Safety impacts of rising urban micromobility: statistical analysis of e-scooter use and risky rider behavior in Ingolstadt, Germany

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1 INTRODUCTION

Micromobility is a growing market, with McKinsey & Company forecasting market capitalization of up to $150 billion in Europe alone by 2030 [1]. Due to the COVID-19 crisis, McKinsey & Company has published an updated analysis of the market capitalization of the micromobility sector, showing a sharp short-term decline, a strong recovery after the pandemic, and even an increase in the sector of up to 10% by 2030 compared to their original prediction [2]. Reasons for this include hygiene, social distancing, preference for privacy [3]. Moreover, micromobility will likely contribute to reduced traffic congestion as well as CO_2 emissions [4] and therefore constitutes a key aspect of an overall strategy for sustainable mobility. If one considers absolute accident figures, one might get the impression that riding e-scooters, which are now present in large numbers in many cities, is less dangerous than riding a bicycle. However, the German Aerospace Center DLR has evaluated e-scooter and bicycle accidents in Germany in 2020 and has concluded that e-scooter riders currently have a significantly higher accident risk per kilometer than cyclists [5], whose risks are already a matter of concern. Hence, it is essential to assess and quantify the impacts of rising e-scooter use, not only on traffic efficiency, but also on traffic safety.
Our paradigm for traffic safety and efficiency assessment is inspired by the concept of randomized controlled trials (RCT) in medical research; here, we design virtual randomized controlled trials by means of agent-based, stochastic (Monte Carlo) simulation and representative probability distributions for all agents in traffic, including their human (mis-)behavior [6]. A realistic assessment process requires properly validated, quantitative, evidence-based models of e-scooter dynamics, including the spectrum of human behavior characteristics of e-scooter riders.
Our research project SAVeNoW includes several instrumented roadway sections and a selected intersection for detailed data acquisition. A key aim is to represent human behavior in a way that can be used to assess proposed infrastructure-based safety countermeasures and to quantitatively predict safety impacts of automated driving. This paper presents an analysis of representative e-scooter rider data in Ingolstadt and proposes applications to modeling behavior of realistic e-scooter riders. Oddly enough, we have indeed found evidence for behavior that is not entirely in concordance with traffic regulations and is thus highly relevant for traffic safety risk assessment and ultimately for risk minimization strategies, particularly in automated vehicles that interact with micromobility users.

2 METHODOLOGY

A German e-scooter sharing company supported our research by providing anonymized data of all e-scooter rides from September 2020 to November 2020 from Ingolstadt, Germany. Each obtained data file describes one ride containing data points with a sampling frequency of 0.2 Hz. Each data point includes timestamp, velocity, GPS coordinate, vehicle id and the battery state. At the time of data collection, the sharing company of cooperation was the only available e-scooter sharing service in this region, so it is highly likely that the sample is representative for the population of all e-scooter trips in Ingolstadt during the period covered.
The current analysis first considers summary statistics including spatial distributions of trip counts, demand by weekday and time-of-day, as well as trip distance and speed distributions. These statistics are important for calibration of key parameters (such as origin-destination matrices or velocity profiles of e-scooter riders) in the digital twin of Ingolstadt that we build within our research project SAVeNoW. The aim is to evaluate the potential impact of traffic measures, such as automated vehicles or I2X communication on micromobility in terms of traffic efficiency and traffic safety. Especially for traffic safety, it is crucial to analyze the causal chain of events leading to conflicts between e-scooters and motor vehicles, particularly at intersections. In this context, the intended methodology in our research project will involve generation of representative virtual trajectories of e-scooter riders and their interactions (and occasional conflicts) with virtual motor vehicles, including human (mis-)behavior. Virtual randomized controlled trials will be designed to utilize this methodology within an agent-based, stochastic simulation framework.
The first step in finding a cure for the vulnerability of e-scooter users is to diagnose the underlying errors and the lack of adequate redundancy in the car-scooter interaction process. According to national regulations in Germany, e-scooters are required to travel on bike lanes. Wrong-way riders (WWR) are defined here from the data as e-scooter trajectories that may appear to be traveling on a bike lane, as prescribed, but that are localized to the "wrong" side of the road. A safety report from Ingolstadt shows that, whereas overall cycling accidents decreased by 14%, the number of WWR accidents increased by 75% [7]. The increasing risk of encountering such WWR could pose a new cognitive challenge for drivers, also in the context of micromobility vehicles, as driver attention and gaze control of drivers are strongly guided by expectation and experience [8]. Thus, of particular interest for evaluation of traffic safety metrics is the frequency and distribution of wrong-way rider trajectories. The classification of trajectory segments as WWR (vs. right-way riders) was performed using an algorithm taking the map-matched waypoints as well as the intersection geometry into account. For this purpose, in the intersection shown in the circle in Fig. 3b, one virtual marker was placed at the exact center of the intersection and four markers were placed at the center of each intersection branch. The delta of the distance to the markers was used to assign and filter the trajectories and thus the classification of the WWR. After automatic sorting by the algorithm, the trajectories were manually checked for correct assignment with respect to WWR using plots for verification, see Fig. 3b. Due to the GPS sampling rate, errors are not impossible, although we expect the GPS errors to be smaller than the statistical errors of the proportion.

3 RESULTS

Table 1 and Fig. 1 show descriptive statistics of the e-scooter shared rides in Ingolstadt. For reasons of visual illustration, only the relevant areas are shown in Fig. 1. The Ingolstadt Police Department provided us with e-scooter accidents reported during this period, which were a total of six. Considering the total number of e-scooter kilometers driven during this period, this results in an average of one reported accident approximately every 23,000 kilometers driven. Unreported accidents could well increase this number by a substantial factor. For example, about 70% of cycling accidents are estimated to be unreported [9].

Table 1 – *Descriptive statistics of shared e-scooter rides in Ingolstadt*

Months	Trips	E-Scooter fleet	Dist. traveled	<Trip length>	<Trip time>
Sep 2020	23573	558	48996 km	2.07 km	9.82 minutes
Oct 2020	25951	568	51145 km	1.97 km	9.26 minutes
Nov 2020	20748	571	39576 km	1.90 km	11.15 minutes

Observing Fig. 1, it is noticeable that e-scooter riders drive at full throttle most of the time. Data points with the velocity of either 19, 20, or 21 km/h account for 56.3% of the velocity data. Considering the duration, as well as the distance covered by the individual journeys, the overall average speed results in 11.8 km/h. Fig. 2 shows time-based e-scooter usage in Ingolstadt. The prominent morning peak presumably reflects use by schoolchildren, students and commuters. The weekend nighttime peak could include riders avoiding DWI risk in cars. However, drunk e-scooter riders have a high accident risk [10], which is likely to reflect greater risk affinity [11]. Analysis of the spatial distribution shows the highest percentage of trips occurs in the city center and near railroad stations, see Fig. 3a.

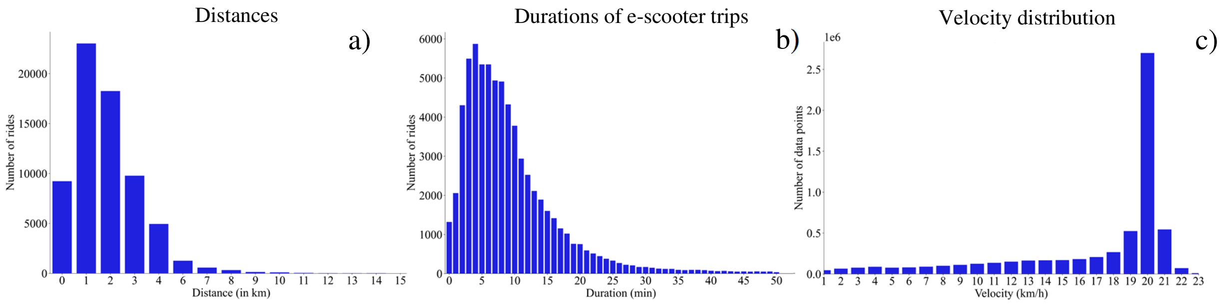

Figure 1 – *Shared e-scooter ride histograms with a) driven distances, b) trip durations and c) velocities of the datapoints as described above in Methodology.*

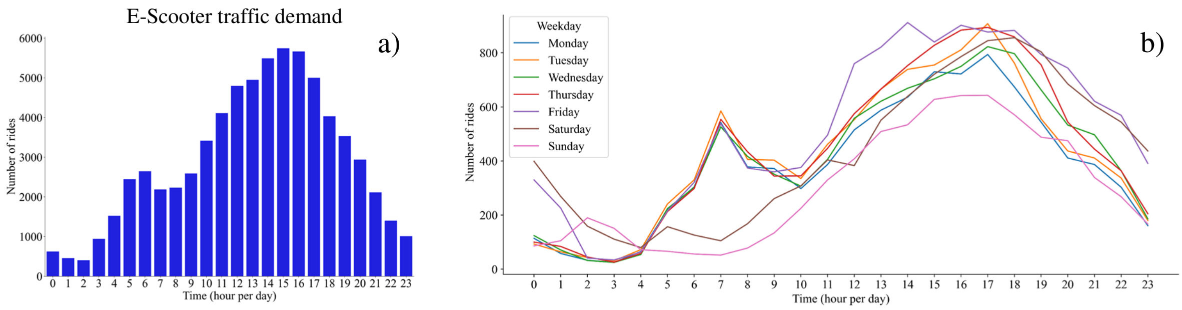

Figure 2 – *Hourly e-scooter traffic demand in Ingolstadt with a) over all weekdays accumulated and b) filtered for each weekday.*

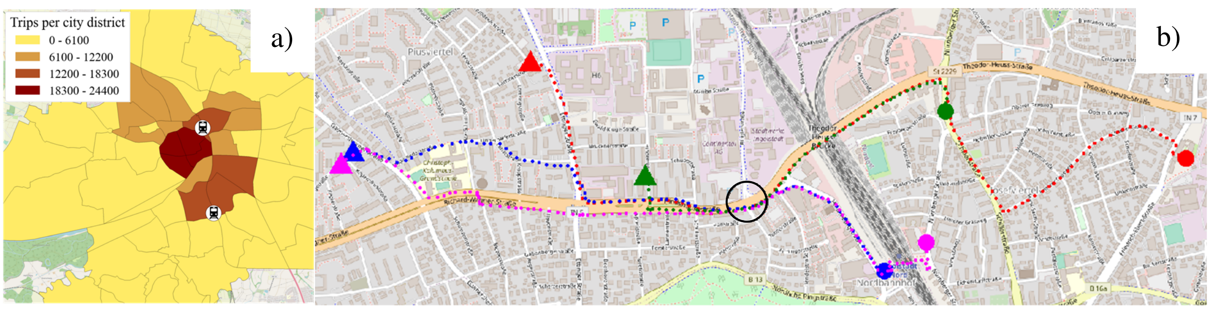

Figure 3 – *a) number of trips per city district. b) example of wrong way rides; filled circle marks beginning of trip, triangle end of trip.*

An initially unexpected result is the high percentage of wrong way rides (WWR) that take place with e-scooters. At the Test Intersection of our research project (marked by a black circle in Fig. 3b) there is a bike lane on both sides (north and south carriageway). Yet, on the southern carriageway, 467 WWR from east to west were counted and 678 in the permitted direction, resulting in 40.7% WWR, 95% CI [37.86, 43.54]. Four of these WWR are shown as examples in Fig. 3b. On the northern carriageway, from west to east and vice versa, a total of 678 e-scooter rides were counted, with 22.1% being WWR, 95% CI [18.88, 25.12]. Analyzing the trajectories, we found that e-scooter riders simply take the path of "least resistance" and, for the sake of simplicity, stay on the side they are already on anyway. Often, the side of the road is only changed shortly before the destination, if necessary. In this context of "least resistance" we also counted rides at our Test Intersection for the southern and northern carriage, where the rider already crosses the lane before the traffic lights; presumably to save time. 4.2% showed that behavior, 95% CI [3.26, 5.14].

4 DISCUSSION

The data presented here are based on a representative sample of e-scooter trips in the city of Ingolstadt, comprising about 70,000 trips and 140,000 km sampled and georeferenced at 0.2 Hz. This comprehensive database has provided us with the opportunity to assess spatial, velocity, and trip length/duration distributions. One evaluation that surprised us was that over 50% of the recorded data points had a velocity value of about 20km/h, indicating that e-scooter riders mostly push the throttle to the limit if possible. The key finding of this paper resulted from a detailed analysis of the georeferenced trajectories: The data reveal a substantial proportion of wrong-way riders, exceeding 20% at the SAVeNoW Test Intersection in Ingolstadt. It should be mentioned that the data were collected during a cold weather season in Germany during the COVID-19 pandemic, during which e-scooter utilization was depressed by about two-thirds in Europe and the US according to the McKinsey report [2]. While this temporary decrease is unlikely to impact the distributional characteristics, the absolute numbers of e-scooter rides will almost certainly rise substantially in the immediate aftermath of the pandemic and are projected to rise steadily thereafter as an important micromobility mode for sustainable mobility.

Besides the data presented here, a video analysis of our studied Test Intersection is taking place in parallel, deriving trajectories of e-scooter riders, pedestrians, and cyclists. These can then be used to refine the data available here, which only has a sampling rate as low as 0.2 Hz. In addition to this video analysis, also a microscopic traffic simulation of Ingolstadt in SUMO is available as open source [12].

The astoundingly high number of wrong-way riders pose severe cognitive challenges to drivers because such riders are often unexpected. The availability of multiple on-board sensors suggests that the introduction of automated driving and advanced driver assistance systems could have important long-term safety benefits in situations where human drivers do not anticipate micromobility users. In the short-to-medium term, it is important to investigate infrastructure-based solutions as well. To quantify the potential benefits of vehicle-based and infrastructure-based approaches, it is essential to construct an adequate micromobility knowledge base to model the current traffic situation for automated vehicles and to perform comprehensive virtual randomized controlled trials.

In addition to a realistic spectrum of risky interaction scenarios, this micromobility knowledge base also should include distributions of velocity profiles of riders approaching intersections and other human factor statistics, such as more precise data on wrong-way rider rule violations, (mis-)perception, human (mis-)behavior. Another central element of micromobility safety assessment is a detailed model of riders' skill in impending accident situations (i.e., swerving or emergency braking) [13]. Our team is conducting research on all these metrics using real-world studies, VR-simulator studies, and natural observations of traffic, and we suggest that micromobility safety research should be strongly prioritized in the near future.

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