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SAFER Pre-studies

Final Report

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Project Title	Safety performances of instrumented micro-mobility modes by leveraging microscopic driving behavior data
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Contents

Summary

Shared micro-mobility services offer a sustainable alternative to cars for short trips and as feeders to public transport in cities. However, in several areas, there are concerns with the safety performance of the users of such services. This results in negative feedback from the public, especially for e-scooters, and the service providers also may be required to pay high insurance premiums to compensate for such safety and security challenges. It is, therefore, imperative from the perspective of all stakeholders to develop new solutions to improve the safety performance of the users of such modes.

The main research question targeted in this prestudy is how to assess the safety performance of a trip using a shared micromobility mode. The process attempted in this prestudy is performing a comprehensive review of the literature and the state-of-the-art and adopting a multi-disciplinary approach with experts from industry and research institutes to identify the research gaps and identify a practical and structured approach to address them. Consequently, an attempt has been made to develop a methodology and identify future research projects that shall help to achieve the end goal.

Three important research directions have been identified: risk quantification, detection of unsafe action, and ride (or rider) classification – which can constitute different work packages for one or more future research projects.

Safety performances of instrumented micro-mobility modes by leveraging microscopic driving behavior data

1. Background

Shared micro-mobility services offer a sustainable alternative to cars for short trips in cities. However, there have been reports of safety concerns regarding the performance of the users of such services. This results in a negative public impression, especially for e-scooters, limits the adoption rate and incurs extra costs to compensate for such safety and security challenges. It is, therefore, imperative from the perspective of all stakeholders to develop new methods, including digital solutions, to improve the safety performance of the users of such modes. The first step is to quantify and monitor safety, for example, by analyzing the accident statistics. However, there are practical challenges associated with the comprehensiveness and extent of available accident databases. Thus, alternative measures, such as monitoring near misses using different surrogate safety metrics, have gained popularity in recent years. Nevertheless, there is still a lack of consensus on how to define and extract such metrics in the first place, and use them to derive the overall safety performances, especially on route-level.

2. Project setup

2.1 Purpose

The main research question targeted in this prestudy is how to assess the safety performance of an entire trip using a shared micromobility mode. This shall require an extensive review of literature in the state of the art, interactions among experts from different backgrounds, and identifying future research scope to be able to address the research question.

2.2 Objectives

The main aim of this pre-study is to develop a methodology to evaluate the safety performance of the user of a micro-mobility mode on a route level.

The initial aim was to derive a single metric for safety performance evaluation. However, the literature review, as discussed later (Section 4) in the report, revealed significant gaps and the need for further research before one is able to derive such a metric. Moreover, to maintain the conciseness and the structure of the report, the entire literature review has not been discussed in detail, but it only includes the main findings and research gaps in the context of the present study.

2.3 Project period

The project period was 8 months (January 01, 2024 – August 31, 2024).

2.4 Partners

The partners involved in the pre-study are VTI (Kinjal Bhattacharyya, Johan Olstam, Mattias Hjort, Sogol Kharrazi, Guillermo Perez Castro), Högskolan i Halmstad (Slawomir Nowaczyk, Mohammed Ghaith Altarabichi), and Voi (Rahman Amandius, Soffi Razavi, Hongyi Liu, Marco Capuccini).

3. Method and activities

3.1 Literature Review

A literature review was conducted based on PRISMA guidelines with the following steps:

- Keywords:

(micromobilit* or micro-mobilit* or bike* or e-bike* or bicycl* or e-scooter* or scooter* or kickbike* or kickspark*)
AND
(instrument* or sens*)
AND
(safe* or surrogate*)

- Database: Scopus, TRID
- Date range: 2015 – 2024
- Total no. of publications: 1060

The articles were grouped in terms of their relevance, as indicated in the following table.

Relevance	Count
Instrumented - Fully Relevant	65
Instrumented - Partially Relevant	61
Lab/Controlled/non-Instrumented - Partially Relevant	42
Review article	8

The literature can be divided into six categories:

i. Methods to identify different types of unsafe actions
ii. Algorithms to quantify risks associated with different factors
iii. Algorithms to detect unsafe or safety-critical events
iv. Algorithms to classify different types of rides/riders
v. Instrumentation setup for micromobility modes
vi. Algorithms to improve estimation accuracy

In the present prestudy project, we have decided to focus on the first four categories since the last two are considered to be more relevant for the implementation rather than the conceptualization phase.

3.2 Methodology Development

The focus of this prestudy has been on utilizing the knowledge gained from the literature review and putting it in the context of experiences from industry (Voi) and research institutes (VTI + Halmstad University) to identify research gaps, develop methodology for safety performance estimation, and identify future research projects. This was achieved by a series of working group meetings that involved going through the literature findings, identifying the gaps and practical aspects and issues with data collection on micromobility modes, brainstorming and collectively identifying the potential research areas and the way forward.

4. Results and Deliverables

The main deliverable from the pre-study is to propose a methodological approach by highlighting the steps needed for safety performance assessment. The proposed methodology comprises 4 major steps, which are identified based on the methods described in the previous section and are discussed in the subsequent subsections. It includes a combination of the findings from the literature review, identification of the research gaps and potential approaches to addressing them.

4.1 Step-1: Identify Unsafe Movements/Actions

The existing literature has identified different movements or actions associated with riding a micromobility mode as well as the ones that may result in creating a potentially unsafe or critical situation. These movements or actions can be broadly categorized into three main categories. However, it is important to note that relatively little is known about the actual risks associated with them; in some cases, these are rather subjective and context-dependent.

i. Longitudinal Movement: There are two movements of interest within this category:
    a. Speeding: Based on a Safe Systems approach, different speed limits are usually suggested for different modes in different types of facilities. A ride where the specific speed limits are exceeded may be considered as an unsafe ride which can expose the rider and the surrounding road users to risk of collision and injury. The speed patterns of a rider while crossing an intersection may also be considered to be an important parameter defined by the speed reduction and adopted speed of the rider. If the rider reduces their speed near the intersection and adopts a lower speed, it indicates that the rider is more attentive to the surrounding traffic while performing the crossing maneuver (Langford et al., 2015).
    b. Acceleration: Sudden large variations in the acceleration profile can be caused by near-miss events (Karakaya et al., 2023). A ride where the rider performs harsh braking may result in an unsafe situation or may also be the result of an unsafe situation created by a surrounding road user. However, a risk-taking nature or distracted riding attitude of the rider can be identified if the rider performs frequent harsh braking during the trip.

ii. Lateral Movement: There are two movements of interest within this category:
   a. Passing/Meeting Maneuver: The combination of high speed and short distances maintained while passing and/or meeting other road users can result in safety-critical scenarios. Lateral Passing Distance (LPD) has been identified in the literature as an important attribute to classify between a safe and unsafe situation during the passing or overtaking maneuver. Usually, critical LPD values have been identified for interactions between cars/trucks and micromobility modes. However, there is a significant gap in research to identify the LPD thresholds for interaction between different micromobility modes. Fonseca-Cabrera et al. (2021) measured clearance distance for bicycles and e-scooters for different types of facilities and attempted to correlate them with the perceived safety of users of such facilities. A possible approach may be to extend this study by using Augmented Reality (AR) environments and assess the perceived safety of a vulnerable road user (e.g. pedestrian, bicyclist, e-scooter rider, etc.) when another micromobility mode passes them at various combinations of speed and distance.
   b. Swerving: Swerving or slalom-motion or lane-weaving has been classified in the literature as a risk-taking behavior by the riders of micromobility modes. There are some works in literature to identify swerving patterns of micromobility modes. For example, Gu et al (2017) illustrate patterns of angular acceleration (obtained from a gyroscope) and longitudinal acceleration (obtained from an accelerometer) to identify a swerving motion.

iii. Use of Infrastructure: The infrastructure can be classified based on the following categories:
   a. Riding surface condition: Riding on some surfaces is more unsafe compared to other surfaces. Surfaces like wet/slippery, grassy, gravelly, etc. are considered to be more unsafe than surfaces like dry, asphalt/concrete, smooth, etc. Attempts have been made in the literature to make an assessment of the riding surface condition based on the vertical vibration profile generated from IMU sensors (e.g., Leoni et al., 2023).
   b. Riding surface transition: The transition from one riding surface to another may also result in an unsafe situation at or near the transition point depending on the combination of two riding surfaces. This is one of the major contributors to single-vehicle accidents.
   c. Riding infrastructure: This can be classified based on the presence of other road users, i.e., footpath (pedestrian + bicycle/e-scooter), bicycle path/lane (bicycle + e-scooter), and shared lane (cars/heavy vehicles + bicycle/e-scooter). The riding location is usually hard to detect from traditional GPS and IMU sensors and may require additional (e.g., vision-based) sensors.

iv. Others: These are several other unsafe movements or actions identified in the literature that cannot be classified under the above three categories, e.g., tandem

riding, use of phone, use of protection (e.g., helmets), single-handed/hands-free riding, and standing while riding (bicycles).

4.2 Step-2: Quantify Risks

This step involves the quantification of risk associated with each (potentially) unsafe movement or action identified in the previous step. This is a crucial and one of the most challenging steps within the methodology. This is because, in order to evaluate the safety performance associated with a ride, it is not only important to know the safety thresholds for each movement or action but also have an absolute or relative measure of how much it contributes to an unsafe ride. One established method is to use the odds-ratio.

There are only a few very recent works in literature that have focused on this aspect. One of the most comprehensive ones is documented by White et al (2023) where an attempt was made to identify safety critical events (SCEs), i.e., crash or near-miss, in a naturalistic e-scooter dataset and determine the odds ratio associated with different factors (hereby termed as unsafe movement or action). The e-SAFER project is also aimed to comprehensively measure the odds-ratio for several factors associated with riding e-scooters in the city of Gothenburg. However, there is still scope for future research and accordingly, the following future steps are proposed:

i. Identify missing factors (context) from previous studies and their interaction, i.e., combinations of environmental situations (weather, time-of-day/illumination, presence of other road users) and unsafe movement or action performed by a micromobility user. For example, one possibility is to cover weekend nights, which may provide more evidence of riding under the influence. Several cities may also be covered to encompass different road and traffic environments. This will help in designing the experiment for the subsequent steps. Ultimately, it is critical to understand what are causes of the risk and which actions are the consequences. For example, single-handed riding is a safety hazard, but we lack understanding of what is causing people to let go of the handlebars.

ii. Estimate the Odds-Ratio by establishing ground truth with a fully instrumented mode and in a controlled/ semi-controlled environment where all possible combinations of events, especially those that have not previously been studied, are generated. Since it can be expensive (both in terms of time and deployment of sensors) to establish the ground truth based only on field tests, a combination of field tests, test tracks (+AR), and VR-based tests (e.g. VRU simulators) may be employed for this estimation. A comparison between field tests and controlled environment tests will also help to eliminate the systematic uncertainties associated with the latter.

iii. Design and perform user/expert surveys to compare the perceived safety risks with the estimated odds-ratio. This will act as a verification step for the established odds-ratio, and also allow us to differentiate between objective risk and the subjective perception of the risk (according to the specific context/circumstances).

VR- or AR- based simulators for vulnerable road users could be used for assessing the level of comfort associated with close interactions with e-scooters. In this context, the cycling comfort index (CCI), proposed by Feizi et al. (2020), may further be augmented to estimate the comfort level associated with different micromobility modes. While level of comfort cannot directly be translated to an accident risk, they are correlated, and the perceived safety of the VRUs is important. The influence from parameters, such as relative speed, distance and direction, on the odds-ratio of a given unsafe movement can be studied, at varying levels of density of surrounding VRUs. Both pedestrians and bicyclists could be studied using e.g. VTI's pedestrian and bicycle simulators. It should be noted, however, that distance estimation is notoriously difficult in traditional driving simulators. The use of VR or AR may lead to improved distance estimation, as getting measurements on lateral movements is more challenging in field tests (compared to longitudinal movements), but that needs to be further investigated. Handling properties of the e-scooter or bicycle is presently not possible to investigate using a simulator, so e.g. limiting values of safe deceleration levels have to be found from field tests.

4.3 Step-3: Detect Unsafe Actions

This step involves the detection of unsafe actions using micromobility modes with different levels of instrumentation. The idea is to find the tradeoff between detecting different types of unsafe actions and instrumentation of micromobility modes to identify cost-effective solutions for commercially available shared micromobility modes.

i. Compare the performance of a fully instrumented mode (i.e., all possible sensors of high quality) with the instrumented modes in practice (i.e., lacking some sensors, low-quality sensors) in a controlled environment (i.e., with detailed surveillance to establish ground truth). Trajectories recorded from the modes by micromobility service providers and operated in a similar environment may be used for the latter. Some issues associated with different sensors have already been identified in the literature. For example, ultrasonic sensors may not accurately record distances in heavy rain, snow, or situations with a lot of background noise (e.g., passing parked vehicles). The sensitivity to weather is also true for the GPS sensor. The accuracy of the GPS can also be affected by urban canyons. While researchers have attempted to improve the estimation accuracy with different sensors, an attempt can be made to further resolve the most important existing issues by comparing the observed values with ground truth and adopting different AI/ML-based methods to improve the accuracies.
   If the current type of shared mode shall require an added level of instrumentation (i.e., additional sensor type or improved quality of a specific sensor type) for detecting sufficient types of unsafe actions, it may be interesting to design an optimization problem in combination with meso/macroscopic modeling to identify the required number and optimal deployment of modes with an improved instrumentation level.

ii. Identify Unsafe Action: This involves applying the sensor data and knowledge of the situation to identify if an unsafe action has been triggered. This can be done by setting up different thresholds for each action. The thresholds can be identified based on past work reported in the literature, e.g., patterns for normal and harsh braking events (Dozza et al, 2023), and/or from evidence from the experiments conducted in Step-3. Data that is unavailable from the instrumented mode may be collected from secondary data sources to understand the average situation. For example, weather station data may be used to understand the weather conditions during the ride, traffic surveillance camera data may be used to identify the pedestrian density, traffic mix, etc. along the ride path, etc. In this step, unsupervised machine learning approaches, e.g., clustering, can help to identify unsafe behavior that is previously unknown or has not yet been identified.

4.4 Step-4: Ride & Rider Classification

This is the final step of the methodology that deals with estimating the ride or rider quality in terms of safety performance. These can be obtained as described below:

i. Identify ride type: If a ride exceeds a certain threshold score based on the unsafe actions and associated risks, then the ride can be considered an unsafe ride. The negative ride score, RS_{neg}, can be obtained based on the equation below:

$$RS_{neg} = \sum_{i,j} n_{ij} \times OR_{ij}$$

where,
n_{ij} = number of instances per km of an unsafe action *i* in a situation *j*.
OR_{ij} = Odds-Ratio associated with combination of unsafe action *i* and situation *j*.
A lower RS_{neg} indicates a safer ride.

In this context, it may also be mentioned that in many cases an unsafe action may be the result of a previous unsafe action, e.g. a cyclist takes a left turn to avoid hitting a dog on the road but in the end has to take a sudden brake in order not to hit a tree. Therefore, further investigation of the microscopic trajectory data will be necessary to assess the correlation between a series of unsafe acts occurring within short intervals of time.

An alternative may be to obtain a positive ride score, RS_{pos}, based on the share of the trip length where the safety thresholds associated with different unsafe actions are not exceeded. This can be represented by the following equation:

$$RS_{pos} = \left(1 - \frac{\sum_i l_{a_i}}{L}\right) \times 100$$

where,
l_{a_i} = length of the trip where the safety threshold associated with the unsafe action a_i has been exceeded.

L = total trip length.
A higher RS_{pos} indicates a safer ride.

A safety threshold is required in this instance instead of a odds-ratio as a quantitative margin can help to check if an unsafe act has been performed, e.g., a e-scooter performs a braking, but the safety threshold distinguishes the margin between a safe and a hard or unsafe braking.

Finally, in order to infer about the overall ride quality, different levels may be set up to the classify the ride scores. This may be achieved by a method similar to estimating the level of service. There are several techniques in literature. An initial idea may be to set up a reinforcement-learning based deep learning algorithm to estimate the threshold scores of each level.

ii. Identify rider type: If a rider repeats certain unsafe movements or actions or has a low overall safety performance over several successive rides, then the rider can be considered an unsafe rider. In this step, unsupervised machine learning approaches, e.g., clustering, can be adopted as an exploratory phase to classify between different levels of aggressiveness/ rider type.

5. Conclusions, Lessons Learnt and Next Steps

A comprehensive literature review of state-of-the-art in different categories related to micromobility is a major task completed as a part of the prestudy. Some of the major research gaps identified from the prestudy are: (i) relatively little is known about the actual risks associated with many unsafe movements or actions and, in some cases, they are subjective and context-dependent. (ii) estimating odds-ratio is identified as an established to estimate risks associated with the unsafe actions but they have not been comprehensively estimated in terms of (a) a combination of factors (e.g., riding hands-free in a gravel road), (b) reflecting the difference between the risks associated with a micromobility mode (e.g. e-scooter and bicycle) for the same unsafe action. (iii) estimating the accuracy of detecting different actions with commercially available sensors installed on shared micromobility modes. The learnings from the literature review created the framework for interactions among multidisciplinary experts to identify the research gaps and structure a methodology to achieve the end goal of estimating safety performance associated with a trip using an instrumented micromobility mode.

Based on the prestudy, three important research directions have been identified as identified in Steps 2, 3 and 4 of the Methodology. These can constitute as three different work packages for a single large-scale research project or can be split up into 2 or more smaller research projects with progressive contributions towards the end goal. An application may also be submitted to Trafikverket Stage 1 call ending on September 15, 2024.

An attempt can also be made to apply the ride score estimators in Step 4 based on current knowledge of risks associated with different rider actions on datasets generated from the currently instrumented shared micromobility modes.

6. Dissemination and Publications

An abstract has been submitted to Swedish Transport Research Conference (STRC) 2024 that explains the overall process of developing the methodology based on literature review and future work.

If an additional budget is achieved from a future project, a literature review manuscript shall be prepared to be submitted to an international Journal (e.g. ETRR).

7. Acknowledgement

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