Analysis of e-scooter Users' Riding Behaviour at Signalized Junctions

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Abstract. During the last few years, micromobility services have blossomed globally. Shared e-scooters are the main microbility mode that have become rapidly a fashionable trend. Yet, this rapid spread also made obvious that urban areas were not adequately prepared for integrating micromobility in their transportation systems. Many issues appeared related with invasion of public space, vandalism of e-scooters, and concerns of road safety. Currently, most countries have already established operating guidelines about micromobility, while some others are in the process of doing so. For establishing appropriate guidelines, or for modifying them based on the actual needs, it is important to constantly monitor micromobility operations and investigate those issues that were mostly influenced by micromobility. This paper aims to shed some light on the riding behaviour of e-scooter users by analyzing their actions at signalized junctions. Observations of 330 e-scooter users were collected at 12 signalized junctions in the city of Thessaloniki, Greece. More specifically, the decision of e-scooter users to cross illegally during the red-light phase or to stop appropriately was observed, as well as the speed difference before and after the change of the traffic signal from green to yellow. Additionally, the geometry and functional characteristics of the junctions were collected as well as user-related attributes. The statistical analysis of the observations aims to identify how the two main variables that express the behaviour of e-scooter users (i.e., decision to cross illegally and speed difference) are affected either by the characteristics of the junctions or by the attributes of users.

Keywords: e-scooters · micromobility · signalized junctions

1 Introduction

E-scooters represent a recent addition to urban transportation systems, and their immediate impact has been noticeable. They have rapidly gained popularity, evidenced by the widespread adoption of shared services worldwide and the significant expansion of their market size. By the close of 2019, shared e-scooter services were available in

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over 220 cities across the United States and Europe, indicating their rapid spread [1]. Additionally, apart from shared e-scooters, there has been an increasing demand for private e-scooters. Private e-scooters dominated the industry in 2022, accounting for nearly 70% of the overall revenue. In summary, the global electric scooter market was valued at $33.18 billion USD in 2022 and is projected to grow at a rate of 9.9% from 2023 to 2030 according to Grand View Research [2].

Previous research suggests that e-scooters can contribute to addressing environmental concerns in cities by reducing air pollution [3]. Moreover, e-scooters are acknowledged as a mode that can serve short trips in a convenient and fast way [4]. Except of short distance trips, e-scooters and especially the shared ones, are considered a mean for improving intermodality through combining its use with public transport services [5, 6].

Concurrently, other studies emphasize the importance of mitigating inequalities in transportation access, promoting cost-saving measures, and enhancing mobility resilience [7, 8]. Numerous studies have explored public attitudes toward e-scooters, particularly among non-users, underscoring significant challenges such as inadequate infrastructure and the absence of a regulatory framework [9, 10]. According to a very recent study, users are eagerly anticipating new laws regulating the usage of e-scooters, such as optimizing speed limits, designating the usage of e-scooter infrastructure, and appointing dedicated parking places [11]. Indeed, appropriate regulatory frameworks seem to be essential for efficiently integrating e-scooters in modern transportation systems and gathering their full potential. As Felix et al. state, e-scooters generate several benefits, however these benefits are highly overshadowed by safety-related issues (almost €6M in annual costs) [12].

Considering the abovementioned issues that are related with the rapid spread of e-scooters, many countries have developed regulations. A report released by The Forum of European Road Safety Research Institutes conducted a comparative analysis across 18 European countries concerning e-scooters, with the goal of delineating disparities in their legal status and safety considerations [13]. As it can be seen in Fig. 1, the majority of the countries regard e-scooters as equivalent to bicycles. In the Czech Republic, scooters are categorized similarly to e-bikes. In several nations, classification is contingent upon speed or maximum power. For instance, in Finland, a scooter is treated as a pedestrian if its speed does not exceed 15 km/h; otherwise, it is classified as a bicycle. About half of the analyzed countries impose an age restriction, in numerous European countries, e-scooters can only be operated by individuals over 14 years old, with mandatory helmet use for those under 18. E-scooters are typically required to be ridden on cycle paths in nearly all countries, where available. In instances where cycle paths are unavailable, they are expected to be used on the road in Austria, France (if the speed limit is not higher than 50 km/h), Germany, Portugal, Sweden, and Switzerland. In Italy, users are permitted to utilize both cycle lanes and roads within areas with a speed limit of 30 km/h.

Interestingly, Germany is the only country where e-scooters are required to have a license plate. Across nearly all countries, the improper parking of e-scooters in public spaces is perceived as a safety concern for pedestrians, the elderly, the visually impaired,

and individuals with disabilities. Despite the significant potential of e-scooters as a transportation solution, particularly in densely populated cities with growing traffic congestion, various legislative challenges must be addressed. Addressing these issues would ensure that e-scooters are not only fast and flexible but also safe [14].

For efficiently addressing legislative challenges, more evidence is needed regarding how e-scooters are being used. It is commonly accepted that the riding behaviour of e-scooter users is inadequately studied. Aiming to contribute in filling this gap, this paper analyzes the behaviour of e-scooter users, specifically when approaching a signalized intersection. It is anticipated that the results of the paper will assist in guiding decision-makers in identifying measures and policies that will promote micromobility safety.

2 Methodology

2.1 Study Area

The study area encompasses the Municipality of Thessaloniki, situated within the Region of Central Macedonia in Northern Greece. The Municipality of Thessaloniki is home to approximately 320,000 inhabitants, making it the second most populous city in Greece. It is renowned as a major educational hub, Thessaloniki hosts four universities, with the Aristotle University of Thessaloniki accommodating around 75,000 registered students and 2,000 academic staff members. Thessaloniki faces traffic congestion issues stemming from heavy reliance on private vehicles and inadequate public transportation services. According to the Thessaloniki Sustainable Urban Mobility Plan [15], private cars account for 41.3% of trips, while public transport and motorcycles represent 33.7% and 11% modal share, respectively. Active modes of transportation, such as walking and cycling, constitute only a small percentage of modal share, at 9.2% and 1.7%, respectively [15].

Thessaloniki has limited bicycle culture and low cycling volumes. The city's bicycle network suffers from fragmentation, indirect routes, and safety concerns. The bicycle lane network is only of 12 km length, while the Municipality covers an area of 19.307 km^2. Prior to the introduction of shared e-scooter systems, Thessaloniki's residents had limited experience with shared mobility services. The city's only existing



Fig. 1. Elements of countries' regulatory frameworks for e-scooters usage [13].

shared mobility option was a dock-based bike-sharing system established in 2013. However, due to the scarcity of docking stations, this system failed to attract many users. Lime introduced a dockless shared e-scooter system in 2018, offering electric-powered scooters that could be parked anywhere. This innovative approach quickly intrigued Thessaloniki's residents, resulting in 850,000 trips within the first year. Following Lime's success, other providers like Hive and Rise entered the market.

All shared e-scooter systems operated without docks within a predefined geofenced area covering Thessaloniki Municipality and surrounding areas, determined by the companies without local authority consultation. Companies regularly redistributed their scooters throughout the day to balance supply and demand and ensure all vehicles were adequately charged.

The initial success of these systems prompted discussions about their benefits and challenges. Local authorities are now considering establishing docking stations to address issues of indiscriminate parking. However, there has been a decline in shared e-scooter usage over time. Factors contributing to this decline include high costs compared to other alternatives like public transport and walking, safety concerns due to inadequate cycling infrastructure, reduced interest following the initial curiosity, and the purchase of personal e-scooters by those recognizing their benefits.

The present paper specifically focuses on 12 signalized junctions, all of them located within the borders of the Municipality of Thessaloniki. The signalized junctions are located along 4 main road-axes of the city, which serve high traffic volumes and have a bicycle lane. Moreover, some of the signalized intersections were located in a close distance from the campuses of city's main universities. The existence of bicycle lane and the close distance from the universities were two criteria that were significantly considered for selecting locations where it would be more likely to have relatively high flows of e-scooters. The 4 selected road-axes are the following:

- Leoforos Nikis (Fig. 2a)
- Konstantinou Karamanli (Fig. 2b)
- Agiou Dimitriou (Fig. 2c)
- Leoforos Stratou (Fig. 2d).

2.2 Data Collection

As a first step, basic geometric and operational attributes were measured in the 12 signalized junctions. A summary of the measured elements is presented in Table 1.

It should be noted that for sequential junctions in the same road-axis, the traffic flow was measured once and it was assumed that the number of vehicles that enters the road-axis in one junction is approximately the same with the number of vehicles that exits the road-axis in the same junction. In the case of Konstantinou Karamanli, junctions 2.1–2.3 were covered with a single set of traffic flow measurements, while a different set of measurements were required for junctions 2.4–2.5, since these two junctions are not sequential with the previous three and the aforementioned assumption would not be plausible. It should be also noted that the traffic flow measurements, as well as the traffic signal measurements were conducted in peak-hours.

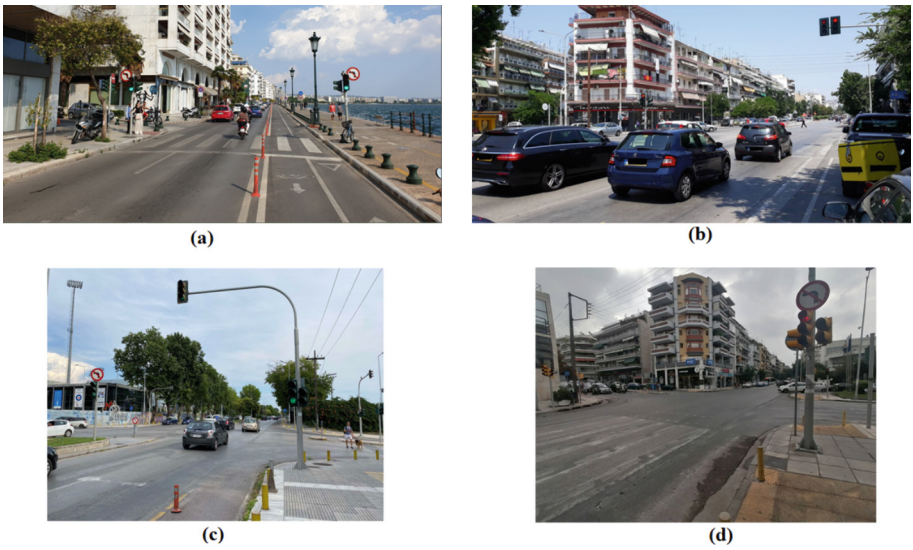

Fig. 2. Images from selected junctions in each of the four road-axes.

Table 1. Basic geometric and operational attributes of the signalized junctions.

Road axis	Junction id	Main road width (m)	Green light phase for main road (sec)	Red light phase for main rad (sec)	Hourly traffic flow in main road (PCU)
Leoforos Nikis	1.1	7	78	19	1824
	1.2	7	78	19	1824
	1.3	7	78	19	1824
Konstantinou Karamanli	2.1	12	57	30	1759
	2.2	12	36	51	1759
	2.3	12	39	48	1759
	2.4	7	49	38	1767
	2.5	10	35	52	1767
Agiou Dimitriou	3.1	10	22	65	1123
	3.2	7	41	56	1123
Leoforos Stratou	4.1	7	46	41	1653
	4.2	6	31	50	1653

The measurements were followed by the formation of a template for the observations. The elements that were included in this template are the following:

- Date/hour
- Gender of the e-scooter user
- Age class (only three wide classes were defined, i.e., < 20, 20–39, > 39, for reducing the possibilities for inaccurate estimations from the observers)
- If there was any source of distraction or not
- Distance of the e-scooter user from the traffic signal at the time that the green light phase was ending (the distance was estimated by initially marking users position in an appropriate drawing and then measuring the distance of this position from the traffic signal)
- Speed of the e-scooter user while the green light phase applies (the speed measurements were made through a handheld speed gun, model LTI 20/20 TruSpeed S)
- Speed of the e-scooter user three seconds after the ending of the green light phase (i.e. when the yellow light phase was shifting to the red one)
- If the user was wearing a safety helmet or not
- If there was at least one pedestrian waiting to cross the road
- If the e-scooter user crossed illegally the road (during the red light phase) or if he/she stopped appropriately.

As it becomes understood from the above description of the elements that were measured, for having a successful observation it was required to capture the e-scooter user at the moment that there was a change in the indication of the traffic light. For instance, e-scooter users that were identified during the green light phase and crossed the intersection without facing a change in the indication of the traffic light phase were not eligible for being observed.

Considering the exclusion of the abovementioned cases and also the low volumes of e-scooters in the city, the collection of a sufficient sample was really challenging. Finally, 331 valid observations were made and used for the analysis. The observations took place during two phases, i.e. October and November 2021 and from Mach to May 2022. The winter season was not utilized for observations, since the micromobility traffic drops significantly in the city. All observations were conducted under fine weather conditions.

In both phases the observations were undertaken by a couple of observers. The one observer was responsible for measuring the speeds before and after the change of the traffic light indication, while the second observer was responsible for observing all other elements and taking notes to the template. All observers initially participated in pilot observations for realizing how the tasks should be handled on site, for gaining familiarity with the handheld speed gun and for identifying the optimal spots where they should stand in each examined junction.

3 Results

The data selected through the observations are initially analyzed descriptively for providing an overview of the sample and the measured elements. Table 2 provides an overview for basic categorical variables of the analysis. It seems that most of the observed e-scooter riders are males. This indicates that e-scooters in Thessaloniki are mostly used

by males. This finding for Thessaloniki was also identified by a previous extensive survey [8] and it also agrees with findings for many other contexts [16–18]. A significant 12.7% had some audio or visual distraction while riding an e-scooter and approaching the signalized junction, while only the 23% of the users wore a helmet, despite the fact that it is compulsory according to the Greek regulations. Interestingly, the majority of the observed users didn't stop in the red light indication. These statistics indicate a highly aggressive traffic behavior of e-scooter users, who tend to the neglect the traffic rules.

Table 2. Descriptive statistics of categorical variables.

Variable	Categories	Frequencies
Gender	Male	240 (72.5%
	Female	91 (27.5%)
Distraction	No	289 (87.3%)
	Yes	42 (12.7%)
Helmet	No	255 (77%)
	Yes	76 (23%)
Existence of pedestrian waiting to cross	No	164 (49.5%)
	Yes	167 (50.5%)
Illegal crossing during red light phase	No	119 (36%)
	Yes	212 (64%)

Table 3 presents the statistics of the continuous variables of the analysis. The measured speeds before and after the change of traffic light indication are reasonable. The statistics of Table 3 show that e-scooters on average reduce their speed by 4.19 km/h within 3 s (assuming that the speed that was measured during the green light phase was maintained until the time that the traffic light indication changed from green to yellow). This speed reduction within the specific time period indicates a smooth deceleration in most cases.

Table 3. Descriptive statistics of categorical variables.

Variable	Mean value	Std. Deviation
Distance from traffic signal when traffic light indication changed (m)	15.16	7.58
Speed "before" (during green light phase) (km/h)	21.80	3.85
Speed "after" (3 s after the end of the green light phase) (km/h)	17.64	4.75
Speed difference (speed "after" minus speed "before") (km/h)	-4.19	4.31

As a next of the analysis, correlations between variables were investigated. More specifically, it was examined which variables affect the speed difference and the decision of the user to cross illegally or not. These two variables were considered as many indicators of the riding behavior in signalized junctions.

The speed difference was found to be correlated with the distance of the e-scooter user from the traffic light when traffic indication changed (Pearson's $r = 0.113$, p-value $= 0.040$). This correlation is presented in Fig. 3, where it can be seen that for distances up to 17 m, the speed difference scatters around −4 km/h. For distances greater than 17 m the speed reduction becomes lower. Interestingly, for distances up to 29 m that are cases where users accelerate instead of decelerating.

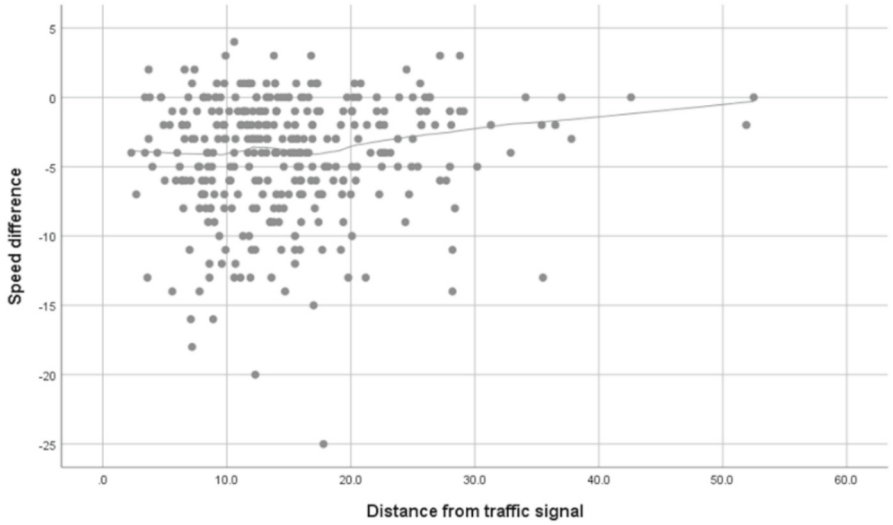

Fig. 3. Correlation between the distance of the user from the traffic light and the speed difference before and after the change of the traffic light indication.

The speed difference was also found to be correlated with the initial speed of the user, i.e. the speed he/she had during the green light phase (Pearson's $r = 0.321$, p-value < 0.001). Figure 4 presents the correlation between the two variables, where it can be seen that for moderate initial speeds (up to 20 km/h) the speed difference is close to the identified mean speed difference (4.19 km/h); however, the speed of e-scooters starts decreasing sharply for high initial speeds (higher than 22 km/h).

With regards to the decision of the e-scooter user to cross illegally the junction during the red light phase, several affecting factors were identified. One of these factors is the gender (p-value < 0.001). Figure 5 clearly shows that males are much more prone to crossing illegally the junction comparing with females. More specifically, the vast majority of males decided to cross the junction during the red light phase, while most females stopped appropriately.

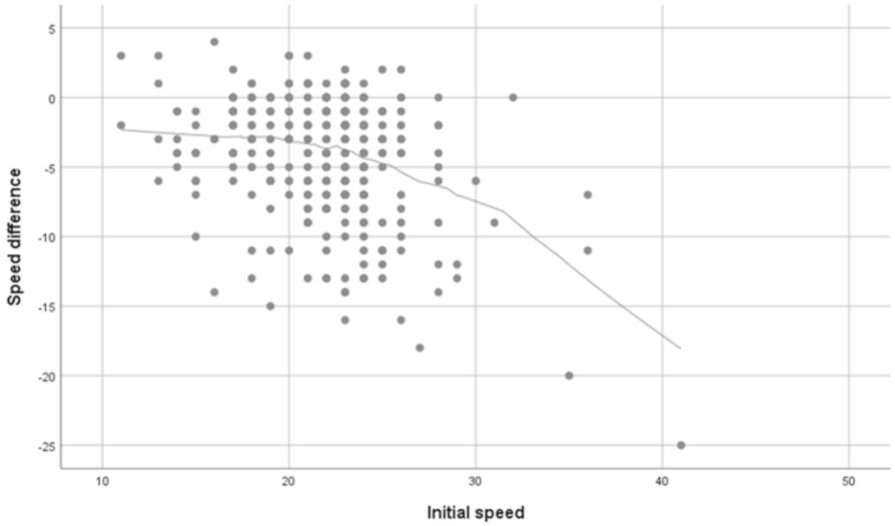

Fig. 4. Correlation between the initial speed and the speed difference before and after the change of the traffic light indication.

An additional factor that was found to affect the decision of e-scooter users to cross illegally or not is the existence of at least one pedestrian that was waiting in the pedestrian crossing of the junction (p-value < 0.001). From Fig. 6 it is identified that even in the case of having a pedestrian waiting to cross, most e-scooter users behaved illegally. However, the likelihood of behaving illegally is much higher in the case of having no pedestrian waiting to cross.

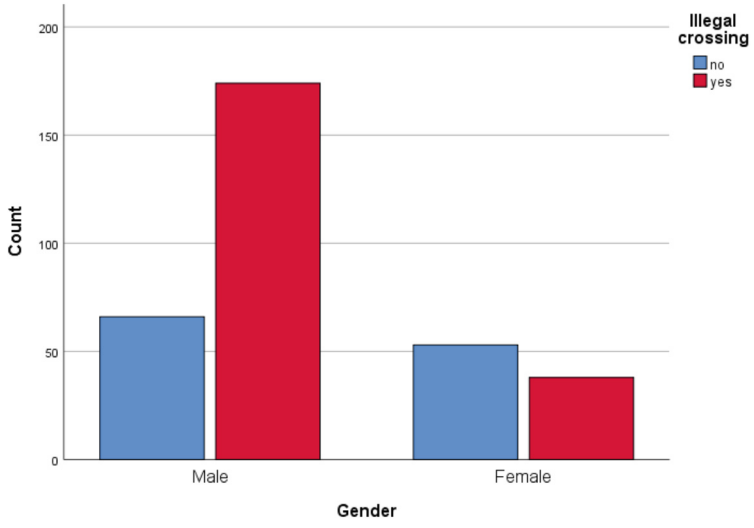

Fig. 5. Correlation between gender and illegal crossing during red light phase.

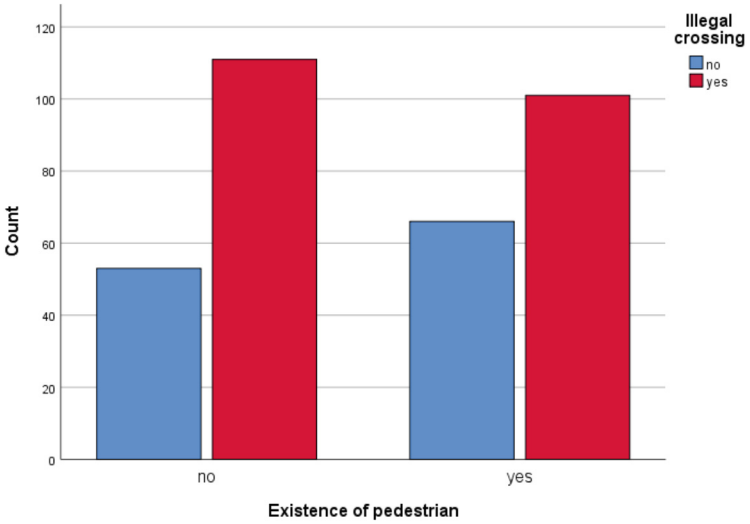

Fig. 6. Correlation between the existence of at least one pedestrian waiting to cross the road and illegal crossing during red light phase.

Illegal crossing during the red light phase found to be also affected by whether the e-scooter user was distracted when he/she was approaching the junction (p-value $<$ 0.001). Figure 7 shows that the majorities of both distracted and undistracted e-scooter users decide to cross illegally the junction; yet, the likelihood of performing this illegal behavior is higher among the distracted ones.

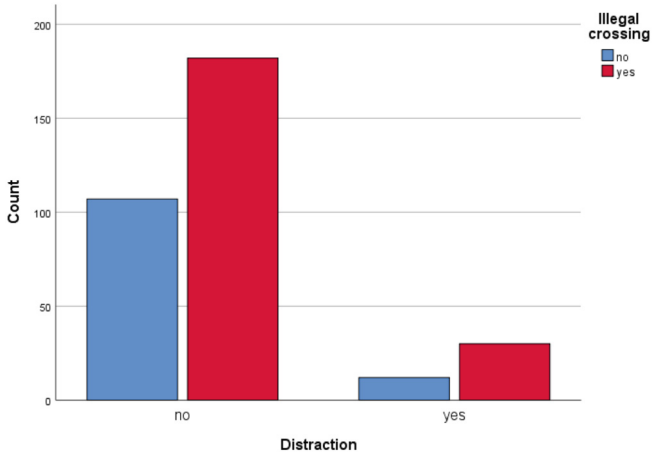

Fig. 7. Correlation between e-scooter user distraction and illegal crossing during red light phase.

Two additional variables were found to be statistically significantly correlated with the decision to of e-scooter users to cross illegally, the distance of the e-scooter user from the traffic light (p-value = 0.026) and the speed difference (in classes) before and after the change of the traffic light indication (p-value = 0.001). Figure 8 shows that those who crossed the junction during the red light phase were on average at a closer distance to the traffic light comparing with those that decided to stop appropriately. Figure 9 shows that those who accelerated or maintained more or less the same speed in the vast majority of

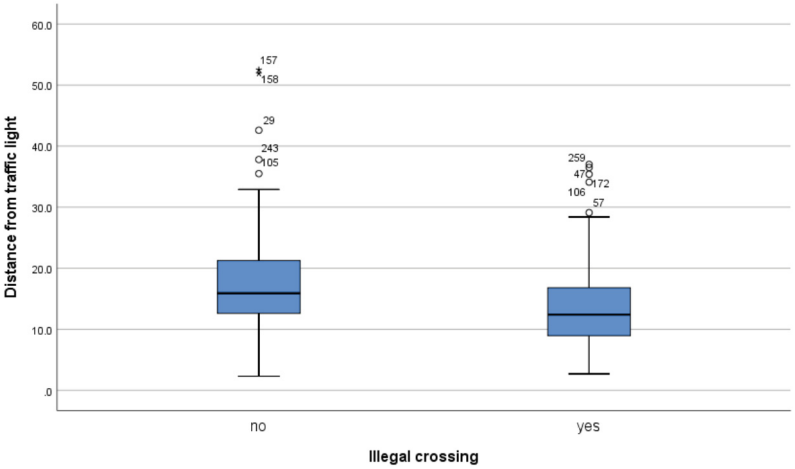

Fig. 8. Correlation between the distance of the user from the traffic light and illegal crossing during red light phase.

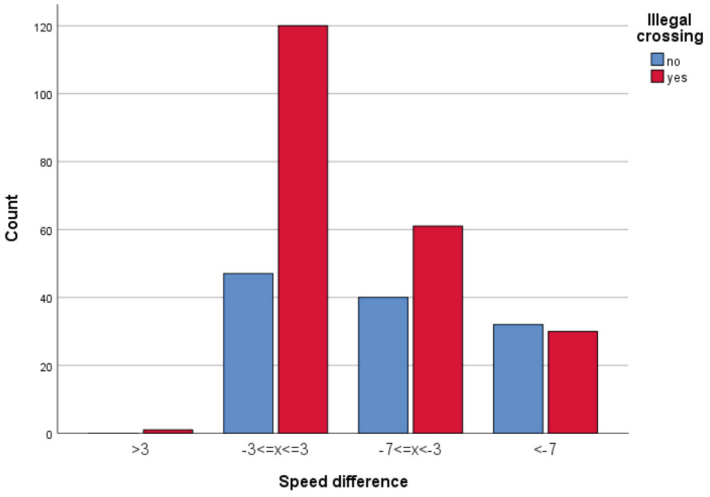

Fig. 9. Correlation between the speed difference before and after the change of the traffic light indication and illegal crossing during red light phase.

the cases decided to cross illegally, while those that decreased relatively abruptly their speed in most cases stopped appropriately.

4 Conclusions

The present paper aims to analyze the behaviour of e-scooter users at signalized junction, by utilizing observations on-site. During the observations, data about the geometric and functional attributes of the junctions were collected, as well as data about the characteristics and the behaviour of the e-scooter user. The collected data were initially analyzed descriptively and then correlations were investigated for identifying factors that affect the behaviour of the user. The speed difference before and after the change in the traffic light indication and the decision to cross during the red light phase or not were used as the two main indicators of e-scooter users behaviour.

The descriptive statistics show an overall high tendency for illegal behaviour among e-scooter users. According to the Greek regulations, e-scooter users are required to wear a safety helmet and not to use any device that could distract them. However, the percentages of e-scooter users that comply with these rules are low, especially for the safety helmet which was used by only 23% of the observed users. Even more alarming is the extremely high percentage (64%) of e-scooter users that ignore the red traffic light and cross illegally the junction.

The correlation analysis indicated that the aggressive behaviour of users is affected by several factors. Remarkable is the difference between males and females regarding the cases of illegal crossing during the red light phase. These findings complement findings from previous studies in the city of Thessaloniki, which show that males are more prone to undertake an illegal behaviour both as car drivers [19] and as pedestrians [20]. It becomes understood that independently of the road user category, males have a much more aggressive and delinquent traffic behaviour from females and this conclusion is in line with findings from other contexts/countries [21, 22]. Also, notable is the finding that most prone to violate the traffic light signal are those e-scooter users that are distracted. A previous study in the city of Thessaloniki focused on the crossing behaviour of pedestrians and identified that distracted pedestrians usually adopt a more cautious behaviour when crossing a road probably for balancing distraction's negative effects [23]. Thus, it seems that pedestrians and e-scooter users adapt their behaviour in different ways when they are distracted and there is a very high risk for e-scooter users who are involved in two illegal actions simultaneously (i.e. using a device that distracts them and crossing illegally during red light phase).

The abovementioned findings indicate that the situation regarding the introduction of micromobility vehicles in modern transportation systems is not yet mature. Still a lot of work needs to be done for educating users of micromobility vehicles. Also, these findings indicate that training activities are required, since it is not even certain that all users of such vehicles are aware of the existing regulations. Traditionally, road safety campaigns are focusing on driving and walking behaviour; however, cities are now accommodating new types of vehicles which are also very attractive to the youth and as such there is a great need for adapting the focus of the campaigns and considering these types of vehicles too.

The present paper is a first attempt to explore the riding behaviour of e-scooter users. Additional efforts are needed for delving deeper in this issue. Future research could be based on data that are gathered automatically and not with observers on-site. More specifically, data through cameras could be collected and analyzed using appropriate software for extracting e-scooter trajectories when approaching and crossing signalized junctions. Such accurate data could feed analyses for modelling e-scooter users riding behaviour at signalized junctions.

Disclosure of Interests. The authors have no competing interests to declare that are relevant to the content of this article.

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