between ADAS and human drivers.



Therefore, the factors affecting the difference between ADAS and human visual perception were investigated more closely through a discriminant analysis. The primary goal of discriminant analysis is to identify factors that maximize the separation between predefined classes. This procedure can consider multivariate factors and provides information on the individual dimensions. Discriminant analysis reveals that combining lower RL values in road sections with wide lanes and narrow shoulders at Daylight conditions is associated with a more evident separation between the two groups with a higher chance of lower agreement between human and ADAS scores.

CONCLUSIONS

The study reveals a moderate overall agreement between ADAS and human evaluations of road marking quality, with ADAS generally rating markings more positively. Ranking agreement varies by environmental conditions, with the highest correlation during night rain/wet and the lowest in daylight and dry pavement. Road geometry also affects ranking consistency, with better agreement on straight segments than curves. The discriminant analysis helped identify the combined roles of RL and distribution of lane and shoulder widths to improve the perception, especially in daylight conditions. These findings highlight the need to consider environmental and geometric factors when assessing infrastructure readiness for human and automated driving and suggest targeted improvements to support both human and machine perception.

73.Estimating Crash Risk at Unsignalized intersection from Traffic Conflicts in Mixed Traffic Using Extreme Value Theory

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Introduction

In many low- and middle-income countries (LMICs) such as Cameroon, traditional road safety analysis primarily relies on crash data, which often suffers from significant underreporting, incomplete records, and delayed reporting. This makes the analysis reactive, ethically problematic, and less effective in identifying emerging safety hazards. In contrast, traffic conflict analysis, which involves the examination of near-crashes or other safety-critical events, offers a more proactive approach to understanding road safety. However, the application of surrogate safety indicators such as Time-to-Collision (TTC) and Post-Encroachment Time (PET)—standard in high-income countries (HICs)—may not be directly applicable to mixed-traffic environments common in LMICs, such as Yaoundé, due to their inherent heterogeneity, less organized traffic flow, and frequent interactions between motorized and vulnerable road users (VRUs). This study investigates how traffic conflict indicators perform in the context of an unsignalized intersection in Yaoundé, Cameroon, and applies Extreme Value Theory (EVT) to model crash risk based on traffic conflict data in an effort to overcome the lack of reliable crash data.

Methodology

The case study was conducted at a busy unsignalized intersection in Yaoundé, characterized by a mixed traffic environment where pedestrians, motorcycles, and cars interact in a largely unregulated manner. Video data were collected over both peak and off-peak hours across four days, providing a representative sample of the intersection's traffic flow. Traffic conflicts were identified based on standard surrogate safety measures such as TTC and PET, along with kinematic indicators like deceleration and the change in velocity of approaching vehicles. These conflict indicators were assessed against established thresholds from HIC studies but were tailored to account for the unique characteristics of Yaoundé's traffic. Given the challenges of direct crash data collection, Extreme Value Theory was applied to the most severe traffic conflicts (the tail end of the conflict distribution) using the block maxima approach to estimate the probability of crash occurrence from traffic conflict data. This method allows for the extrapolation of rare events, such as crashes, based on observed conflict severity and frequency.

Results

- Surrogate safety indicators such as PET and TTC revealed high false positives when applying the standard thresholds from HIC studies. This is primarily due to the high frequency of close interactions in Yaoundé’s mixed-traffic environment, where vehicles and pedestrians often maneuver closely without necessarily resulting in crashes.
- The composite kinematic indicators (e.g., deceleration rates and vehicle speed reduction) proved to be more reliable in identifying critical conflicts than the standard proximity-based measures, particularly in high-risk interactions such as those involving pedestrians and motorcycles.
- EVT models applied to the upper tail of the PET distribution demonstrated a strong correlation between observed conflicts and predicted crash risk. The model provided reasonable estimates of crash probabilities, even in the absence of historical crash data, highlighting the potential of EVT as a tool for proactive safety management in resource-constrained environments.
- Vulnerable road users, especially pedestrians and motorcyclists, were involved in the highest-risk conflicts, underscoring the importance of focusing on their safety in mixed-traffic settings.

- The intersection's safety risk was largely concentrated in specific conflict types—especially crossing pedestrians and left-turning vehicles, which exhibited the highest conflict severity and potential for collision.

Discussion and conclusions

This study shows that HIC-based safety indicators like TTC and PET need adjustment for LMICs, particularly in Yaoundé's mixed traffic. Kinematic indicators, especially deceleration, offer a more accurate measure of conflict severity. Extreme Value Theory (EVT) provides a promising method to estimate crash risk in the absence of reliable crash data but requires local calibration due to traffic heterogeneity. Vulnerable road users, particularly pedestrians and motorcyclists, are more involved in severe conflicts, highlighting the need for targeted interventions.

In conclusion, conflict-based safety analysis, combined with localized surrogate safety indicators and EVT, is essential for predicting crash risk and guiding safety interventions in LMICs. Future research should focus on refining these indicators and using microsimulation for real-time risk prediction.

74. A Software Solution for Analysis and Heatmap Generation for Pupil Core Eye Tracking Data

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INTRODUCTION

Eye tracking is a prominent method used in behavioural research, mostly to study cognitive and visual attention-related processes (Krishna & Choudhary, 2025; Zhang et al., 2022). It quests the curiosity of researchers to know where a person is looking and also reveals insights into the attention and decision-making behaviour of the person (Krishna & Choudhary, 2025; Lévêque et al., 2020). The growth and advancement in the use of eye-tracking technology leads to the need for affordable and precise software to process this huge data of eye-tracking, extract the required parameters and do comparative analysis.

AIM

This study aims to develop open-source eye tracker parameter extraction software that helps process eye-tracking data. This software package is currently being developed considering pupil eye trackers, but it is expected to be extended to other eye trackers. This software aims to generate a heatmap for the custom-designed Area of Interest (AOI) for a stimulus to understand user behaviour comprehensively.

METHOD

In this study, a pupil core eye tracker is used to capture the eye movements of the participants. The eye tracker data is collected from pedestrians involved in road crossing activity using a pedestrian simulator setup. The eye tracker parameter extraction is a two-stage process: i) obtaining raw pupil and fixation data from the pupil player software and ii) extracting eye tracker parameters from the software package.

Raw data extraction: Pupil player software is used to visualize and pre-process the raw data obtained from the pupil core eye tracker.

Parameter extraction: The pre-processed data is directly fed into the custom-designed software, and useful parameters are extracted as CSV files. In addition, a heatmap is also generated based on fixation data and AOIs by producing 2D Gaussian distributions at the middle of each AOI, scaling by fixation frequency and applying a threshold to remove low intensity noise.

Obtaining comparative base data: From the PyTrack repository, Tobii Pro eye tracker data is used to obtain relevant parameters as base values. Further, the same data is transformed into a compatible format as input to custom-designed software to obtain relevant parameters for comparison.

RESULTS

The extracted parameters, such as interpolated pupil size data for the eye after fixing blinks, x and y coordinates of gaze for both left and right eye and the onset and offset data of blinks for both eyes from the Tobii raw data using PyTrack are shown in Figure 1. Similarly, the parameters such as the count, amplitude, and velocity of saccades, as well as count, peak blink duration, and average blink duration, extracted from custom-designed software using pupil data, are shown in Figure 2.

	ETRows	FixationSeq	Gaze_left_x	Gaze_left_y	Gaze_right_x	Gaze_right_y	InterpPupilSize	InterpGaze_left_x	InterpGaze_left_y	InterpGaze_right_x	InterpGaze_right_y	GazeAOI
2	0	-1	609.5672	253.0071	618.7541	250.7501	3.251190543	609.5671997	253.0070953	618.7540894	250.7501068	1
3	1	0	612.0703	254.9737	617.286	250.0298	3.249855042	612.0703125	254.9736938	617.2860107	250.0298004	1
4	2	0	611.1938	258.9674	614.8091	254.7547	3.270766973	611.1937866	258.9674072	614.809082	254.7546997	1
5	3	0	613.558	254.5444	614.3433	250.5129	3.256165028	613.5579834	254.5444031	614.3433228	250.5128937	1
6	4	0	613.5972	251.4746	614.0929	248.0512	3.258507013	613.597229	251.4745941	614.0928955	248.0511932	1
7	5	0	611.4723	255.2386	614.9269	252.9486	3.260528445	611.47229	255.2386017	614.9268799	252.9485931	1
8	6	0	610.219	257.7009	612.743	252.5071	3.266479492	610.2189941	257.7008972	612.742981	252.5070953	1
9	7	0	613.1401	257.0662	614.5437	257.2897	3.255798459	613.1400757	257.0661926	614.5437012	257.2897034	1
10	8	0	610.6551	252.63	612.95	257.3961	3.257545471	610.6550903	252.6300049	612.9500122	257.3960876	1
11	9	0	613.6504	253.6702	612.7264	251.9153	3.256096005	613.6503906	253.6701965	612.7263794	251.9152985	1
12	10	0	614.1464	250.3089	613.8099	245.7491	3.249046564	614.1464233	250.3088989	613.8098755	245.7490997	1
13	11	0	612.8929	250.277	616.6858	254.283	3.25276196	612.8928833	250.2769928	616.685791	254.2830048	1
14	12	0	609.8797	255.3501	614.5151	253.1047	3.256767511	609.8796997	255.3500977	614.5150757	253.1047058	1
15	13	0	610.9262	252.9637	611.3455	245.1213	3.246825933	610.9262085	252.9636993	611.34552	245.1213074	1
16	14	0	613.8459	250.7006	616.0353	250.6723	3.2629776	613.8458862	250.7006073	616.0352783	250.6723022	1
17	15	0	606.8486	250.5827	618.5262	249.9635	3.260315061	606.8485718	250.5827026	618.5261841	249.963501	1
18	16	0	610.575	258.3244	611.2964	251.0886	3.256637454	610.5750122	258.3244019	611.2963867	251.0885925	1
19	17	0	612.7543	247.3368	613.3429	253.3593	3.249748468	612.7542725	247.3368073	613.3428955	253.3592987	1
20	18	0	609.3394	255.3383	614.2374	253.5043	3.243713498	609.3394165	255.3383026	614.2374268	253.504303	1
21	19	0	610.9399	256.4947	613.3391	247.6872	3.266212583	610.9398804	256.4946899	613.3391113	247.6871948	1
22	20	0	612.0701	252.7717	613.5733	245.7885	3.248268008	612.0701294	252.771698	613.5733032	245.7884979	1
23	21	0	608.054	256.2679	611.6772	250.5858	3.254867435	608.0540161	256.2679138	611.6771851	250.5858002	1
24	22	0	612.5834	259.1968	612.7907	244.0939	3.242348075	612.583374	259.1968079	612.7907104	244.0939026	1
25	23	0	605.7459	256.9689	614.1198	250.5275	3.24612391	605.7459106	256.9689026	614.119812	250.5274963	1

	Blinks_right_onset	Blinks_right_offset
2	177	367
3	628	725
4	842	887
5	11465	12276
6	12659	12857
7	24595	24755
8	29262	29339
9	39158	39221
10	48338	48399
11	50634	50960
12	56457	56540
13	62875	62917
14	64167	64215
15	64467	64666

	Blinks_left_onset	Blinks_left_offset
2	250	359
3	621	726
4	841	888
5	1020	1027
6	11469	11710
7	11896	12276
8	12659	12857
9	24596	24754
10	29259	29341
11	39157	39220
12	48337	48398
13	50634	50955
14	56455	56607
15	62875	62936
16	64167	64230
17	64537	64664

Figure 1: Parameter obtained from PyTrack using Tobii data

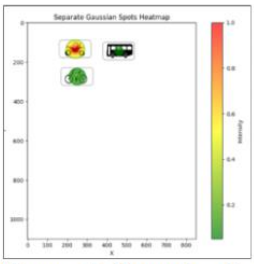
	diameter	timestamp
2	0	51976.33131
3	0	51976.3416
4	0	51976.34725
5	0	51976.36325
6	0	51976.37129
7	0	51976.37924
8	0	51976.38735
9	0	51976.39526
10	0	51976.40326
11	0	51976.41129
12	0	51976.41926
13	0	51976.42736

	x	y	confidence	timestamp
2	22.22309	0.04124	0.85224	51976.36128
3	266.33091	-42.84721	0.78565	51976.36729
4	247.6354	-46.92433	0.99	51976.40727
5	246.70969	-48.15004	0.81965	51976.4153
6	246.00556	-49.05112	0.89677	51976.42328
7	245.386	-49.59764	0.82097	51976.43127
8	244.69216	-50.64547	0.97539	51976.47124
9	246.66462	-50.30698	1	51976.47937
10	247.44111	-48.76817	1	51976.48733
11	248.09097	-47.82677	0.97193	51976.4953
12	248.79569	-47.22087	1	51976.50327
13	251.41767	-45.32356	1	51977.20739
14	247.70295	-45.51203	0.99	51977.74263
15	321.48394	-170.56722	0.99	51977.90175
16	325.89824	-165.72351	0.75959	51977.9593

```
Count of Saccades : 53209
Amplitude of Saccades : 19161.3
Velocity of Saccades : 39924926
Count of blinks : 2180
Peak Blink Duration : 208.852
Average Blink Duration : 0.456758
```

Figure 2: Parameter extracted from custom-designed software using Pupil Core Eye Tracker data

Generation of Heatmap: The semi-transparent overlay heatmap generated using the code shows the gradual variation of colour from green to yellow to red, indicating the increasing focus or activity in that AOI. The AOIs that are visited most often have the brightest red glow, and the ones that are not visited remain transparent. The software is designed to customize any AOI of interest in any shape and size and get the coordinates of the AOI, as shown in Figure 3.




```
Image file exists: True
Image array type: <class 'numpy.ndarray'>
Image array shape: (1100, 850, 4)
Heatmap shape: (1100, 850)
Processing label: 18
Center: (241.0, 136.0)
Processing label: 16
Center: (462.0, 146.75)
Processing label: 4
Center: (250.75, 275.25)
```

Figure 3: Sample of a generated heatmap

Feature	Other software's	Our Software
AOI-based heat origin	**No:** It uses raw gaze points binned into 2D histograms.	**Yes:** It uses labeled AOIs, calculating the heat origin from the centroid of each defined polygon.
Weighted by attention metrics	**No:** Intensity is derived from raw frequency of gaze hits.	**Yes:** Intensity is scaled based on custom metrics such as time spent.
Per-AOI Gaussian smoothing	**No:** Applies a global Gaussian filter after histogram creation.	**Yes:** Custom per AOI. Generates per-AOI multivariate Gaussian distributions for controlled smoothing.
Noise threshold & transparency	**No:** Not included	**Yes:** Applies a customizable intensity threshold, removing noise and allowing transparency rendering.
Overlap-aware heatmap merge	**Yes:** Simple binning	**Yes:** Glues (no maximum) for combining Gaussian layers, with layering for clarity.
Aggregated/group analysis	**Yes:** Built-in	Manual (extension possible)

Figure 4: Feature-by-feature comparison

DISCUSSION

This software can easily extract required parameters related to saccades, blinks, and pupil size from the raw data obtained from Pupil player software, especially from the pupil core eye tracker. Moreover, this software gives greater flexibility in designing AOIs and heat maps for the same. The most important difference between the developed software package and other software packages is in heatmap generation. Further, the feature-by-feature differences are explained in Figure 4.

CONCLUSION

This easy-to-use software can extract useful parameters simply by giving the files exported by the pupil player as they are in the input. The most important difference between the developed software package and other software packages is in custom-designed AOIs with heatmap generation.

75. Conflict prediction of vehicles and cyclists at urban intersections by time-series classification

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Background

Conflict prediction in traffic situations—especially for interactions of vehicles and cyclists—still offer research questions: for example, it is still unclear what exact features are the most important, what Surrogate Measures of Safety (SMoS) are most suitable and generally applicable, what thresholds should be applied, and if and to what extent threshold values and their uncertainties are depending on distance to a collision point during a situation. Moreover, it remains a challenging task to identify conflicts at an early stage and if conflicts can be predicted solely based on trajectory data and thus implicit features like mutual awareness (lowering the probability of a conflict) can be deduced—despite noisy data—or if additional visual features like gaze direction of the cyclist are necessary to achieve high prediction accuracies.

Goal

The goal is to determine the possibility of an early detection of upcoming conflicts during an approachment of a cyclist and a (right-turning) vehicle and the probability of conflicts depending on the distance to a conflict or collision point, respective. Further, determine a minimal feature set necessary to achieve that goal and the best method. This includes the analysis of the influence of SMoS, which are themselves derived from trajectory data (and their motion prediction). An additional goal is to determine the necessity of motion prediction for conflict prediction, or if observed motion and estimated collision point are sufficient.

Method

Consider the prediction task as a supervised classification task of partial trajectories, i.e. time-series of status of the interacting road users (time, position, velocity, acceleration, heading). Several baseline machine learning methods like Random Forest and Support Vector Machine and deep learning methods, e.g. LSTM based variational autoencoder and transformer network are applied and their accuracies compared. A minimal feature set is determined, including an analysis of influence path/motion prediction and derived SMoS like predicted PET (pPET) on the accuracy of the classification.

Data and experiments

Evaluation (training and testing) is conducted on the publicly available LUMPI dataset [1] provided by the Leibniz University of Hannover. Video data and object bounding boxes of traffic participants on an urban intersection in Hannover are available, although object detection and road user tracking have to be re-done for extending trajectories to be able to get sufficient early prediction possibilities during the approach phase of an interaction. Conflicts are determined by a visually detectable evasion maneuver and manually labelled.

Outcome and conclusion

The LUMPI dataset is provided with new trajectories and conflict labels and made publicly available. The expected results on this dataset are, that conflicts can be detected early solely based on trajectory classification. Further, it is expected, that the machine learning methods, i.e., Random Forest and Support Vector Machine achieve lower accuracies than the Deep Learning methods, which should be able to capture time dependencies and learn complex temporal features from time-series representing behavioral patterns in trajectories.

The evaluation will provide results of prediction accuracies for conflicts depending on the distance to the potential collision point. It will also provide details about feature importance and thereby, e.g., show what influence additionally provided SMoS have on the classification outcome. Depending on the quality/accuracy of classification outcomes the question can be answered, if implicit features can be detected from trajectory data.

References

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76.Factors Influencing Average Fixation Duration of Pedestrians: Insights into Situational Awareness Under Time Pressure

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Introduction and Objective

The average fixation duration (AFD) is a measure used to understand the attention span of pedestrians while crossing the road. A longer AFD usually means more focus and a higher level of awareness. Therefore, pedestrians' situational awareness, which helps in making safe crossing decisions, is correlated with the amount of time spent observing vehicles and signals to gather additional information about their environment. When pedestrians are under time pressure, the pedestrians opt for more risky crossings, which may be the result of reduced attention towards vehicles or signals. Therefore, the current study aims to understand the dynamics of situational awareness of pedestrians under time-pressure situations by assessing the AFD of vehicles and signals.

Methodology

The pedestrian behaviors were tested using a projector-based pedestrian simulator setup (Figure 1) with a pupil eye tracker (Figure 2). Figure 3 displays the intersection layout, where pedestrians crossed from point A to B. Pedestrians' experiments were conducted under three conditions. The first is the baseline condition, which has no time pressure (NTP) induced. The other two-time pressure levels, which are Low Time Pressure (LTP) and High Time Pressure (HTP), were induced using hypothetical situations. A timer showing the amount of time left to cross the junction was also used (Figure 4). Finally, in total, 171 observations were obtained from 57 participants.

Figure 1: Projector-Based Pedestrian Simulator Setup

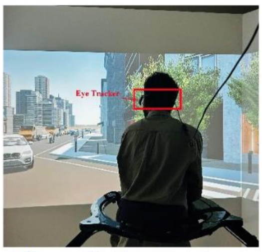

Figure 2: Eye Tracker Setup

Figure 3: Intersection Layout with Crossing Locations

Figure 4: Stopwatch Timer

Results

Since the AFD is a continuous dependent variable with multiple observations from each participant, a generalized linear mixed model (GLMM) with gamma distribution and log link was used. Two different

GLMM models were prepared: (i) Vehicle AFD and (ii) Signal AFD. In the current study, the effects of various factors, like time pressure conditions, scenarios, age, gender, crossing speed, waiting duration and whether they crossed the intersection in two stages, were observed on the AFD of vehicles and signals.

According to the results, the effects of time pressure were not significant for Vehicle AFD but for Signal AFD. It explained that under HTP, pedestrians were less likely to focus on signal lights. The signal scenario (i.e., End of Green (EG), Middle of Red (MR) and End of Red (ER)) was significant for Vehicle AFD only and not for Signal AFD. It showed that pedestrians crossing during the ER scenario have lower vehicle AFD than those crossing during the EG scenarios. Further, the interaction effect of EG and MR with waiting duration showed that pedestrian's Signal AFD decreased with each unit increase in waiting durations when they were crossing during the EG and MR scenario. However, these effects were insignificant for Vehicle AFD. Pedestrians who crossed the road in two stages had a considerably longer Signal AFD and a shorter Vehicles AFD than those who crossed the road in one go. Further, as the pedestrian's speed increases, the Signal AFD also increases. Age also played a significant role in influencing the AFD. It was observed that the vehicle AFD of middle-aged (30-45 years) pedestrians was lower than that of younger pedestrians (18-30 years). Finally, the results showed that males had a higher fixation duration than females.

Discussion and Conclusion

The current study evaluated the effects of various time pressure levels on the AFD of vehicles and signals. It was found that time pressure conditions had no impact on Vehicle AFD, but it significantly affected Signal AFD. Pedestrians may have attempted to avoid being engaged in collisions in each of the conditions; therefore, they might have thoroughly looked at the vehicles in every condition. However, under HTP conditions, the overall AFD at signals decreases, most likely as a result of pedestrians evaluating the surrounding information by looking at the traffic conditions in general.

Understanding these parameters can help to understand pedestrians' behaviors and take adequate measures to improve road safety and avoid accidents. Future research can continue to explore the dynamics of pedestrians in varied environments with a wider population range to validate and expand the results.

77. Analysis of the combined effect of AVs and cycling infrastructure on the gaze behavior of cyclists

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Introduction

To explore cyclist behavior in controlled yet realistic conditions, a validated indoor bicycle simulator was developed at the University of Győr, Hungary. The system is capable of recording various physiological and biomechanical parameters including speed, leaning angle, steering angle, and heart rate. Additionally, the simulator integrates advanced sensing systems such as computer vision for skeletal tracking and a head-mounted eye camera to capture real-time gaze behavior. This comprehensive setup enables the multi-modal analysis of cyclists' responses in various traffic scenarios.

Aim

The primary objective of this research is to better understand the behavior and visual attention patterns of cyclists in diverse traffic and infrastructure contexts. Cyclists, as vulnerable road users, require careful consideration in the design of future mobility systems, especially in environments shared with Autonomous Vehicles (AVs). By investigating how different road infrastructures and traffic compositions affect cyclists' attention, this study seeks to contribute toward the development of safer, more inclusive transportation networks.

Data Collection

The experiment involved 50 participants, whose data were collected anonymously in accordance with ethical standards. Each participant completed 11 distinct scenarios featuring variations in both infrastructure and traffic composition. The scenarios were designed to reflect realistic urban conditions, including the presence of AVs along with human-driven vehicles. A 200-meter-long test track was used to simulate the 11 scenarios, featuring various combinations of physical infrastructure (sharrows, colored and non-colored dedicated cycling lanes) and traffic compositions with varying AV Market Penetration Rates (MPR) (0/50/100 %) (Table 1). Cycling data were collected in real time using an Arduino-based system:

- a gyroscope measured leaning angles,
- a potentiometer recorded steering inputs,
- a Hall sensor captured speed data.

Heart rate was continuously monitored using a dedicated heart rate monitoring (HRM) sensor. Cyclists' gaze behavior was tracked using a Pupil Labs NEON eye-tracking camera, which also recorded egocentric video footage for synchronization and contextual analysis. Following the experiment, in the current study we aim to focus on gaze behavior data. This analysis is ongoing, and we can report on the expected outcome of our study.

Expected Outcome

Using the collected fixation and gaze data, heatmaps are generated for each scenario, both on an individual and cumulative level. These visualizations aim to highlight Areas of Interest (AOIs) that consistently draw cyclists' attention. By comparing the heatmaps across scenarios, the study seeks to reveal patterns and critical factors influencing where cyclists direct their gaze. Furthermore, the analysis focuses on identifying specific sections of the road where fixation density and fixation duration are notably higher. By quantifying the intensity of attention in these segments, the study aims to better understand how different road features and traffic conditions impact cyclist focus and visual engagement.

	Scenarios				
Features	**A**	**B**	**C***	**D**	**E***
Infrastructure descriptions	Road with sharrows	AVs and bike separated lanes by continuous coloured lines.			
Pavement marking	Sharrows every 50 m 	Yellow continuous line, no coloured pavement for cyclist 		Yellow continuous line; Red bike lane 	
Lane width	Total 4m	AVs L_w=2.75m Bike L_w=1.25m	AVs L_w=2.5m Bike L_w=1.5m	AVs L_w=2.75m Bike L_w=1.25m	AVs L_w=2.5m Bike L_w=1.5m
Traffic composition	AV penetrations rates (0%; 50%; 100%) (*C&E only 100%)				
Traffic volume	Moderate				
Speed limit	50km/h				

Table 1 Scenarios

Automation plays a key role due to the large dataset (~100 GB), facilitating efficient data synchronization, pre-processing, and heatmap generation. The anticipated result is the identification of infrastructural or traffic-related elements that either enhance or impair cyclists' situational awareness. These findings will support evidence-based planning and the integration of AVs into urban mobility in a manner that prioritizes cyclist safety and comfort.

78.Traffic safety in synergy and conflict with other target areas

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Despite significant advancements in traffic safety over the last few decades, numerous challenges remain. The burden of road safety is very uneven globally and even in countries that have seen significant improvements in road safety during the last few decades, the rate of progress is stagnating [1]. Moreover, not all types of traffic accidents have been effectively targeted. While fatalities among occupants of four-wheel vehicles have decreased, the number of deaths and severe injuries among road users like pedestrians and bicyclists remains high [2], [3]. To tackle these issues, there is a push for a more integrated approach between traffic safety and other sustainability targets as road safety is now explicitly included in the Sustainable Development Goals (SDG) [4].

One argument for using a more integrated approach is that it would open new opportunities for implementing traffic safety measures by leveraging synergies among the SDGs [1]. However, this approach will require increased collaboration and cohesion between previously distinct fields, and management of potential conflicts will be essential. There is limited knowledge about what these synergies, conflicts and increased cooperation will mean for traffic safety.

This study aims to identify the related fields and analyse the synergies and conflicts between them and traffic safety. These interactions can be both actual and perceived, in the sense that they are based on the perception and knowledge that individuals in a related field or target area have about road safety, which may differ from those of the traffic safety experts themselves [5]. Therefore, the study also seeks to understand the perspectives on traffic safety within these related fields and the scientific disciplines connected to them.

The study is ongoing and involves a literature review to scope out existing literature on the integrated approach and the related fields to identify potential synergies and conflicts. In addition, interviews with practitioners on a national level from different target areas are carried out. Various intersecting areas have been identified revealing numerous synergies and conflicts. For example, one relevant field with both synergies and conflicts is sustainable mobility and the modal shift to active forms of transportation. Active forms of transportation, such as bicycling and walking, offer many benefits for individuals and society, making the increase in modal shares a desirable development [6]. However, these modes are not without injury risks, and there are differing opinions on how to address these risks across disciplines. The ongoing debate concerning bicycle helmets is one such example. From one perspective, the emphasis on protective gear may portray bicycling as inherently dangerous and that a law-making helmets mandatory may discourage people from choosing the mode of transport. Another critique is that it might shift the focus from the danger motorised vehicles pose to others in the transport system [7]. Conversely, the arguments from a traffic safety perspective are that the advocacy for helmets is based on the empirical evidence showing the positive effects on injury outcomes [3], that the implementation of mandatory helmet law would be a highly cost-effective traffic safety measure, and that there is no evidence that a mandatory helmet law discourages bicyclists.

These differences are based on different values but also different ideas of knowledge and identifying synergies and conflicts between traffic safety and other goals is an initial step for a more integrated approach.

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79.Does Segregating Motorcyclists Improve Safety on Non-Urban Highways? An Extreme Value Theory Approach

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Developing economies like India host a considerable proportion of motorized two-wheelers (MTW) within traffic flow, leading to a higher frequency of MTW-related crashes. Previous studies highlight's that segregating MTW traffic from the main stream by providing a dedicated lane and physical barrier, stands as an effective measure to enhance the safety of motorcyclists and mitigate conflicts with other vehicles in the intricate and diverse traffic environment. Despite these positive findings, a comprehensive safety analysis of Exclusive Motorcycle Lanes (EMCLs) are missing in the existing literature. Therefore, the present study evaluated the safety performance of exclusive motorcycle lane using the traffic conflict technique. The study presents a framework for assessing crash risk at mid-block sections using extreme value theory with time-to-collision data from traffic conflicts pre- and post-EMCL implementation. The study aims to assess the alterations in rear-end conflict and crash risk probability before and after the implementation of EMCL, employing the Extreme Value Theory (EVT) approach.

However, EMCLs are not operational in India. For this sake, the temporary implementation of EMCLs on non-urban highways was made to analyze the safety performance of EMCL corridors. The motorcyclists were segregated using traffic cones and tape from the mixed traffic stream. The vehicular trajectory data were extracted utilizing a fully automated trajectory extraction software and analyzed using traffic conflict techniques, i.e., time-to-collision (TTC). The motorcyclist's interactions were divided into two categories, i.e., safe and unsafe interactions, using an observer rating-based approach for both with and without EMCL cases. The categorization of interaction between vehicles was majorly based on their relative position and speed. The absolute agreement approach was utilized to ensure the reliability and consistency of the ratings given to vehicle interactions by the trained observers. The intra-class coefficient among the trained observers was obtained to be greater than 0.85 in both cases (i.e., with and without EMCL), which signifies good agreement among the observers. To categorize the interactions into safe and critical, the popularly used supervised classification technique, the support vector machine (SVM), has been used. A simple linear kernel function was used to develop the hyperplanes between two severity classes with Bayesian optimization.

Figure 1 presents the SVM classification plots for the TTC indicator, classifying the interactions into critical and safe classes. All interactions between different vehicle categories were considered. It is perceptible from the classification plots that the interaction severity also increases with a vehicle's speed; however, the increasing rate is different among different cases, as shown in Figure 1. It can be witnessed from Figure 1 that in the case of with EMCL case, the hyperplane varied from 0.4 to 0.8 second TTC with different speeds, whereas in the case of without EMCL, it was 0.75 to 1 second. These values were considered as a threshold for developing POT models.

After identifying the thresholds, the POT model was developed for each threshold to estimate the shape and scale parameters based on the negated TTC data. Model estimation results were obtained for each case using minimum, mean, and maximum thresholds. The threshold with the lowest negative log-likelihood value, AIC, and BIC was selected to determine conflict and crash probabilities. As illustrated in Figure 2, rear-end conflict and crash probabilities decreased following the implementation of EMCL. This reduction is attributed to fewer MTW interactions with the rest of the traffic, thereby enhancing the safety of both motorcyclists and other road users.

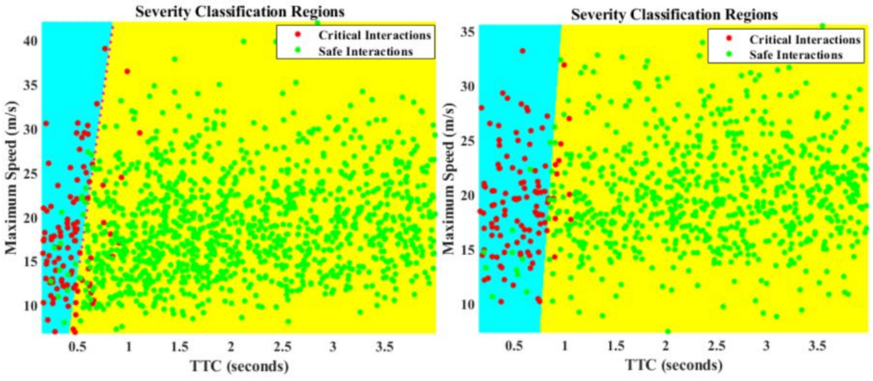

Figure 1 SVM severity classification plots

The key findings of this study are valuable for transport planners, researchers, and government agencies. However, certain limitations should be noted. EMCLs are not yet operational in India, with only pilot studies conducted and limited public awareness. Enforcement efforts are needed to ensure motorcyclists use these lanes. Additionally, the generalizability of the findings may be limited due to the study's site-specific focus. While this study concentrated on evaluating safety, operational performance was not assessed and could be considered as a potential area for future research.

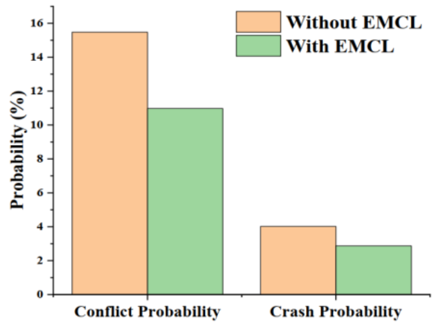

Figure 2 Rear-end conflict and crash probabilities

80. And after one or two boozy drinks? Investigating Young E-scooter Riders' Decision-Making through Conjoint Analysis

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Introduction

E-scooter crashes or injuries at night account for around 50% of all cases [1] and are a major concern, as they are often alcohol-related. With most incidents between 11 PM and 3 AM, alcohol is listed as one of the main crash-related causes in e-scooter riding [2]. Young riders represent the majority of users and are also the most present user group in crash statistics [3]. Our understanding of the factors that influence young riders' decision-making on (drunk) e-scooter riding at night is still limited.

Aim

The present study aims to investigate the influence of the provided transport alternative, availability of this alternative, the e-scooter availability, peers, and security on the decision-making of young users about riding an e-scooter at night or under the influence of alcohol.

Method

We conducted an online conjoint study with 934 respondents from Switzerland, Germany, and Denmark. All respondents indicated that they were at least open to riding an e-scooter, and they were 16 to 35 years old. In the study, respondents were presented with illustrations of nightly scenarios. They were instructed to imagine being on a night out and not having planned how to get from their current location (a bar) to their next one (a club). They were then presented with ten scenarios and asked how likely (6-point Likert scale) they would be to choose the e-scooter (which was always an option) or an alternative transport mode in that scenario (N = 934) and additionally, for the case of having had one or two boozy drinks (n = 717). Five attributes (independent variables) were systematically varied (orthogonal design) across the illustrated scenarios: transport alternative (bus, shared bike, walking), availability of alternative (direct, 5 min), e-scooter availability (direct, 5 min), peers (none, peers suggest the use of e-scooter, peers suggest transport alternative, undecided), and security (low, high). We performed Conjoint Value Analysis with hierarchical Bayes regression, which allows us to calculate the outcomes for all other possible scenarios on relatively few attribute combinations.

Results

The analysis showed that peers and transport alternative were the most critical factors for the riding decision. This pattern is similar to the general riding decision at night and the decision to ride under the influence of alcohol (Figure 1).

A sensitivity analysis was conducted to quantify the influence of the different attribute levels in more detail. A reference scenario is set, and simulations vary one attribute at a time while holding all others constant. That way, each attribute level's isolated protective or deterrent influence can be determined. As a reference, the worst-case scenario linked to the highest e-scooter riding likelihood (shared bike a 5 min walk away, e-scooter directly available, peers decide on e-scooter, security low) was selected. The results show that the likelihood of riding decreases most if peers decide on a transport alternative compared to the reference (-19% general, -11% drunk riding decision). The availability of a bus connection as an alternative to e-scooter riding (-13% general, -10% drunk riding decision), its direct availability (-9% general, -4% drunk riding decision), and a not directly available e-scooter option (-8% general, -4% drunk riding decision) also contribute to lowering the likelihood to ride an e-scooter. The average likelihood over all 80 simulated scenarios to ride drunk (35%) is lower than the general likelihood of deciding on night-time riding (46%). Though the patterns for the sensitivity analysis are similar for both decisions, for the drunk-riding decision, the peers' choice of a transport alternative is not as important.

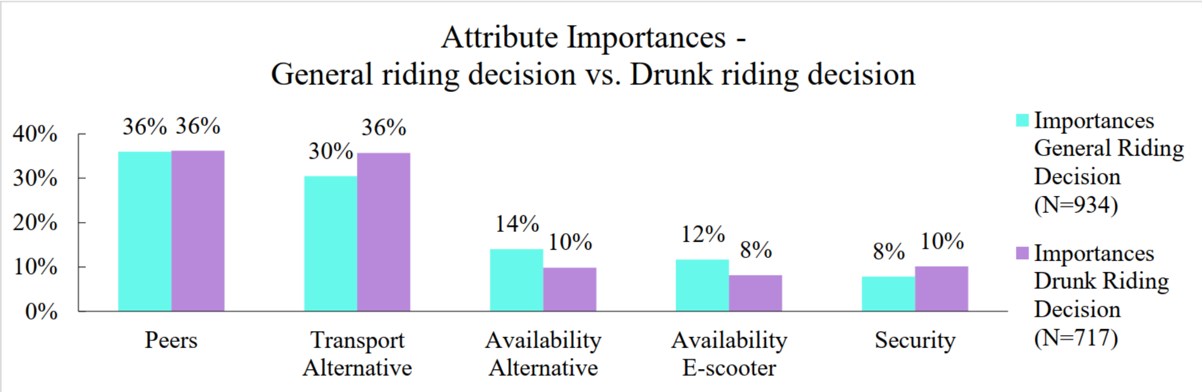

Figure 1. Attribute importance of general vs. the drunk riding decision at night.

Discussion and Conclusions

The first finding is the importance of peer influence on young riders' decision to ride an e-scooter at night, which aligns with studies on peers. Thus, road safety campaigns might target the user group by picturing significant others, e.g., influencers, deciding against the e-scooter in nightly scenarios.

As indicated by mode choice studies, we can confirm the crucial role of providing a public transport alternative. Good public transport connections at late hours are likely to prevent, at least a share of nightly e-scooter rides. While the availability of transport options was of subordinate importance, the findings confirm that measures such as e-scooter restrictions via geofencing, e.g., around pub and club districts, also bear the potential to prevent nightly (drunk) rides.

Funding: The project received funding from the Swiss AXA Foundation for Prevention.

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81. Analysis of the combined effect of AVs and cycling infrastructure on perceived level of safety: a bicycle simulator study

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Introduction

Increasing use of active transportation is a leading strategy towards promoting sustainable mobility. Aligning with this strategy, cyclists' safety has received increasing attention in the last decades, especially that cyclists crash rates involving motorised vehicles are high. Thus, introducing autonomous vehicles (AVs) on urban roads heightened further concerns about AVs' impact on cyclists' safety and the improvements to the current infrastructure. Since AVs are known for their perceptual capabilities and their lane-keeping algorithm accuracy, one of the common recommendations in the literature is to shift from shared roads to separated roads by implementing narrower lane widths for AVs and dedicating the gained space for cycling lanes. While previous research revealed the impact of several factors on cyclists' safety, including the separate facilities, few studies took into consideration the presence of AVs or identified the impact of the AVs' market penetration rate (MPR) experimentally on cyclists. Therefore, this study addresses this gap by examining the impact of autonomous vehicles (presence and market penetration rates) and cycling facilities design features on the cyclists' perceived level of safety, comfort and stress using a bicycle simulator experiment.

Methodology

Experiment design: The bicycle simulator study was conducted with 52 volunteer cyclists between 31 January and 19 March, 2025. The bicycle simulator used in the study is the updated version of the developed one at the University of Gyor, Hungary. The bicycle simulator (Figure 1) consists of a physical bicycle attached to a motion platform allowing ± 6º of tilting on both sides and three monitors with a 180º field of view to display the virtual environment. For a realistic experience, an audio of traffic sounds was played, and the setup of the bicycle simulator was equipped with six ventilators mitigating the wind. The participants experienced 11 scenarios of a 200m length of straight road section under different conditions. By filling out a questionnaire survey, for each scenario, participants evaluated their level of safety, stress, and comfort on a 7-point Likert scale. The scenarios involved 3 AV MPRs (0, 50, and 100%) as well as shared and separated designs (sharrows or advisory bicycle lane and separated bicycle lanes with varying widths and colour) (Table 1).

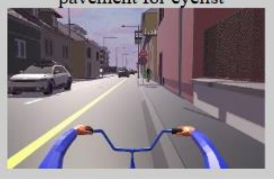
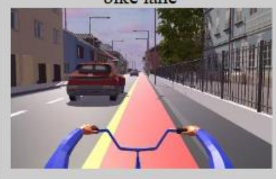
Statistical analysis: An ordinal logistic mixed-effect model was fitted to the observed data to examine the impact of MPRs, road characteristics, individual characteristics on safety, comfort, and stress level.

Results

By analysing the effects of cyclists' characteristics and design features using univariate mixed models, results show that among cyclists' characteristics (age, gender, cycling skills, and cycling frequency), only cycling frequency has a significant effect on the perceived level of safety, comfort, and stress. Regarding penetration rates, there is a trend towards increased comfort at 50% MPR, but it is not statistically significant, whereas 100% AV greatly enhanced cyclists' perception of comfort. However, the improvement of safety was not significant. For red-coloured lanes (Scenarios D, E), we found a significant improvement in terms of safety and comfort. For separated road scenarios (Scenarios B, C, D, and E), wider lanes significantly affected only the safety level.

Figure.1 Bicycle simulator setup

Table 1. Scenarios description

	Scenarios				
Features	**A**	**B**	**C***	**D**	**E***
Infrastructure descriptions	Road with sharrows	AVs and bike separated lanes by continuous coloured lines.			
Pavement marking	Sharrows every 50 m 	Yellow continuous line, no coloured pavement for cyclist 		Yellow continuous line; Red bike lane 	
Lane width	Total 4m	AVs L_w=2.75m Bike L_w=1.25m	AVs L_w=2.5m Bike L_w=1.5m	AVs L_w=2.75m Bike L_w=1.25m	AVs L_w=2.5m Bike L_w=1.5m
Traffic composition	AV penetrations rates (0%; 50%; 100%)				
Traffic volume	Moderate				
Speed limit	50km/h				

Discussion and conclusion

As the literature suggests, cyclists wider cycling lanes are the safest facilities. Even though the comfort was enhanced in AV-dominated environments, cyclists' safety perception did not improve significantly at all MPR, suggesting the reduction of AV benefits when they share roads with conventional vehicles.

Further research is needed to investigate the predictive power of variables by multivariate models and/or decision tree analysis.

82. Examining the variations in situational awareness of impaired pedestrians using Markov Entropy modelling

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INTRODUCTION

Situational awareness (SA) is defined as the extent to which pedestrians perceive, process, and understand their surrounding environment (Lim et al. 2015; Krishna and Choudhary 2025). It can be described as the "measure of how aware pedestrians are of their environment" (Aghabayk et al. 2021). The road-crossing decision-making behaviour of pedestrians largely depends on their visual and auditory sensory systems (Zito et al. 2015; Liang et al. 2022). The visual sensory system, in particular, plays a crucial role during road crossings, allowing individuals to quickly and accurately gather a significant amount of information from a distance (Zito et al. 2015; Liang et al. 2022). Moreover, if pedestrians do not employ a systematic visual search strategy—meaning they fail to assess the surrounding traffic situation while crossing the road—they may misjudge the situation, potentially leading to collisions with other road users (Liang et al. 2022).

METHODOLOGY

In this study, the situational awareness of distracted pedestrians under the influence of different activities like gazing at billboards (BB), texting (TXT), talking (TLK) and listening to music (LM) at signalized intersections is evaluated by using the Markov entropy modelling. The Markov entropy is computed by using equation 1. The distraction behaviour of the pedestrian is assessed in a pedestrian environment, as shown in Fig. 1, which is complemented with a pupil core eye tracker to record the gaze behaviour of the pedestrian

$$H = -\sum_{i=1}^{n} P_i \sum_{j=1}^{n} P_{ij} \log_2 P_{ij} \quad (1)$$

Where, H = Markov entropy; n = Number of AOIs; P_i = Initial probability (or stationary probability) of the i^{th} AOI; P_{ij} = The probability of gaze transition from the i^{th} AOI to the j^{th} AOI.

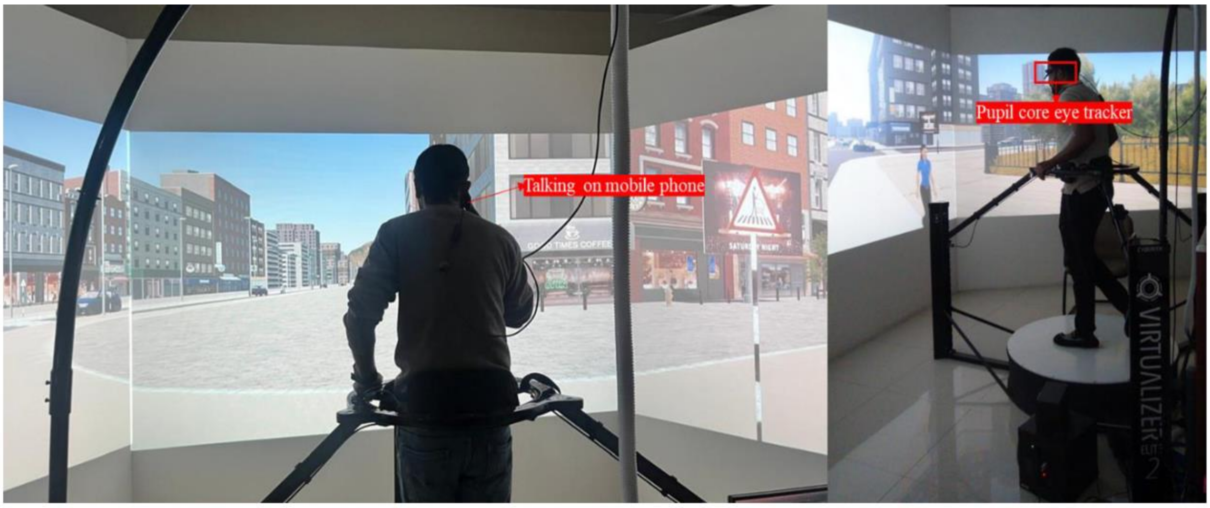

Fig. 1: Pedestrian crossing the road in a virtual environment using a pedestrian simulator setup

The eye tracker data was processed using GazeCode software, and the fixations were mapped onto six Areas of Interest (AOIs): vehicles, wayfinding (WF), fellow pedestrians (FP), multi-task inducing objects (MTIO), traffic infrastructure relevant objects (TIRO), and non-traffic relevant objects (NTRO) (Krishna and Choudhary 2025).

RESULTS AND DISCUSSION

The sequence of gaze fixations observed in different AOIs with respect to different distraction activities is used to quantify the SA of pedestrians using Markov Entropy modelling by Equation 1. The obtained Markov Entropy with respect to each distraction activity is shown in Fig. 2. A higher peak (median Markov values) and more variation in the distribution show less situational awareness with increased cognitive load with inconsistent decisions and delay in transitions, while lower peaks with low variability show a different but equally dangerous drop in awareness, which causes quick, uniform, and possibly unsafe transitions.

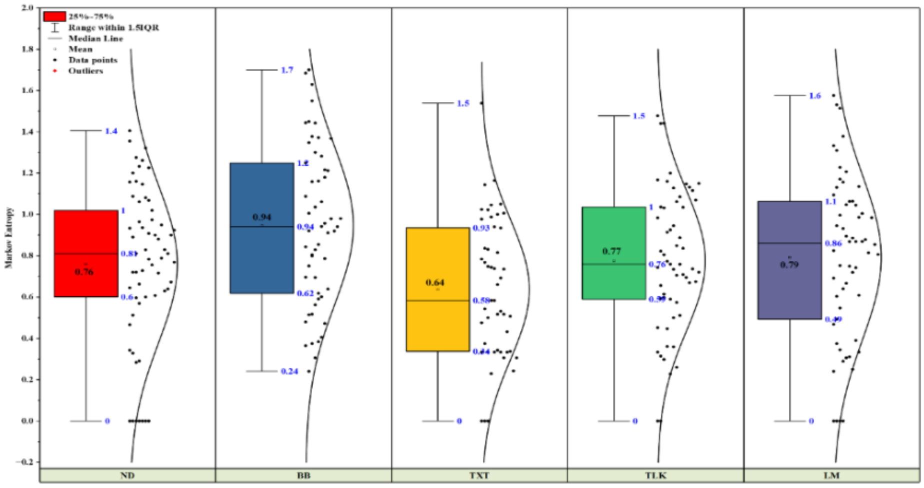

Fig. 2: Box plot and data distribution of Markov Entropy with respect to distraction activity

The Markov values in Fig. 2 illustrate how various distractions affect pedestrian situational awareness by examining both peak values (median) and variability (spread). The ND and TLK activity show low entropy with a moderate peak of around 0.76 and moderate variability, indicating that decision-making is stable and predictable (refer to Fig. 2). On the other hand, BB distraction has the highest peak at approximately 0.94 and the widest spread, resulting in high entropy and unpredictable behaviour, which points to a significant decrease in situational awareness. TXT displays the lowest peak at around 0.64 and minimal variability, suggesting a consistent but risky approach that can lead to quick transitions and low awareness despite its low entropy (refer to Fig. 2). LM has a somewhat higher peak near 0.79 with moderate spread, indicating reduced situational awareness and inconsistent decision-making (refer to Fig. 2). Overall, the greater spread seen in BB and LM conditions indicates increased unpredictability and higher entropy, while the lower spread found in ND and TXT conditions reflects more stable yet varying awareness outcomes.

CONCLUSION

Out of all distraction activities, pedestrians involved in reading billboards exhibited the highest Markov Entropy, indicating reduced situational awareness with an increase in rapid gaze shifts. Moreover, it also implies highly unpredictable decision-making. Moreover, high variation in data distribution is observed among the pedestrians who are involved in reading billboards and listening to music, which clearly showcases the differences in visual attention behaviour of the pedestrians.

83. Insights from an Automotive Use Case for Integrating Services in a Gaia-X Data Ecosystem

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In many modern business use cases, achieving a goal requires collaboration among multiple companies and organizations, particularly when data-oriented assets and services are involved. These collaborations occur because individual companies either lack essential resources or prefer to concentrate on their core competencies due to different areas of expertise and the separation of concerns. For instance, for the homologation of an automated vehicle, various stakeholders, including original equipment manufacturers (OEMs), regulatory bodies, and testing services, must work together to ensure that all safety standards are met. As part of this process, extensive testing, both in the field and through simulation, is conducted to validate vehicle behavior under different conditions. Various type of data, such as high-definition maps and driving scenario description files, is required, along with data-oriented services like test field, simulation, and monitoring services, to conduct and analyse a driving test.

The Gaia-X initiative aims to facilitate the collaborations among companies by enabling a federated data ecosystem. However, our observations and practical experience within the automotive sector of a Gaia-X ecosystem, reveal that this collaborative process is inefficient and tedious. This is because, although Gaia-X federated services support compatibility, secure sharing, and proper data governance, additional challenges must still be addressed by Gaia-X ecosystem participants. Many of these challenges originate from a traditional market mindset, including individually negotiated contracts, isolated metadata queries, and fragmented service integration, all of which slow down processes and delay innovation.

This work aims to address how data and services can be integrated within a Gaia-X ecosystem, and how various metadata serve as the interface between services. Among the various use cases in Gaia-X, we focus on a specific automotive application that is sensor model validation. In developing this use case, we faced significant challenges, particularly in data exchange and aligning stakeholder expectations. Misunderstandings around data and service requirements led to problems. For example, inconsistencies arising at the interfaces between services due to differing data formats and deviations from agreed performance parameters delayed the processes. Furthermore, integration was complicated by the later realization that additional data inputs that initially overlooked were in fact very important.

This work presents the solutions developed as part of a collaborative effort within the sensor model validation use case. We demonstrate how standardized approaches to specify data and services can overcome the challenges. We show how data and services can be effectively offered and accessed within Gaia-X through the specification of detailed metadata, policies, and contracts. In particular, we emphasize the importance of standardized descriptions. For services, this includes defining the expected input and output formats, the parameters involved, and the operational characteristics. For data, this involves specifying the data format, its semantic meaning, indicators of quality, and the policies that govern access. Our findings provide concrete insights into how Gaia-X can enhance the visibility, usability, and seamless integration of services and data within a federated ecosystem, and improve the processes within a collaborative data-driven ecosystem.

84.Understanding Crash Risk at Uncontrolled Intersections: A Driver Perception-Based Conflict Analysis Using PLS-SEM

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Objective

Road safety continues to pose a critical public health challenge, particularly in low- and middle-income countries that account for nearly 90% of global road fatalities. In the South-East Asian region, including India, uncontrolled intersections have emerged as hotspots for road crashes due to their disordered and mixed traffic environments. Although traditional conflict-based analyses offer quantitative insights into intersection safety using objective metrics like time-to-collision and post-encroachment time, they often overlook the psychological and perceptual dimensions that influence driver behaviour. This study seeks to fill this gap by examining how drivers' risk perception, decision-making, and perceived vehicle control contribute to crash risk at uncontrolled intersections. Further, it explores how these relationships are moderated by human factors such as age, gender, driving experience, and vehicle type (car vs. motorcycle).

Method

The study adopts a proactive, conflict-based safety analysis approach that integrates subjective perceptions into traditional traffic conflict frameworks. Data were collected through structured questionnaires administered to drivers who regularly navigate uncontrolled intersections. The survey measured constructs such as perceived crash risk, decision-making tendencies in conflict situations, perceived vehicle control, and individual characteristics (age, gender, vehicle type, and driving experience). A Partial Least Squares Structural Equation Modelling (PLS-SEM) technique was employed to explore both direct and moderating relationships among the psychological constructs and crash risk frequency. This method was chosen for its robustness in handling complex models with latent variables and its suitability for exploratory research.

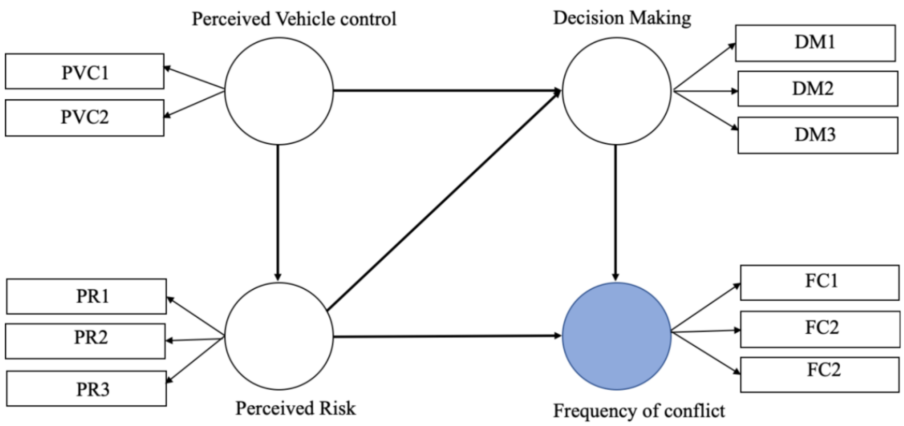

Figure 1: Proposed framework for estimating crash risk frequency of conflict

Results

The PLS-SEM analysis revealed meaningful associations between key driver perception constructs and the frequency of perceived crash risk at uncontrolled intersections. Specifically, risky decision-making demonstrated a strong positive influence on crash risk frequency, whereas a higher sense of vehicle control was associated with a reduction in perceived crash risk. Additionally, risk perception was found to negatively influence risky decision-making, indicating that drivers with heightened risk awareness tend to make safer choices. Figure 1 illustrates the conceptual framework developed to examine these relationships.

The study also investigated the role of driver demographics and vehicle type in shaping these behavioural patterns as shown in Figure 2. Moderation analysis indicated that younger drivers and two-wheeler users were more prone to risky decision-making, thereby increasing their likelihood of encountering conflict situations. While gender and driving experience were found to have a direct influence on crash risk frequency, they did not significantly moderate the relationship between decision-making behaviour and perceived crash risk. These insights highlight the varying safety vulnerabilities among different user groups in complex, mixed-traffic environments, underscoring the need for targeted interventions that account for these behavioural and demographic differences.

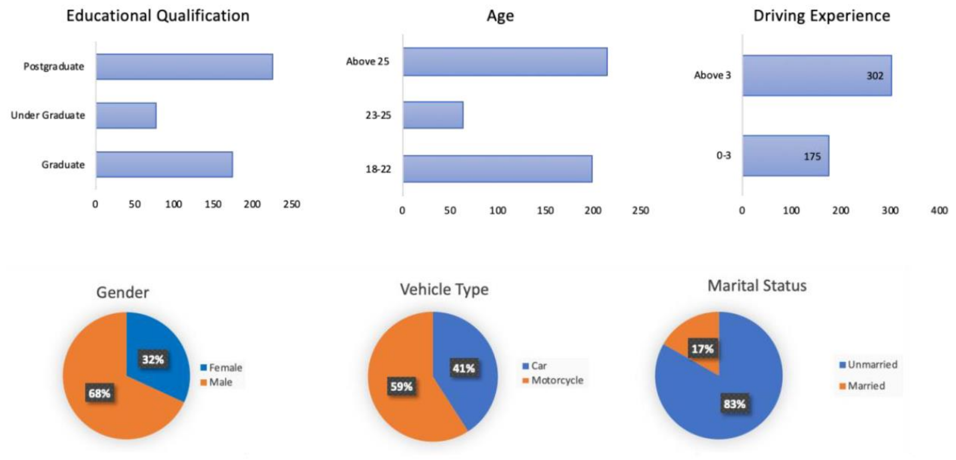

Figure 2: Demographic characteristics

Conclusion

This study contributes to a more nuanced understanding of crash risk at uncontrolled intersections by incorporating driver perception and psychological factors into the traditionally objective framework of conflict analysis. The findings suggest that interventions aimed at improving intersection safety must move beyond infrastructural changes to address the behavioural tendencies of road users. Tailored policy measures, such as targeted awareness campaigns for high-risk groups (e.g., young two-wheeler riders), driver training programs emphasising decision-making in ambiguous traffic situations, and intersection design guidelines informed by human behaviour, can play a pivotal role in reducing crashes. By integrating human-centric insights with empirical conflict data, the study offers a comprehensive framework for enhancing traffic safety in Southeast Asian countries like India, having complex traffic conditions.

85.Towards zero road deaths by 2050? Challenges and gaps in the EU

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Background

Over the past decades, the European Union has developed a road safety policy. In 2011, the European Commission first set out a very ambitious long-term goal to almost completely reduce road deaths by 2050. The EU later reaffirmed this long-term goal several times.

Although road fatalities have fallen since then, progress in Europe has stagnated in recent years. It seems unlikely that the European Union's current medium-term goal of halving road fatalities between 2020 and 2030 will be met. External factors contribute to these results, as do the extent, quality and quantity of systematic intervention and institutional implementation.

Aims

This contribution presents the results of a foresight analysis designed to determine the gap between expected developments and road safety targets in the EU. This foresight study was commissioned by the European Commission to support its assessment of the status of current EU road safety policy.

Methods

Foresight analysis serves as a strategic instrument aimed at proactively identifying emerging challenges and formulating resilient, future-oriented policies aligned with a long-term vision. In this study, a primarily qualitative approach was adopted. The objective of the foresight analysis was to systematically examine trends and anticipate future developments that could influence road safety in Europe. To support the development of resilient and forward-looking policies, uncertainties around the development of megatrends, trends, drivers of change and potential emerging issues must be considered. The foresight analysis was designed to capture these key elements and was conducted in two distinct phases. The first phase focused on scoping, collecting and summarising relevant information. The second phase involved a more in-depth analysis.

Results

After reviewing all proposed topics, the collected literature and stakeholder input, 14 key elements were defined that are likely to affect road safety in the near and more distant future. These elements are listed below (Table 1).

The selected elements were subsequently subjected to a more detailed analysis through the development of individual fiches, each constructed using a horizon scanning methodology. This approach aimed to systematically identify and incorporate emerging issues and trends with potential implications for road safety. To ensure a structured and consistent analysis, a standardised template was employed across all topics. The underlying information was gathered through desk research and further complemented by insights obtained from a stakeholder survey and semi-structured expert interviews.

Table 1: List of elements of the foresight analysis

Number	Element of the foresight analysis
01	Vehicle fleet composition
02	New urban mobility patterns
03	Connected and automated driving
04	Trends in demographic dynamics
05	Trends in driver behaviour
06	Road infrastructure challenges
07	Disruptive events
08	Increasing consumption
09	Increasing costs of health care
10	Trends in artificial intelligence (AI)
11	Behavioural influence through traffic measures
12	Gaps in the EU Safe System Approach
13	Gap between research and policy
14	Challenges in data and monitoring frameworks

Discussion and conclusions

To synthesise the anticipated impact of each element, a scoring system was applied based on four criteria:

- Magnitude of the expected evolution until 2050
- Impact on Road Safety
- Likely impact of interventions
- Added value of EU action

This structured assessment framework enabled a comparative analysis across elements, facilitating the identification of priority areas for policy and research.

While many of the underlying factors are expected to undergo significant changes by 2050, their respective impacts on road safety will likely vary considerably. The analysis identified key gaps and challenges that Europe must address to achieve the long-term objective of zero road deaths by 2050. It is important to note that the study did not involve the formulation of a comprehensive policy strategy to realise this Vision Zero target. Instead, the findings serve as an evidence base to support the European Commission in shaping its updated road safety policy. The presentation concludes with reflections on the application of the Safe System approach and its implications at the EU level.

86. Measuring the Impact of Road Safety Education for Cyclists: A Novel Approach to Design and Assess Interventions

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Background

Overall, the number of road fatalities across the European Union has decreased over the last decade (European Commission, 2021). Nevertheless, an overarching trend that can be witnessed that there is an increase in cycling accidents, for instance in the Netherlands and Switzerland (ASTRA, 2024; CBS, 2024).

Cycling in a safe manner requires a set of competences, including bodily fitness, steering and balancing skills and knowledge of local traffic systems and rules (Larsen, 2017). However, safe cycling requires more than just motoric skills, including the ability to recognize traffic hazards and predict critical traffic situations ahead (de Winter et al., 2019). Finally, to improve cycling safety, reducing risk-taking behavior is essential.

These skills align with the Goals for Driver Education (GDE) (Hatakka et al., 2002), which outlines four levels: from basic vehicle control (level 1) and traffic management (level 2) to trip-related factors (level 3) and personal motives and social values (level 4). The effectiveness of driver education in general and cycling training specifically can be assessed using various metrics, including the number of accidents, behaviour, knowledge and attitudes (Richmond et al., 2013). Additionally, it is possible to employ self-report measures for this assessment, for instance along the items of the Cycling Skills (de Winter et al., 2019) or evaluate actual behaviour, either in an experimental or naturalistic setting. Van Eggermond et al. (2025) developed, implemented, and evaluated an online cycling training program for adults as part of a pilot study. Self-report measures indicated improvements in cycling skills, which were further supported by a subsequent simulator study in virtual reality, demonstrating enhanced cycling competencies.

To sum up, there are several gaps in the literature the study at hand attempts to close. Current applied research lacks the implementation and evaluation of a cycling safety training that implements GDE Level 4. Further, there is a lack of investigations examining the impact of a cycling safety training in field tests, leaving a significant gap in understanding its real-life applicability and impact.

Aim

Building on previous work, the aim of this study is to advance the development of an online cycling training program—from its initial pilot phase to the full-scale, real-life intervention “Level Up Your Ride”—targeted at adults in Switzerland. This intervention was launched in April 2025; until June 2025 over 100’000 adults will receive an invitation to participate. These efforts are complemented by an online campaign. This next phase enables evaluation within a larger and more diverse sample. Unlike the earlier simulator-based study, the current research will involve a field study to assess the effectiveness of the training in real-life conditions.

Method

All participants that take part in the online cycling training, will have their cycling skills assessed both before and after the training. The training includes a component addressing level 4 of the GDE framework (personal motives and social values), which will be evaluated separately, alongside participants' intention to increase their cycling activity.

The field study, that will be conducted in June 2025, will compare the effectiveness of the online cycling training to a traditional in-person (field-based) cycling training, with an additional control group receiving no intervention. To assess behavioural outcomes, participants' real-world cycling behaviour will be recorded using a camera and systematically coded for analysis.

Expected Results

It will be evaluated whether the online cycling training results in improvements in participants' cycling skills, as assessed through a pre- and post-training evaluation. In the field study, it will be evaluated whether real-world cycling behaviour improves as a result of the online training. It will also be evaluated whether the effectiveness of online versus field-based training differs.

Conclusions

This study will contribute to the understanding of online cycling training. By examining the impact of this training approach on a broader scale, the study will help evaluate the generalizability and provide insights into how they can be implemented in larger public health or educational initiatives. In addition, the field study will provide valuable information about how online training methods translate into real-world cycling behaviour.

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87.Evaluating Geometry-Induced Stability Risks for Micromobility Users Under Free-Riding Conditions: A Multi-Indicator Approach

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Introduction

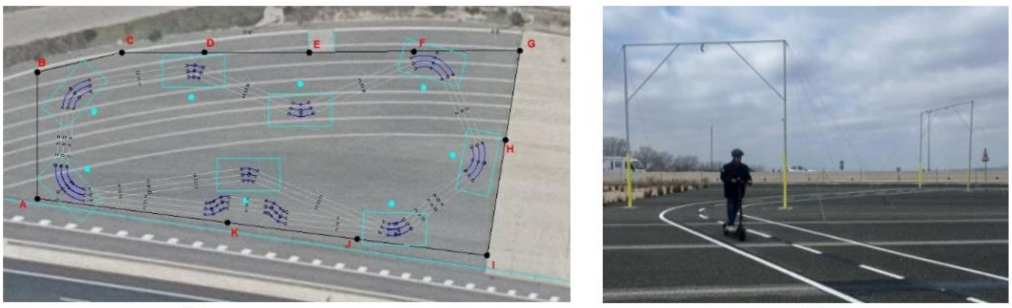
The inherent high maneuverability of micromobility devices, combined with their sensitivity to the geometric characteristics of cycling infrastructure, introduces unique challenges for conventional road safety evaluation methods. Traditional Surrogate Measures of Safety (SMoS), grounded in Hyden's safety pyramid, predominantly focus on observable interaction-based events such as conflicts and near-misses. While these indicators are valuable for detecting imminent collision risks, they often overlook latent instability behaviors, such as unintended path deviations, loss of balance, or falls, which may occur without the presence of direct interactions. These stability-related events are critical early warning signs that can later escalate into fall incidents, near-misses or even fatal crashes. The objective of this study is evaluating such risks under free-riding conditions, where user behavior is not influenced by interactions with other road users, allowing for an isolated assessment of the effects of infrastructure geometry and rider perception on stability.

Research Methodology

The study integrates three key operational indicators to assess micromobility user stability on curved alignments under controlled free-riding conditions: (i) instantaneous speed, measured at 50cm intervals; (ii) lateral deviation (LD) from the centerline, recorded at 50cm intervals for high spatial resolution; and (iii) lane change frequency, reflecting users' lateral repositioning behavior. For this purpose, a closed-loop test track featuring a range of curve configurations (radii 5m; deflection angle from 30 to 105 degree) was designed (see Figure 1).

Preliminary Results

This study examines the relationship between curve geometry, speed adaptation, lateral deviation, and lane-change frequency to identify latent stability risks for cyclists and e-scooter users under free-riding conditions on a bidirectional test track. As data collection is ongoing and scheduled for completion in May 2025, some preliminary results are presented below to illustrate the analytical framework. Figures 2 and 3 show a sample speed heatmap and lateral deviation plot for left-turning cyclists (wide rectangle in Figure 2) and e-scooter users (narrow rectangle in Figure 2) at curve R2 (radius = 5m, deflection angle = 45°). The motion data were extracted using a custom computer vision-based tracking tool and visualized via feature distribution heatmaps generated with Python.



(a) (b)

Figure 1 Test track: (a) geometric layout; (b) 6 m tall overhead camera gantries for motion monitoring.

The initial data collected a sample of users navigated curve R2 indicates that left-turning e-scooters tend to navigate along the inside of the curve, staying close to the center line, particularly between the PC (Point of Curvature) and the MP (Midpoint). The highest lateral deviation typically occurs just before reaching the MP. As shown in Figure 2, e-scooter riders, much like cyclists, tend to accelerate between PC and MP and maintain relatively higher speeds from MP to PT (Point of Tangency). However, on the tangent sections leading into the curve, they generally begin decelerating.

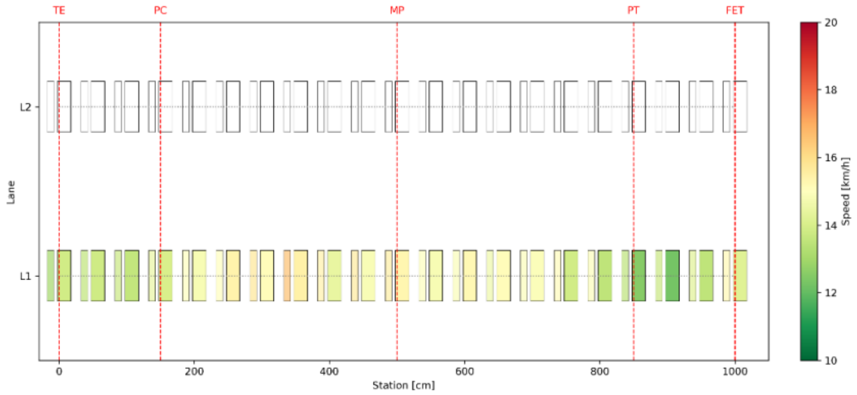


Figure 2 Speed distribution heatmap at 50cm station intervals for left-turn maneuvers on curve R2.

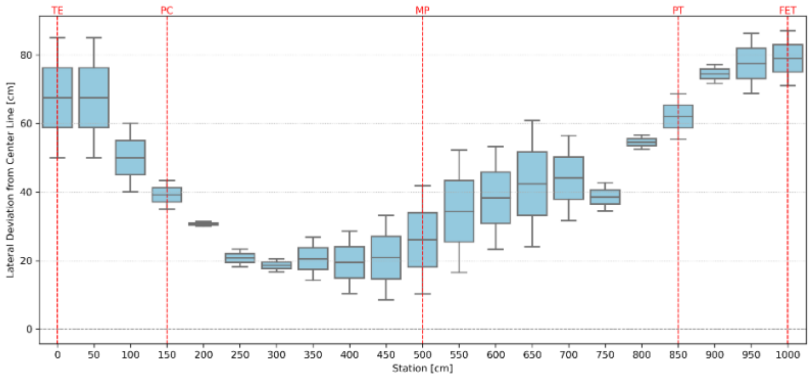


Figure 3 Distribution of lateral deviation at 50cm station intervals for left-turn maneuvers on curve R2.

Discussion and Conclusions

The findings so far confirm that horizontal geometry, especially curve design, directly influences micromobility user behavior, affecting speed regulation, lane choice, and lateral stability. By combining speed, lateral deviation, and lane-change metrics, this approach enables a high-resolution identification of patterns that can reduce instability of users during curvature, and can also reveal the sections associated with the highest instability risk. Further discussion will be provided upon completion of data collection and extraction, and the results will be presented at the conference.

88.Selected risk factors of senior crashes mechanism

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Human aging is a complex process involving, among others, the deterioration of cognitive, perceptual, and motoric abilities and also psychological and behavioral changes. Concerning higher age, the crash causation of the elderly is more likely to be influenced by a reduction of cognitive and psychomotor function (Bucsuházy et al., 2020, 2023; Petridou a Moustaki, 2000). Numerous studies (e.g. Bucsuházy et al., 2023; Mayhew, 2006) have found that senior drivers' crashes are more likely to occur in complex situations, especially at the intersections. The consequences of senior crashes are often reported as more severe, as seniors are one of the most vulnerable road user groups. They are predisposed to a variety of diseases, especially chronic illnesses, and take multiple medications (e.g. Zhao et al., 2018; Schmucker, 2005).

To better understand the characteristics of crashes involving senior drivers the study aims to analyse selected risk factors related to both the crash occurrence and also consequences. Mainly, the most frequent crash scenarios will be defined and subsequently analyzed to determine the scenarios with higher risk for seniors.

Methods

Data from the Czech In-Depth Accident Study (CzIDAS) were used as a basis for the analysis of selected risk factors related with senior crashes. CzIDAS is carried out by the Transport Research Centre (CDV) since 2011. The investigation teams document all relevant information at the scene immediately after the occurrence. Collected and subsequently analysed data proved a comprehensive view to all factors related to the crash concerning the whole system vehicle – infrastructure – human.

Results

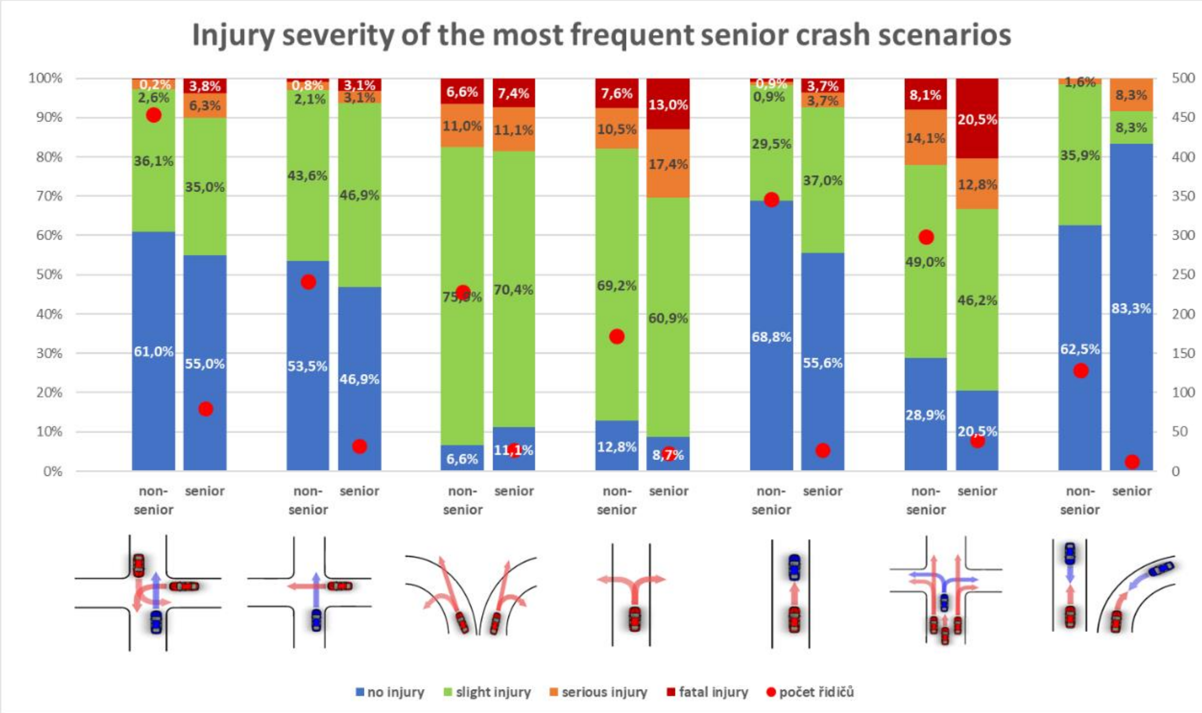
The paper is based on the previous partial thematic analysis of the authors (Bucsuházy et al., 2023), while selected results related to the crash mechanism were further analyzed. The results describe selected risk factors of senior crashes related to crash mechanisms considering seniors' vulnerability in road traffic.

Elderly driver crashes (older than 65 years) often occur at intersections, especially when drivers turn left and need to give way to oncoming traffic. The most frequent crash scenario is not the scenario with the highest injury severity of vehicle passengers (see Figure). If we assume only passenger driver injury severity, head-on collisions have a higher risk of fatal injuries (including senior and also non-senior crashes) following by the single-vehicle run-off-road crashes. Among all vehicle passengers, injuries of head and thorax are the most severe, fatal thoracis injuries are more often among elderly in comparison to younger crash participants.

Crash consequences are also reflected in the higher treatment time or hospitalization. CzIDAS data shows a higher proportion of hospitalization longer than 15 days (approximately 24% of senior crash-participants in comparison to 12 % of non-senior crash participants).

Discussion and conclusion

Understanding the crash patterns of senior drivers has become increasingly important as life expectancy increases (Mayhew et al., 2006; Vaupel, 2010). The crash consequences of senior crashes are more severe and even lower-speed crashes could, with higher probability, result in severe or fatal injuries. The deterioration of cognitive and motoric abilities is reflected in crash contributory factors, which are also related to the crash mechanism. The measures on road infrastructure and also improvement of vehicle protection should reflect the specifics of senior crashes, such as described by authors (see also Bucsuházy, 2023) e.g. improvement of intersection design including reduction number of collision points or improvement of pedestrian crossings (design of traffic islands, traffic signals, etc.).



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89.Impact of the Shisa Kanko Method on Driver Perception of Road Signs: An Eye Tracking Study

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Within the scope of this research work, the impact of the shisa kanko (“pointing and calling”) method on drivers' perception of road signs was investigated by using eye-tracking technology. This method, involving verbalization of observed environmental elements, aims to enhance drivers' concentration and reduce perceptual errors. The field study involved 21 participants who completed two drives along the same route: the first time was without any additional tasks, and during the second one it was required to verbalize road signs. Driver number 21 was advanced familiar with the whole route and, consequently, was considered as a control driver. The road section of 315m was selected for further detailed analysis. There are 20 road signs located along the selected section, two of which was not obligate for the driving direction. Beside their types of road signs, their visibility distances were assessed. For each sign, the application of shisa kanko increased essentially the number of drivers, who observed it (Fig. 1). It was happed even in case of signs not obligated for test drivers (road sign number 9, 10, and 12).

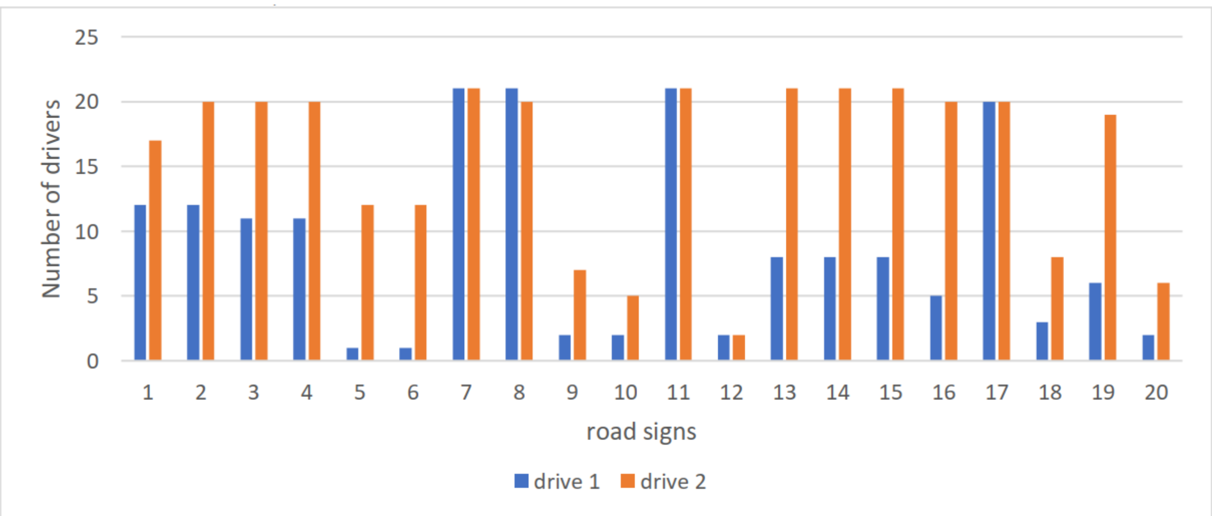

Figure 1. Number of drivers who observed individual road signs

In Figure 2 there is an outcome, which showed how many statements about the meaning of road signs were correct, partially correct or incorrect. Firstly, drivers did not say anything about non-obligatory road signs. Secondly, the strong correlation was found between the number of correct statements and the visibility distances of road signs (r=0.604): better visibility increased the amount of correct description.

Average reaction times are presented in Figure 3. Road sign number 20 had the smallest visibility distance, which required the fastest reaction. Road sign number 1 (information about paid parking zone) was situated near another 5 signs and, it seems, was interpreted by drivers as the last one.

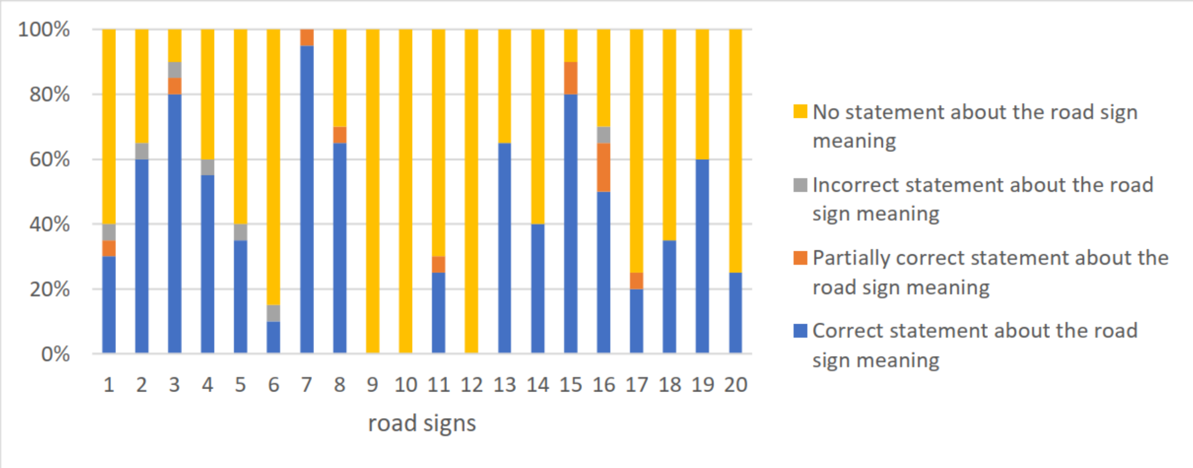

Figure 2. Statements about the meaning of road signs

Summarizing, the outcomes showed that during the task drive, drivers noticed road signs significantly more often and paid them more attention. Eye-tracking analysis indicated that verbalization improved focus on signs, especially, those ones positioned on the right side of the road. The study suggests that the implementation of the shisa kanko method could contribute positively to road safety by increasing drivers' awareness and enhancing processing of visual information.

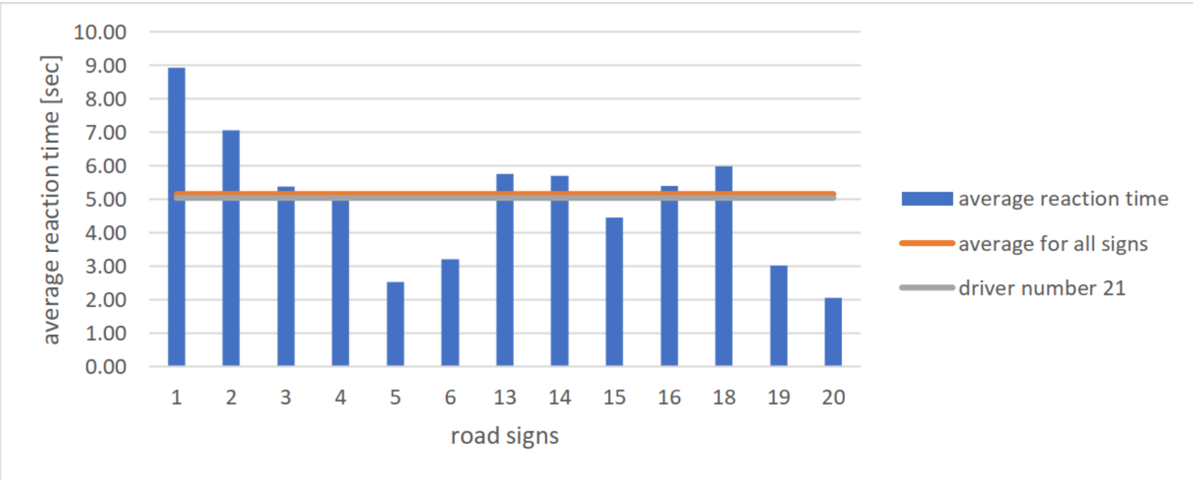

Figure 3. Statements about the meaning of road signs

90. Merging onto a motorway in the presence of platooning trucks: preferences from car drivers

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Introduction

The freight industry is evolving, with vehicle automation technology presenting potential solutions for increasing efficiency through the introduction of increasing levels of automation. In the near future, automated vehicles will play a central role in shaping traffic dynamics, but a crucial challenge will be ensuring seamless interaction between these autonomous vehicles and manually driven ones at shared road spaces. In this paper, we focus on truck platooning technology, linking multiple trucks through automated driving and vehicle-to-vehicle communication, allowing them to travel in close proximity in a coordinated manner. This concept can potentially revolutionize the freight industry by improving efficiency and reducing operational costs, such as fuel consumption and pollutant emissions.

Truck platooning has not yet been deployed in the real world, as there is still a level of maturity in technology that needs to be achieved to overcome existing risks and challenges. Nevertheless, the expected percentage of users adopting this technology will remain relatively small compared to the total number of road users. Thus, one of the most crucial factors is the interaction between all parties, namely the ability of light-vehicle drivers to interact with large convoys of trucks. In this way, the objective of this work focuses on analysing car drivers' behaviour in mixed traffic scenarios with truck platooning.

Research methodology

A literature review was conducted beforehand to define the number of trucks and the gap between trucks. Considering the literature review and interviews with actors from the industry, we developed a use case scenario focusing on how average road users react when encountering a truck platoon, specifically when merging onto a motorway. Participants drove three times through the same scenario, where the ego driver follows a primary road for approximately one minute (~700 meters) before approaching a motorway entrance, with a speed limit of 80 km/h. Trees and barriers were placed to obstruct the driver's view of the highway until the merging point, where they encounter a platoon of seven trucks traveling at a constant speed of 80 km/h. The gap between trucks varies between runs: 8, 15 and 22 m; the minimum is associated with communications latency, the intermediate with the feedback from professional drivers about comfort, and the maximum with tangible fuel benefits. The order of the scenarios was set different for different groups, aiming to decrease the learning effect of the simulation. The three gap configurations tested are: (A) 8, 22, and 15 meters, (B) 15, 8, and 22 m, and (C) 22, 15, and 8 m. After merging, the ego driver continues on the highway for a short period.

The main objective was to analyse whether the participants would cut-in, disrupting the platoon, wait for the last truck of the platoon or accelerate and merge in front of the platoon leader. Our sample consisted of 60 licensed drivers, balanced by gender (30 female, 30 male) and divided into three age groups of 20 participants each: 18-25, 26-55, and 55+. The experiment was conducted using a driving simulator equipped with an eye tracker, while participants wore a smartwatch to monitor heart rate. Besides the simulator runs, each participant answered two short questionnaires: one pre-experiment questionnaire allowed for participant sociodemographic characterization; and one post-experiment questionnaire provided feedback on experiment comfort, safety perceptions and preferred gaps.

Results

Based on the questionnaires' results, drivers did not perceive truck platooning as an element that significantly increases traffic complexity or difficulty (43; 71.7%), often comparing it to routine driving situations. However, some collisions occurred during the simulations (7; 3.9%), mostly when intra-platoon gaps were 15 and 22 m (6; 85.7%). Overall, data from the simulations shows that drivers tended to adopt a more defensive and cautious driving style, with most choosing to merge onto the highway after the platoon had passed (127; 70.6%). Some drivers performed cut-ins within the platoon (43; 23.8%), and only few accelerated to merge ahead of the first truck (10; 5.6%). The cut-ins were predominantly executed in the 15- and 22-m gaps (38; 88.4%), with very few occurring at the shortest 8-m gap (5; 11.6%), indicating low confidence in merging within this smaller space. Regarding drivers' perception of comfort during the simulation, the habituation effect played a key role, as participants generally preferred the final simulation (27; 45%). However, this does not suggest a clear preference for a specific gap distance between trucks.

Discussion and conclusions

On a first analysis, the results of the simulations are aligned with the results from the focus groups performed earlier in the project with different stakeholders. Road operators and concessionaires had raised the issue of traffic management being more difficult in motorways where there is a higher volume of heavy vehicles, being the "wall" effect that trucks cause one of the major concerns regarding truck platooning. The results from the simulations showed that drivers do recognise this situation but are willing to adjust their behaviour to avoid major disruptions in traffic. Moreover, truck drivers had already mentioned that finding the optimal gap is hard because some light-vehicle drivers may cut-in the platoon even when gap distances that are considered low for professional drivers (e.g., 15 m).

Nonetheless, these preliminary results indicate that light vehicle drivers are willing to coexist with truck platoons on the road and do not perceive them as a threat or a complicating factor. To gain deeper insights into these findings, the next steps of the work include integrating data from all different devices and sources, including vehicle dynamics (e.g., speed, acceleration/deceleration, lane positioning), steering and pedal inputs, eye tracking, and heart rate monitoring data. This work presents a new perspective on truck platooning, giving emphasis to other road users' (un)safe behaviour.

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91. Comparison of Individual differences in vibration and comfort of e-scooters and e-bikes

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INTRODUCTION AND OBJECTIVES

E-scooters are treated as motorized bicycles if they have an output of 0.60 kWh or less now. From July 1, 2023, those 16 years and older will be able to ride them without a driver's license or helmet. Currently, social experiments for deregulation of e-scooters are being conducted mainly in Tokyo, and there are several businesses that offer paid rentals. Although efforts are underway to popularize e-scooters in this way, ensuring their safety and creating a comfortable environment for their use are still insufficient. The high number of traffic accidents involving bicycles is a particular problem in Japan. However, the current regulations on e-scooters, other than the speed limit, are not sufficient.

The objective of this study is to compare the operability and riding comfort of e-scooters and e-bikes, which are becoming popular under various specifications, and to gain insight into their safety and comfort.

METHODOLOGIES

Eight subjects (7 males and 1 female) were asked to ride along the same route to collect data. The experimental route was approximately 2,400 m set in Tokyo, which was completed only by turning left, for safety reasons. Data was collected using a triaxial acceleration sensor to record vibrations, or by having eight test subjects ride along a predetermined route, and having them rate the ride comfort, operability, and whether they felt scared while riding in a 5-point scale for downhill, flat, and uphill conditions.

In this study, three types of e-scooters and one type of e-bike were prepared.

1) Luup: Maximum speed is 15 km/h, but there is no limiter, so the rider can accelerate downhill.
2) Swing: Maximum speed is 15 km/h with a limiter.
3) Movicle: Maximum speed is 30 km/h and has the same specifications as a motorized bicycle.
4) Electric bicycles: Electric power assisted bicycles provide a certain ratio of power to human power up to 24 km/h. They have a limiter and a maximum speed of 15 km/h. They have the same specifications as motorized bicycles.

RESULTS

According to the results of the questionnaire survey on downhill, the two e-scooters were generally rated similarly, but there were differences in operability and other aspects of riding. This is thought to be related to the fact that only the swing model brakes at speeds exceeding 15 km/h and is unstable, and that the swing model requires a large kick to move when starting off. In addition, movicle treated as mopeds received significantly worse ratings than other vehicle types in all three questions on whether they felt scared. From the free descriptions, it is considered that the reason for this is that movicle have the highest speed and the vehicle stability is poor. Electric bicycles received high ratings in all three questions on starting, despite their high vibration. This is thought to be because many people are used to riding these bicycles, and their large tire diameter makes them stable even with high vibration.

CONCLUSIONS

A comparison of e-scooters with various specifications showed differences in the evaluation of the magnitude of vibration and riding comfort depending on the type of vehicle. In particular, the e-scooters with a maximum speed limited to 15 km/h had low vibration and were highly rated by riders, while those treated as mopeds had high vibration and poor ratings. It can be said that for e-scooters, running at low speeds is the key to ensuring stability, and that speed control is important. On the other hand, it is difficult for the rider of a bicycle to feel the bike wobble, even though the rider is actually wobbling. However, it was found that the two subjects who were accustomed to riding a motorcycle on a regular basis did not feel fear even when riding a vehicle treated as a moped, which travels at a high speed. We plan to conduct more surveys with a larger number of subjects.

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92.Enhancing Road Safety for Vulnerable Road Users: A Gamified Bicycle Simulator Training

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Background

Cycling is becoming increasingly popular due to its benefits for reducing traffic congestion and improving environmental sustainability. In many countries, cycling is the third most common mode of transport, with a significant portion of the population cycling regularly. However, cyclists, along with pedestrians, are among the most vulnerable road users (VRUs), accounting for a large proportion of road traffic fatalities in urban areas. Improving cyclist safety is critical, as this group is disproportionately affected by traffic accidents, often due to a lack of protective infrastructure and the vulnerability of cyclists in collisions.

Simulation technology offers a valuable tool for studying and addressing traffic safety, providing controlled, safe, and reproducible environments. While driving simulators have been widely used in research, bicycle simulators have not seen the same level of development. However, research into cycling simulators has been growing in recent years, as they allow for precise behavioral measurements, such as speed and steering, in a safe setting, which is especially important for assessing and improving cyclist safety.

A key challenge with simulators is simulator sickness, which can negatively impact the user experience and training outcomes. Therefore, designing simulator training that minimizes negative effects while maintaining realism and training effectiveness is crucial.

Aim

This project aimed to develop and evaluate a standardized and efficient training for the bicycle simulator at DLR, designed to increase user acceptance and minimize negative effects such as simulator sickness. The goal was to create a training environment that is modular, reproducible, and incorporates gamification elements to enhance learning outcomes and user experience.

Method or methodological issues

A small sample (16 participants) was used to test the initial research questions, applying an experimental between-subjects design. Participants (VPs) were randomly assigned alternately to one of two versions of the training: the Gamify version (with gamification elements) or the Default version (without gamification).

The training environment was developed using Unreal Engine 5 (UE5) and included modular, reproducible scenarios, an adapted bicycle model matching the simulator's hardware, and predefined task paths. This was designed on the digital map of an existing traffic training area in the city of Braunschweig. The environment was integrated with two DLR internal plugins for simulator coupling and data recording.

Dependent variables (training success, simulator sickness, presence, and acceptance) were measured under the influence of the independent variable (training version). Data collection methods combined subjective questionnaires and objective performance metrics recorded during runtime. This methodological setup enabled an evaluation of both training variants regarding user acceptance, simulator sickness, training effectiveness, and immersion quality.

Results obtained or expected

Both the gamified and non-gamified versions of the training showed positive outcomes. Participants reported feeling well-prepared and successfully executed the required tasks. Simulator sickness scores remained low across both groups.

Comparison between the two versions indicated a clear tendency favoring the gamified training. Acceptance ratings were higher, simulator sickness symptoms were notably lower, and participants in the gamified version collected more points while completing tasks more quickly. Presence levels, particularly sensory fidelity, were also slightly enhanced in the gamified condition.

Conclusions

The results suggest that gamification elements enhance attention, motivation, and user experience without introducing significant negative side effects. Consequently, incorporating gamification into simulator training appears highly beneficial. Future work includes optimizing gamification features, employing improved hardware interfaces, and conducting studies with larger and more representative participant samples to further enhance and validate the training approach.

93.Cargo Bikes in Everyday Business Use: Insights from Six Pilot Companies

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Sope

While cargo bikes are increasingly replacing car trips in private life, their potential in the business sector remains underutilized. To fully unlock this potential, targeted incentives and knowledge about suitable industries and vehicle types are needed. In our FFG-funded research project ANTRIEB (Incentives for Business Cargo Bike Use), we focus on companies operating in the service and people-oriented sectors.

In addition to exploring how national, regional, and local governments can support cargo bike use in companies, our main research interest lies in identifying the conditions that enable employee acceptance and integration of cargo bikes into daily business routines.

Method

As part of the project, six businesses in Vienna and Graz are testing electric cargo bikes free of charge over the course of one year, allowing them to experience both the benefits and challenges throughout all four seasons. The participating companies are continuously evaluated during the pilot phase—qualitatively through interviews with management and staff, and quantitatively via GPS tracking of the bikes. In addition, various incentive measures, such as voucher campaigns, have been introduced to encourage employees to use the cargo bikes, with their impact on usage carefully assessed.

Results so far

The perceived benefits of cargo bike use were largely consistent across the six participating businesses: avoiding the hassle of parking, enabling direct access to destinations, taking efficient shortcuts, faster travel for urban assignments, improved employee health, the positive experience of cycling, and encouraging feedback from customers.

Key success factors for continuous use of the cargo bike included motivated management, expert guidance in selecting the right bike, proper training before use, bike-friendly staff, and assignments located in inner-city areas.

The pilot phase will conclude in summer 2025, with final results to be presented at the ICTCT conference.