e-SAFER - Computational models for a safe interaction between (automated) vehicles and e-scooters

Public report

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FFI Fordonsstrategisk Forskning och Innovation

Content

FFI in short

FFI, Strategic Vehicle Research and Innovation, is a joint program between the state and the automotive industry running since 2009. FFI promotes and finances research and innovation to sustainable road transport.

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1. Summary

Today, micromobility is on the rise, posing new challenges for a safe transport system. As e-scooters have proliferated, so have e-scooterists' visits to emergency care. Today, data about e-scooter safety are scarce but alarming. While several studies describe significant injurious outcomes from e-scooter crashes, we still lack an understanding of the injury and crash-causation mechanisms—and we are even further from developing effective countermeasures against e-scooter crashes. This is true especially for collisions with motorized vehicles, which account for 80% of the fatalities from e-scooter crashes. We also do not know what "normal" e-scooterist behaviour is, or how e-scooterists typically interact with motorized vehicles to complete their journey safely. This information is crucial for intelligent transport systems (ITS) and connected automated vehicles (CAV) that need to predict e-scooterist intent and act on such predictions to keep safe.

In this project, we have investigated e-scooters as the present concern for micromobility to understand this new trend in transportation, its safety implications, and the necessary countermeasures to help motorized vehicles safely interact with e-scooterists and new micromobility vehicles yet-to-come. The focus has been on modelling the interaction between drivers and e-scooterists to support the development and evaluation of ITS and CAV. The main assets for the modelling were data from test-track and naturalistic data collected in the project. The project also analysed the contextual circumstances from crash and insurance databases, which informed the design of the test-track experiment. Finally, the project organized a final event where the application of the models developed in the project were demonstrated on the Vårgårda airfield.

Key synergies with other projects (SIMT and e-Model, sponsored by Trafikverket and Chalmers, respectively) boosted the scientific impact of this project. The results from e-SAFER have been presented at several international scientific conferences and have been published in top international scientific journals in the traffic safety area.

2. Sammanfattning på svenska

Idag är mikromobilitet på frammarsch, vilket innebär nya utmaningar för ett säkert transportsystem. I takt med att elsparkcyklar har ökat i antal, har även antalet besök på akutmottagningar för elsparkcyklister ökat. Idag är data om elsparkcyklars säkerhet begränsade men oroande. Flera studier beskriver allvarliga skador från olyckor med elsparkcyklar, men vi saknar fortfarande en förståelse för mekanismerna bakom skador och olyckor – och vi är ännu längre ifrån att utveckla effektiva motåtgärder mot olyckor med elsparkcyklar. Detta gäller särskilt kollisioner med motorfordon, som står för 80 % av dödsfallen i olyckor med elsparkcyklar. Vi vet heller inte vad som är ”normalt” beteende för en elsparkcyklist eller hur elsparkcyklister vanligtvis interagerar med motorfordon för att slutföra sin resa säkert. Denna information är avgörande för intelligenta transportsystem (ITS) och uppkopplade automatiserade fordon (CAV) som behöver förutse elsparkcyklisters avsikter och agera utifrån dessa för att upprätthålla säkerheten.

I detta projekt har vi undersökt elsparkcyklar som ett aktuellt användningsfall för mikromobilitet för att förstå denna nya transporttrend, dess säkerhetsimplikationer och de nödvändiga åtgärder som krävs för att motorfordon ska kunna interagera säkert med elsparkcyklister och framtida mikromobilitetsfordon. Fokus har legat på att modellera interaktionen mellan bilförare och elsparkcyklister för att stödja utvecklingen och utvärderingen av ITS och CAV. De huvudsakliga tillgångarna för modelleringen var data från testbana och naturliga data insamlade inom projektet. Projektet analyserade också de kontextuella omständigheterna från olycks- och försäkringsdatabaser, vilka låg till grund för utformningen av testbaneexperimentet. Slutligen organiserade projektet ett avslutande event där tillämpningen av de modeller som utvecklats inom projektet demonstrerades på flygfältet i Vårgårda.

Viktiga synergier med andra projekt (SIMT och e-Model, finansierade av Trafikverket respektive Chalmers) ökade den vetenskapliga påverkan av detta projekt. Resultaten från e-SAFER har presenterats vid flera internationella vetenskapliga konferenser och har publicerats i ledande internationella vetenskapliga tidskrifter inom trafiksäkerhetsområdet.

3. Background

The rise of micromobility and its implications for safe interactions with motorized vehicles

E-scooters proliferate in several Swedish cities, causing several safety and acceptability concerns (Göteborgs Stad, 2019; Stigson et al., 2020; Stigson & Klingegård, 2020). Although e-scooters are mainly deployed in urban areas, **80% of the fatalities occur in crashes with motorized vehicles** (International Transport Forum, 2020). Because the number of e-scooters is growing and *new mobility vehicles* are entering the market at a fast pace, interaction between motorized and micromobility vehicles is not likely to get better any time soon, unless new safety measures are adopted. *Novel* in-vehicle intelligent transport systems (ITS), in the form of advanced driving assistance systems (ADAS) or connected automated vehicles (CAV), have great potential for improving the interaction between micromobility vehicles and motorized vehicles (Gössling, 2020; Dozza et al., 2022). However, before ADAS and CAV may deliver on their expected potential to increase the safety of micromobility users, the scenarios and the behaviour leading to failed **interaction between micromobility and motorized vehicles** need to be understood in such a way that machines can predict the behaviour of micromobility users in different scenarios (Dozza et al., 2022; Eichholz et al., 2021; Garman et al., 2020).

Modelling road-user behavior to improve safety through ADAS and CAV

Today, automated driving is not a widespread reality because it is not safe. The technology to enable automated driving is constantly developing, but several challenges are still present. In urban environments, micromobility is arguably the biggest of all challenges, because these vehicles are small (therefore hard to detect and recognize), and their behaviour is difficult to predict. For the same reason, current ADAS, such as automated emergency braking, are challenged by detecting and predicting micromobility behaviour and perform better for cars and trucks (that are larger and have kinematics easier to foresee) than for micromobility vehicles. For CAV to be safe and ADAS to effectively support drivers, ITS need to understand micromobility user behaviour so well that they may predict what users will do in a time horizon sufficiently long (2–5 seconds) to be able to take decisions (e.g., warnings or automated interventions) in time to preserve safety (Camara et al., 2020; Rasch et al., 2022; Society of Automotive Engineers, 2021a, 2021b). In other words, **computational models of rider behaviour are needed**.

Defining scenarios and modelling road-user behavior from crash data, naturalistic data, and test-track data

Predicting road-user behavior is not easy; still, it is a necessary and common task for any human driver to safely negotiate the infrastructure—especially at intersections where the interaction with micromobility users is the most critical. Predicting the behavior of a rider approaching an intersection is hard because it depends on several factors related to the vehicles, the environment, and the road-users. Not all factors are equally critical though. Traditionally crash databases have been used to derive critical scenarios for road-user interaction. Euro NCAP is a clear example; in fact test scenarios are based on most critical scenarios from crash databases, defining the geometry of the infrastructure and the vehicles kinematics. However, when it comes to road-user behavior, crash database fall short. In fact, human error (from e.g., distraction, inattention, intoxication, drowsiness) has been repetitively reported as a main or contributing cause in all crashes, but very little information about road-user behavior is available in crash databases. Naturalistic data, on the contrary, offer great insights into driver behavior and how that influences crash causation. It is therefore not surprising that modelling of road-user behavior makes continuously increasing use of naturalistic data. While, in the future AI promises to accurately predict road user behavior by developing models from large naturalistic datasets; today, we cannot yet rely only on naturalistic data to model road user behavior. This is not only an economical issue as naturalistic data is costly to acquire and to process, but also an ethical concern as new road-users (e.g., e-scooterists) join the transport system every now and then; consequently, waiting several years for naturalistic data to be abundant enough to enable modelling of a new road user, may not be ethically acceptable because it requires an unnecessary human sacrifice. Test-track experiments offer the opportunity to control several factors, thus providing a "clean" dataset for timely modelling of road-user behavior. With their controlled environment, test-tracks experiment may help defining parameters in selected scenarios (e.g. for Euro NCAP testing) and investigate critical factors (e.g., speed, glance behavior) which may be crucial to model for correctly predicting road-user behavior.

In summary, while in the future AI and naturalistic data may provide scenarios and models able to predict all safety-relevant behaviors form all road users in all situations; today, crash database and test-track data are critical for identifying critical scenarios and modelling critical behaviors, respectively.

Relevant on-going research projects modelling e-scooterist behavior and analyzing naturalistic data

It is important to mention four research projects that are critical to e-SAFER. The E-safe pre-study (E-safe pre-study; 2021-05060) sponsored by FFI piloted a data collection using instrumented e-scooters designed and tested by Pai (2022). Figure 1 shows a screenshot of a dashboard developed to visualize naturalistic data—most notably video data. The platform for naturalistic e-scootering data collection developed in the Master thesis project (Pai 2022) (Figure 2) is very relevant because it enabled the collection of (video) naturalistic data from e-scooters in an urban environment from a rental fleet. In other words, this platform is an enabler for large-scale collection of naturalistic data that may help 1) identify critical scenarios and 2) model road user behavior during the interaction between micromobility users and motorized vehicles. Another project worth mentioning is SIMT, sponsored by Trafikverket. Within SIMT previous methodologies for analysis of naturalistic cycling data were adapted to e-scootering for the purpose of understanding crash causation (which clearly depends on user behavior and is conditioned by interactions with other road users in specific scenarios). Finally, the project e-Model, sponsored by Chalmers, supported the work of a PhD student since September 2022 to determine how e-scooterist control their vehicle and thus giving new insights into how user manoeuvres e-scooters (a critical information to determine the boundaries for what e-scooters can do in terms of braking and steering maneuvers). Figure 3 illustrates the main relations between the projects above mentioned and e-SAFER. This figure is qualitative and does not give credit to the synergies across analyses (e.g., analysis tools and data pre-processing that may be shared across studies).

Figure 1: Analysis tool developed in Pai (2022). It is worth noting that the data from the rider camera was not collected in the data collection.

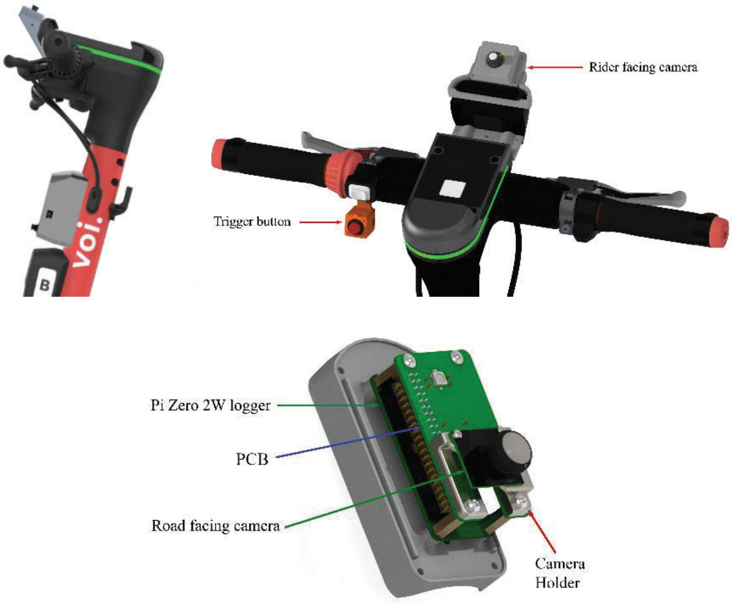

Figure 2 – Hardware from Pai (2022) that enables collection of naturalistic data from e-scooters.

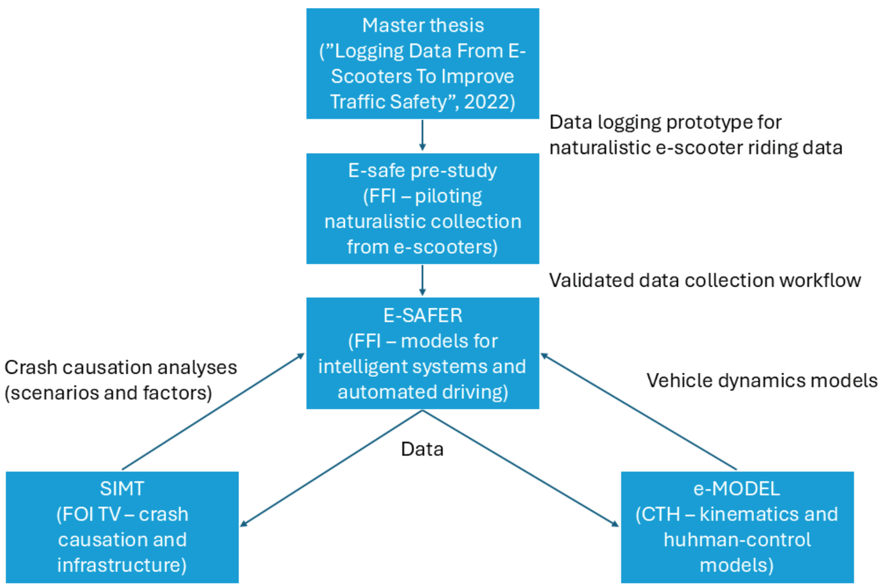

Figure 3: Representation of the relation between several projects connected to e-SAFER: each box represents a project; the project name is included in each box together with the sponsor and the main goal of the project (which are reported in between parentheses). The arrows show how project share their results with each other.

4. Purpose, research questions and method

This project was driven by curiosity about micromobility and its many controversial issues. For instance, cycling is probably the healthiest means of transportation of all, but it is also very dangerous—second only to motorcycling. While most micromobility crashes are single crashes, most deaths happen in crashes with motorized vehicles (cars, trucks, and vans). E-scooters are loved by e-scooterists and hated by almost all other road users. Micromobility is green, silent, inclusive and—when active—also very healthy; but still, safety and acceptance concerns hinder its popularity. Finally, micromobility could contribute to a less polluted world but, today, poor recycling practices, short life cycles, and high relocation (environmental) costs for rental vehicles cast a shade on the environmental friendliness of micromobility. This project was also driven by the belief that 1) technology could harness the potential of micromobility and help solve some of its (safety) issues, and 2) road user behavior (including social norms, expectations, traditions and beliefs) is the largest issue to understand for a safe, acceptable, and efficient integration of micromobility in the transport system.

Therefore, the general purpose of this project was to employ technology (data, analytical tools and techniques, and ITS) to improve micromobility safety by modelling road user behavior; the project focused on the interaction between motorized vehicles and e-scooterists.

The following research questions were addressed in this project:

- RQ1: What scenarios are the most (safety) critical for the interaction between motorized vehicles and e-scooterists?
- RQ2: In such scenarios what are the actors' configurations that are more likely to lead to a crash?
- RQ3: What factors (speed, road user behavior, etc.) may affect the criticality of the situation in such scenario?
- RQ4: How can we figure out these factors from crash, naturalistic, and test-track data?
- RQ5: How can such factors be modelled and used for predictions?
- RQ6: How can the model be integrated into ADAS and CAV to improve safety today?

Later in this report, we will present the work breakdown for the project and introduce its three work packages (WP). As for now, it may be worth pointing out that RQ1–RQ4 were addressed in WP1, RQ2–RQ5 in WP2, and RQ6 in WP3. This project combined crash and naturalistic to understand what the most critical scenarios for the interaction between motorized vehicles and micromobility are. The contribution of this project to the development of naturalistic e-scootering data collection and analysis is particularly important. In fact, this project leveraged a data collection workflow tested in another FFI project (E-safe pre-study) and that was scaled up to collect over 7,000 trips from rental e-scooters in Göteborg. These unique data were not only exploited by this project but shared with the SIMT project, where a PhD student, Rahul Pai, used the data for crash-causation analyses. Many analysis and modelling efforts were done in the project combining machine learning and Bayesian statistics. The models not only included kinematics of road users but also glance behavior from the driver to inform warnings and automated interventions. The demonstration, on the Vårgårda airfield, of a new ADAS enabled by the models developed in this project is the testament of this project to the potential of technology to contribute to a safer integration of micromobility in the transport system.

5. Objective

The aim of this project was to develop models that help explain how the interaction between drivers and e-scooterists can be safe. The models are intended for ITS and CAV to improve safety, especially for micromobility users such as e-scooterists.

More specifically, this project's objective included:

1) Collecting naturalistic and test-track data
2) Identifying scenarios critical to the interaction between e-scooterists and motorized vehicles
3) Analysing and modelling road-user behaviour to provide models able to support ITS and CAV to predict e-scooterist's behaviour at intersections
4) Disseminating the research results through open scientific publications and open innovation
5) Demonstrating on the field how the models can be integrated in a prototypical ADAS

6. Results and deliverables

Project contents

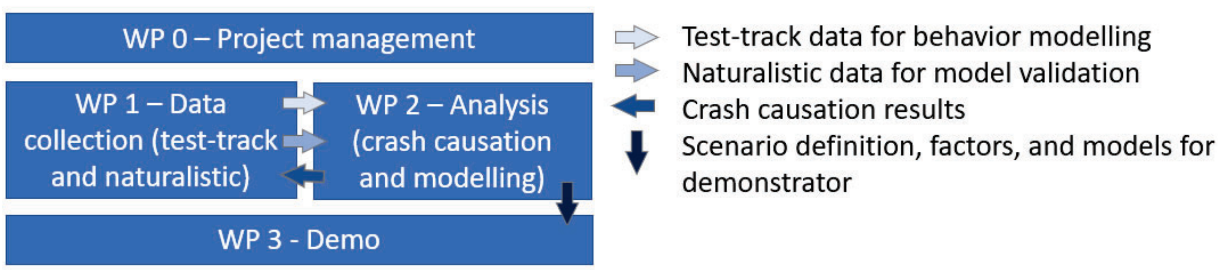

Figure 4 - Work packages within the project and their main interactions.

Figure 4 presents the work breakdown for the e-SAFER project in four work packages (WPs), as well as the main interactions among them. An overarching WP0 manages the project. Its main results were reports to follow up the project (including financing and human resources); this work package was also responsible for this report and will not be further discussed. WP1 (Data collection, led by Voi) collected data from test-track and real traffic (naturalistic data) to enable the analysis in WP2. WP2 (Analysis, led by Chalmers) used the test-track data to create models and naturalistic data to verify the models, however the amount of naturalistic data proved to be insufficient for this task. WP2 also performed crash causation analyses, for instance from insurance data that was used to inform the design of the test track experiment. Finally, WP3 (Demo, led by Magna Electronics) organized a final event where a demonstrator showed on test track how the models from e-SAFER may contribute to safer ITS and CAV.

Below, the results and main work are presented for each WP.

WP1 – Results and deliverables

Naturalistic Data Collection

Voi Technology AB developed and deployed a small fleet of 17 camera and sensor logging-equipped e-scooters to the fleet in the city of Gothenburg. The scooters used were identical to Voi’s standard street models, with the only modification being the addition of the camera module. The e-scooters were equipped with front-facing street-view cameras (for privacy reasons, no rider-view cameras were used) of a 220-degree field of view. The camera modules were directly linked to the scooter to record videos with 0.4 MP at 30 fps. This footage was synchronised with internal sensor data collected at 10 Hz which included 3-axis acceleration, 3-axis angular speed, wheel speed, and the positions of the two handlebar-mounted brake levers. The data was stored in an encrypted format and uploaded when the e-scooter connected to the mobile network. Data was collected during 2023 until March 2024.

Scooters were accessible to end-users in the same way as regular scooters, with no change in unlock or ride procedures, allowing for the most naturalistic data collection possible. Participation was voluntary, and users consented to video recording. Recorded data was stored on the module’s internal memory and uploaded to a secure cloud space after each ride.

A data collection pipeline was established, and the workflow was maintained throughout the project. The data was continuously shared with project partners for further analysis in WP2.

Over the course of the project, ride and sensor data was collected for:

- 4,900 riders

- 7,000 trips
- 10,000 km ridden
- 790 hours of riding time
- Average trip distance: 1.45 km
- Average trip duration: 6.19 minutes

Figure 5: Left: Snapshot from one of the front-facing cameras in the experiment. Right: Heatmap of data collection of the camera-equipped fleet in Gothenburg as it was circulating through the fleet. All of these rides are naturalistic customer rides.

Test Track Data Collection

The test track experiments were led and carried out by Magna at the Vårgårda Airfield during September and October 2023. The setup was designed to resemble an urban intersection, following the Euro NCAP Car-to-Bicyclist Turning Adult (CBTA) scenario. The layout consisted of a straight two-lane road, a side road with a right turn, and a marked cycle lane transitioning into an unsupervised bicycle crossing. Containers and a stationary car were placed to increase realism and provide drivers with a natural spatial experience.
Twenty-five participants (seven female), employees of Magna Electronics, were recruited locally. They were between 18 and 60 years old (average age 39) and drove an average of seven times per week, mostly on rural roads. All held valid driver's licenses, were not professional drivers, and had annual mileages between 10,000 and 20,000 km.

Participants drove a Lincoln MKZ 2016 with automatic transmission (the ego vehicle). The e-scooter rider was represented by a dummy target placed on a remote-controlled platform, traveling at 20 km/h. Both the ego vehicle and the dummy scooter were equipped with high-accuracy RTK GPS to measure position, heading, speed, and acceleration. Brake and throttle pedal signals were also recorded, with all signals synchronized to 10 Hz.

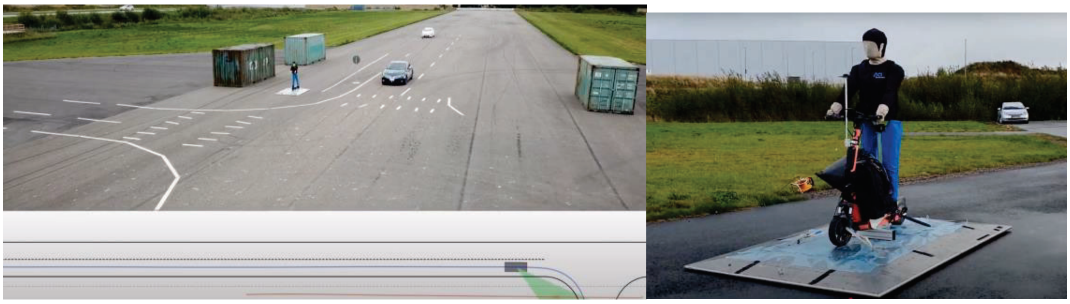

Figure 6: Left: experiment setup showing the right-turn intersection including both the dummy e-scooter rider and the ego vehicle. Right: close-up of the e-scooter dummy target on the remote-controlled platform.

Participants drove as they normally would, performing right turns at an intersection on the Airfield. Eight trial configurations were tested, combining:

1. Ego-vehicle approach speeds of 30 and 50 km/h.
2. E-scooter travel paths: going straight or turning right.

When the e-scooter travelled straight, three conflict scenarios were studied: (a) car crosses first, (b) e-scooter crosses first, and (c) both arrive on a collision course. Trial conditions were randomized for each participant to minimize learning effects. Before the main trials, participants completed two baseline right-turn trials without the e-scooter at both 30 and 50 km/h. After all trials, participants completed a questionnaire about their driving experience.

A total of 250 runs were recorded (including baseline trials). Nine runs were discarded due to missing or invalid e-scooter data. Of the remaining 241 runs, three resulted in crashes where the e-scooter collided with the ego vehicle. These occurred because drivers expected the e-scooter to slow down, but due to technical constraints, it did not. These crash runs were excluded from analysis, as the number was too small to be useful and the behavior was unintended. The data were made available for WP2.

WP2 – Results and deliverables

Folksam and Autoliv investigated e-scooter crashes with passenger cars. Folksam analyzed 613 e-scooter crashes in the STRADA database, which happened between 2020 and 2022, and found that more than half of them (363) took place at intersections. In most of these crashes, the paths of the car and the e-scooter were crossing, and the car took a right turn. Most crashes (71%) resulted in slight, 12% in moderate, 2% in severe injuries, and one crash ended fatally. Autoliv further investigated the German In-Depth Accident Study (GIDAS) and found that in the version released in July 2023, only 11 crashes between e-scooters and cars were recorded, most of them happening at bicycle crossings with a turning car. These results supported the decision of the test-track scenario (right turn) in WP1.

Chalmers, Magna, and Autoliv further processed and analyzed the test-track data provided by Magna in WP1, and prepared a dataset that was used for investigations and modeling of driver behavior in the given scenario. Given the trials where the e-scooter was traveling straight, i.e., on a collision course, a Bayesian logistic regression model was developed that could predict whether the driver would yield and slow down in response to the e-scooter. The model used as input the approaching speed of the driver and the difference in (projected) time-to-arrival (TTA) to the conflict point of the two road users. The model coefficients of these variables revealed that drivers yielded less often at higher approaching speeds and when the projected difference in TTA was larger (indicating an earlier arrival of the car driver). In a leave-one-driver-out cross-validation, the model achieved an AUC (area under the Receiver Operating Characteristic curve) of 0.94 and an accuracy of 0.82. Additional models were developed for drivers' brake *timing* (TTA at brake onset) and *intensity* (mean braking deceleration), yielding RMSEs (root mean square errors) of 1.42 s and 0.33 m/s^2 in cross-validation. The corresponding paper is published in the journal of Transportation Research Part F (Rasch et al., 2025).

Further analyses of drivers' glance behavior in the test-track experiment are ongoing in a collaboration between Chalmers and Magna. Preliminary results hint that drivers indeed look less towards the e-scooter at higher speeds and when yielding. A model is currently under development that can predict how long drivers glance at the e-scooter.

Further in WP2, Autoliv developed a computational framework for driver modeling. The framework utilizes Spiking Neural Networks (SNNs) to model time-series signals of driver behavior, such as the brake-pedal deflection. SNNs are a form of artificial neural networks that mimic neural activities such as evidence accumulation in the brain and are implemented in existing machine-learning frameworks, contributing to the usability of the framework. Results on the test-track data from WP1 show a promising correspondence between the data and the model responses. A pre-print of the paper describing the framework can be found on Arxiv (Morando 2025).

Chalmers processed a large part of the naturalistic riding data from Voi, collected in WP1, intending to analyze real-world right-turn interactions between drivers and e-scooter riders, with the final goal of validating the models developed on the test-track data. Using map information from Trafikverket on locations of unsupervised bicycle passages in Gothenburg (similar to the one used in the test track), together with the collected GPS and camera data, computer-vision models (YOLOv7) and manual review were employed to find relevant events. However, only a few such events could be identified, and the number of these events was deemed too low for statistical analyses.

Naturalistic data from e-SAFER was also analyzed within the SIMT project to investigate crash causation. Several factors were found to significantly increase crash risk for e-scooterists. For instance, riding single-handed, using the mobile phone (independently on whether it was installed on the handlebar or held in a hand), and riding in groups all increased risk 3-6 times. Two open access publications, one on Accident Analysis and Prevention (Pai and Dozza, 2025) and one on Transportation Research Part F (Pai and

Dozza, 2025), details these analyses and report all factors. Further, the first publication had a large echo in the media both in Sweden and internationally. Several magazines and newspapers (e.g. GP) reported on this study which was also featured on several radio (e.g., P4) and TV (e.g., Nyhetsdagen TV4) programs.

WP3 – Results and deliverables

In WP3, Magna developed and demonstrated a prototype vehicle equipped with an advanced sensor suite designed to enhance situational awareness and collision avoidance capabilities, particularly in scenarios involving vulnerable road users such as e-scooter riders. To extend perception beyond the vehicle's line of sight, the onboard sensors were integrated with infrastructure-based sensors through a collective perception system. This setup enabled the detection of non-line-of-sight objects, such as e-scooters approaching from behind vehicles or other occlusions, significantly improving the vehicle's ability to anticipate and respond to potential collision scenarios.

A live demonstration was carried out on the same test field where the data was collected during WP1, Vårgårda airfield. This work package demonstrated the predictive model created during WP2 for collision avoidance and included three distinct warning levels displayed to the driver:

1. V2X Connection Notification – A symbol indicating that the vehicle was connected to an e-scooter via V2X communication.
2. Orange warning with pipping sound – Triggered when the vehicle was near an e-scooter, suggesting a potential interaction. Notably, this warning was suppressed if the driver glanced towards the e-scooter, indicating situational awareness.
3. Red warning with faster pipping sound – activated in near-crash scenario, prompting immediate driver attention and potential evasive action.

The warning logic was powered by behavioral models developed in WP2, including predictive algorithms based on driver speed, time-to-arrival, and glance behavior. These models were validated using test-track data. Their integration into the demo vehicle demonstrated their applicability in real-world scenarios. The design of the warning system—including the visual and integration of the behavioral models—was developed as part of a master thesis project, contributing a user-centered and research-informed approach to the interface and alert strategy.

7. Dissemination and publications

Publications

Theses

Pai, R. R. (2025). *Is the risk worth the ride? Crash causation analyses of naturalistic e-scooter data*. Chalmers University of Technology. https://research.chalmers.se/en/publication/545202*

Papers on International Scientific Journals:

Rasch, A., Morando, A., & Thalya, P. (2025). *The right turn: Modeling driver yielding behavior to e-scooter riders. Transportation Research Part F: Traffic Psychology and Behaviour*, *115*. https://doi.org/10.1016/j.trf.2025.103353

Pai, R. R., & Dozza, M. (2025). Understanding factors influencing e-scooterist crash risk: A naturalistic study of rental e-scooters in an urban area. *Accident Analysis and Prevention*, *209*(June 2024), 107839. https://doi.org/10.1016/j.aap.2024.107839*

Pai, R. R., & Dozza, M. (2025). What influences crash risk and crash prevalence for e-scootering? Insights from a naturalistic riding study. *Transportation Research Part F: Traffic Psychology and Behaviour*, *114*, 160–170. https://doi.org/10.1016/J.TRF.2025.05.030*

Pai, R. R., & Dozza, M. (2025). Is e-cycling safer than e-scootering? Comparing injury risk across Europe when vehicle-type, location, exposure, usage, and ownership are controlled. *Journal of Safety Research*, *94*, 469–472. https://doi.org/10.1016/j.jsr.2025.06.015*

Pre-prints:

Morando, A. (2025). *Akkumula: Evidence accumulation driver models with Spiking Neural Networks*. https://arxiv.org/abs/2505.05489

Conference contributions:

Pai, R. R., & Dozza, M. (2023). E-Scooters: Transport or leisure? Findings from naturalistic data collection. *International Cycling Safety Conference (ICSC) 2023, Book of Abstracts*, 16–18. https://research.chalmers.se/en/publication/536489*

Stigson, H., Kullgren, A., & Lubbe, N. (2024). Descriptive Statistics on Crashes of E-Scooters with Passenger Cars in Sweden. *IRCOBI Conference 2024*, 934–935. https://www.ircobi.org/wordpress/downloads/irc24/pdf-files/24122.pdf

Dozza, M., Pai, R. R., & Rasch, A. (2024). Naturalistic micromobility data: opportunities and threats. *8th Annual Meeting of the Cycling Research Board*. https://research.chalmers.se/en/publication/542369

Dozza, M. (2024). Micromobility: new road-user interactions in the urban landscape. *3rd Human-Centered VRU Workshop*. https://research.chalmers.se/en/publication/542370

Rasch, A., Thalya, P., Morando, A., Boda, C.-N., Jan, H., & Dozza, M. (2024). The right turn: Investigating interactions between drivers and e-scooter riders. *12th International Cycling Safety Conference*. https://research.chalmers.se/en/publication/542041

* indicates a scientific contribution that happened in collaboration with SIMT.

Videos

Demonstration at the final event in Vårgårda, September 16th 2025.
https://youtu.be/pDlLny0fWZs

The e-SAFER test track experiment: a human driver negotiates a right turn with a robot e-scooter at an unsignalized intersection. The video at the bottom shows the glance behaviour of the driver.
https://youtu.be/pnkqXpgrtEE

AI-generated podcast based on Pai, R. R., & Dozza, M. (2025)
https://studio.youtube.com/video/_UTtr9xJ54Y/edit

Presentations

Results from the MICA2 project were presented in several conferences, most notably at ICSC in 2023 and 2024 and POLIS in 2024.

Finally, at the final event in Vårgårda on September 16th 2025, the results from all WP were presented to several stakeholders.

Links on the web

https://research.chalmers.se/en/project/10803
https://www.vinnova.se/en/p/e-safer---computational-models-for-a-safe-interaction-between-automated-vehicles-and-e-scooters/
https://research.chalmers.se/en/project/10804

8. Conclusions and future research

This project employed crash data, test-track data, and naturalistic data to improve micromobility safety. While crash data and naturalistic data mainly supported the identification of relevant scenarios for the interaction between motorized vehicles and micromobility, test-track data was the primary input to create computational behavioral models. The potential for computational behavioral models to improve micromobility safety have been demoed on the Vårgårda airfield when a new prototypical ADAS delivered a warning to a driver based on the probability that the driver missed the potential crash with an e-scooter while turning at an intersection. In other words, this project took behavioral computational models for the interaction between motorized vehicles and e-scooters from TRL2 to TRL6 for a specific scenario where the driver intends to turn right at an intersection while crossing the path of an e-scooter. This scenario was found to be among the most relevant from the combined analysis of crash data from GIDAS, STRADA, and Folksam. Interestingly, the crash data also showed that this scenario is also relevant for cyclists, opening the opportunity to port the models developed in e-SAFER for e-scooterists to cyclists as well.

From a methodological perspective, the most innovative part of the project was the collection of naturalistic data from e-scooters. With about 7,000 trips from 5,000 e-scooterists, totaling 10,000+ km, this dataset was unprecedented and gave ground-breaking insights into crash causation for e-scooters (Pai and Dozza, 2025). The same data was used to verify the relevance of the scenario described above. However, although unprecedently large, the size of this naturalistic dataset and its information about road users in proximity was not sufficient for us to verify or validate our models on real world data.

Several publications were produced in this project in collaboration with SIMT, a project sponsored by Trafikverket to investigate crash causation for e-scooterists crashes. The results from e-SAFER were also presented at several international conferences. To contribute to open innovation, not only are all papers published with e-SAFER/SIMT open-access but also our models are available on GitHub. It may be worth mentioning that the project also got some media attention not only in Sweden but worldwide.

While this project proved the immense value of naturalistic e-scootering data and the viability of behavioural models to assist drivers at intersection for a safe interaction with micromobility users, much research and development is still needed to make the interaction between motorized vehicles and micromobility safer. For instance, although no naturalistic e-scootering database larger than the one presented in this project is available today, our dataset was still too small for model validation. A larger data collection on many different cities would make it possible to use naturalistic data in a totally new way and open many opportunities for ADAS and CAV development.

The models produced in this project proved to work in a test-track demonstration but are limited to a specific scenario and still need to be verified and validated in the real world. Future studies may expand the models developed by e-SAFER, porting them to different micromobility vehicles and other urban scenarios (possibly including a larger number of road-users than a single driver and a single e-scooterist).

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