How Did Shared E-scooter Usage Change Before and After the Enforcement of Parking Regulations? Empirical Evidence from Stockholm, Sweden

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***Abstract*—Shared e-scooters have emerged as a popular mode of micro-mobility in urban areas, while their widespread adoption has also led to regulatory challenges, particularly concerning improper parking. Several governments and local authorities have established parking regulations to tackle the challenges. However, less is known about their effects on shared e-scooter usage patterns. This paper explores how shared e-scooter usage changed before and after the enforcement of parking regulations from statistical, spatial, and temporal perspectives by conducting a case study in Stockholm, Sweden. The results indicate that the parking regulations have a significant influence on shared e-scooter usage in terms of trip frequency, service area, and usage efficiency. This research is beneficial for urban planners and policy-makers to develop evidence-based parking regulations and practices for regulating shared micro-mobility.**

Keywords-Shared e-scooter usage; Micro-mobility; Parking regulations; Spatial and temporal patterns.

I. INTRODUCTION

The proliferation of shared micro-mobility services, especially shared e-scooters, has revolutionized urban transportation systems, and offered a sustainable and flexible alternative to traditional travel modes worldwide [1]. These services have rapidly gained popularity due to their potential to mitigate traffic congestion, reduce carbon emissions, and address the First-Mile-Last-Mile (FMLM) problems in urban areas [2], [3]. However, their rapid adoption has introduced a host of regulatory challenges, particularly related to public safety and parking management [4].

Parking rules and regulations for shared e-scooters are integral to their successful integration into urban transport systems. Poorly implemented or inadequately enforced parking policies often result in cluttered sidewalks, obstruction of pedestrian pathways, and hazards for individuals with disabilities [5]. Such outcomes can undermine the benefits of micro-mobility by creating friction between users, non-users, and city authorities. Conversely, well-designed parking strategies have the potential to improve service usability, reduce urban clutter, and foster a positive public perception of shared e-scooters, encouraging their wider adoption.

To combat the bad reputation of shared e-scooter services, a number of countries and local governments have implemented a range of strategies, including designated parking zones, geofencing, and financial penalties for non-compliance [6]. These regulations vary significantly across regions and cities, reflecting differing urban layouts, population densities, and governance priorities [7]. For instance, it is permitted to park e-scooters on the pavement in France as long as it does not obstruct pedestrians. However, parking on pavements is prohibited in Paris, and 49 Euros could be imposed. To tackle the parking and regulatory challenges, new parking rules regulating scooter traffic have also come into force in Sweden on 1 September 2022. Concretely, parking on pavements or cycle paths is prohibited, and e-scooters may only be parked in specially designated parking spaces.

In this context, it is important and necessary to understand the influence of parking rules on shared e-scooter usage for effective regulatory strategies and transportation management. Scholars have conducted a strand of studies on shared e-scooter usage patterns and influencing factors in different cities [8]–[10]. For instance, a comparison study is implemented to reveal the similarities and differences of shared e-scooter usage patterns in 30 European cities [9]. Despite the growing implementation of parking rules and studies on understanding shared e-scooter usage, limited research has systematically examined the impact of parking rules on shared e-scooter usage. To fill the above-mentioned research gap, this study aims to conduct an empirical study to explore how shared e-scooter usage patterns changed before and after the enforcement of parking regulations from a spatiotemporal perspective, with a case study dataset from Stockholm, Sweden.

The paper is structured as follows. Section II reviews the existing literature on regulations and usage patterns of shared e-scooters. Section III outlines the data and methods used to analyze the influence of parking rules on e-scooter usage patterns. Section IV presents and discusses the main results, highlighting the spatiotemporal variations of shared e-scooter usage patterns in the case study area. Finally, Section V concludes the paper with key findings and future research.

II. RELATED WORK

A. Shared micro-mobility regulations

Shared micro-mobility regulatory challenges and parking regulations have attracted notable attention in recent years. A number of studies have documented a high number of scooter-related injuries and accidents [11], which calls for more attention to the research on regulatory frameworks, policies, and regulations. Shaheen et al. [12] systematically discussed shared

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micro-mobility policies and practices for managing vehicles and operations, such as service area limitations, designated parking areas, maximum allowable operating speeds. Mehranfar and Jones [5] emphasized the need for comprehensive analysis of e-scooter incident data and targeted interventions to address safety risks (e.g., helmet use, speeding, and infrastructure adaptation), and highlighted the importance of tailored regulatory frameworks, rider education, and device design to enhance stability, reduce injury severity, and improve overall safety. Although these regulations and strategies have been indicated to be effective in mitigating shared micro-mobility regulatory challenges, they also present a significant influence on shared micro-mobility usage. Lo et al. [13] conducted an online survey to explore the relationship between potential scooter-share regulations and ridership in New Zealand, and indicated that the regulations governing user behavior negatively impact shared e-scooter usage. Wincent et al. [14] also developed a survey to examine the effects of parking regulations on shared e-scooter usage in Sweden. It is reported that the usage frequency, walking distance, and travel time for e-scooter trips have been affected in Stockholm and Malmö after the introduction of parking regulations. The usage in Gothenburg was affected to a less extent, which could be due to the delay in the introduction of parking regulations.

B. Shared e-scooter usage patterns

The increasing availability of vehicle availability data and empirical trip data from micro-mobility operators has led to a large amount of studies on understanding shared e-scooter usage patterns. For instance, Jiao and Bai [8] examined the spatial and temporal usage patterns of shared e-scooters in Austin by analyzing monthly trip counts, total vehicle miles traveled, average trip distance, and average operation time. McKenzie [15] explored the spatial and temporal differences in usage patterns between six shared micro-mobility services in Washington, D.C. Notable differences in spatial and temporal usage patterns were observed between the micro-mobility services. Heumann et al. [16] analyzed the spatial and temporal usage patterns of shared e-scooters in Berlin, and suggested that the usage patterns are influenced by points of interest characteristics. Foissaud et al. [17] examined the spatial and temporal patterns of e-scooter trips in 4 European cities, including Paris, Malaga, Bordeaux, and Hamburg. The results displayed similar usage patterns across the cities but also local characteristics in each city. In recent studies, scholars further investigated how shared e-scooters are used to improve the FMLM connectivity in public transport. For example, Guo et al. [18] explored the integration between shared e-scooters and public transport and how the integration was influenced by the urban built environment in Stockholm and Helsinki. Aarhaug et al. [19] analyzed the relationships between shared e-scooters and public transport in Oslo, and also demonstrated that shared e-scooters can both complement and compete with public transport. Li et al. [20] investigated how shared e-scooters are used as a feeder to complement public transport for solving the FMLM problem by conducting a comparison study in 124 European cities. The results showed that these cities can be divided into 4 clusters according to the temporal usage patterns.

III. METHODOLOGY

A. Study area and data

The data was collected in Stockholm, the largest city and capital of Sweden. The trip records of shared e-scooters were collected from two micro-mobility operators from September 1st to December 31st, in 2021 and 2022. The abnormal trips were filtered out first based on the criteria of duration (more than 1 minute and less than 1.5 hours) and distance (more than 100 m and less than 10 km) according to the previous study [21]. After the data preprocessing, the dataset contains 2,139,381 and 542,337 trips in the periods of 2021 and 2022. Each trip record consists of the fields of vehicle id, longitude, latitude, and timestamp of start and end points. Since the parking regulations came into force in Sweden on September 1, 2022, the dataset was divided into two parts based on the date, namely the Period Before Regulations (PBR) and the Period After Regulations (PAR). A summary of data description is displayed in Table I.

TABLE I
BASIC INFORMATION OF THE E-SCOOTER TRIP DATA DURING PBR AND PAR.

	The number of trips		The number of active vehicles	
Operator	PBR	PAR	PBR	PAR
Operator1	1,705,810	378,077	7,141	2,256
Operator2	433,571	164,260	6,983	1,715

In addition, Sweden's regional division data based on DeSOs (demographic statistical areas) as well as public transport stations in Stockholm were also collected.

B. Indicators for shared e-scooter usage measurement

According to the survey results in previous studies [13], [14], parking regulations presented negative effects on shared e-scooter usage. In this study, three indicators are calculated to model the shared e-scooter usage patterns before and after the introduction of parking regulations, including trip frequency, service area, and usage efficiency.

Trip frequency reflects the usage intensity of shared e-scooters, which have been commonly used in shared micro-mobility analysis. To examine the temporal variations of trip distribution before and after the enforcement of parking regulations, a trip frequency signature for each period is constructed to capture the temporal fluctuations of e-scooter trip frequency. Considering that the date ranges of the two periods are not completely consistent due to data gaps in the collection process, the temporal signature for each period is calculated by aggregating and averaging the trips based on the day of a week and the hour of a day, according to the method by Li et al. [9]. The signature can be denoted as a 1 × 168 vector that covers the average trip frequency on each hour from Monday to Sunday:

$$S = [F_{1,0}, ..., F_{i,j}, ..., F_{7,23}] \quad (1)$$

where S represents the temporal signature of trip frequency. i is from 1 to 7 to represent the day of a week from Monday to Sunday, j is from 0 to 23 to represent each hour of a day.

Service area describes the areas where shared e-scooters are active, which can be used to explore how parking regulations influence users' parking behavior. Since it is not publicly available from micro-mobility operators, we calculated the service areas before and after the introduction of parking regulations in a data-driven manner. Concretely, the Stockholm city was split into cells with a 0.001 longitude × 0.001 latitude size. The number of origins and destinations of trips is calculated within each cell. Only the cells that contain origins and destinations are used to calculate the service area.

The indicator Time to Booking (TtB) is calculated to measure the usage efficiency of shared e-scooters. Compared to traditional usage indicators such as cycling duration, usage frequency, and turnover rate, TtB provides a more accurate reflection of supply and demand in a specific area, making it a more effective measure of usage efficiency in that region [22]. It can be used to clearly indicate the change in usage efficiency of shared e-scooters after the enforcement of parking regulations in terms of idle time. Longer idle time implies lower usage efficiency.

C. Shared e-scooter usage in combination with public transport

We further investigate how shared e-scooter usage in combination with public transport changed before and after the introduction of parking regulations. In particular, the integration between shared e-scooters and public transport at the trip level is explored according to the spatial relationships between origins and destinations of e-scooter trips and public transport stations [18], [20]. Concretely, an e-scooter trip is classified as complementary if either its origin or destination falls within the catchment area of public transport stations, indicating that the trip involves people traveling to or from these stations (e.g., addressing the first/last mile problem). Conversely, if both the origin and destination are within the catchment areas, the trip is considered competitive, as it suggests that e-scooters are being used within the service range of public transport, potentially competing with it. If neither of the origin and destination is within a catchment area of a public transport station, the trip is classified as the category of 'others'.

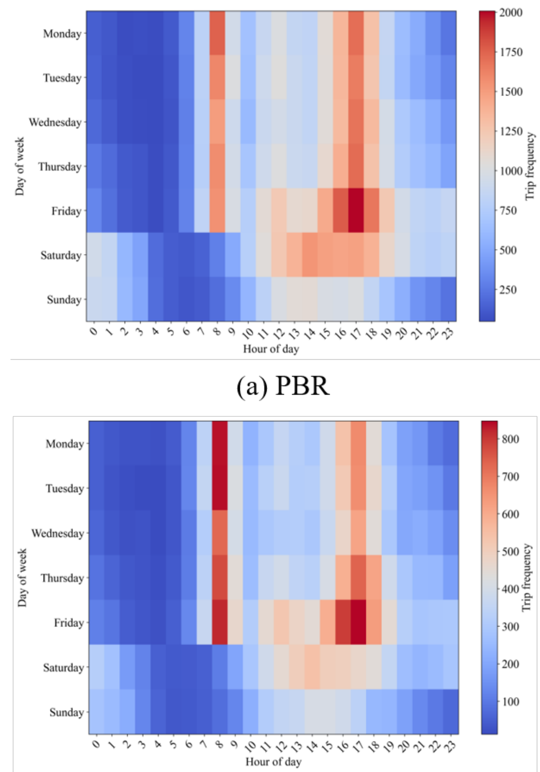
IV. Results and discussion

In the experiment, statistical, temporal, and spatial analyses were implemented to examine the changes in shared e-scooter usage patterns based on the above-mentioned three indicators.

A. Trip frequency

As displayed in Table I, there are 2,139,381 and 542,337 trips during PBR and PAR. It can be observed that the number of trips decreased dramatically, approximately 74.6% of the trips, after the introduction of parking regulations. The significant decrease could also be related to another issued policy, which reports that a maximum of 12,000 e-scooters were legally registered in 2022.

Next, the temporal variations of trip frequency on an hourly basis before and after the parking regulations were explored. As described in the method section, a temporal signature of trip frequency in terms of a 1 × 168 vector was calculated for each period. As shown in Figure 1, the temporal distribution of trip frequency from Monday to Sunday displayed similar patterns between the two periods. First, the usage of e-scooters on weekdays showed three obvious peaks during morning (i.e., 8:00–9:00), noon (12:00-13:00), and evening (i.e., 17:00–18:00), corresponding to the two commuting peaks and lunchtime. The findings are consistent with the e-scooter usage patterns in Zurich [21]. By comparison, the temporal distribution of trip frequency also presented similar patterns on weekends during the two periods, while the peak was shifted to the afternoon on weekends. Although the temporal distribution of trip frequency showed similar patterns, the average hourly trip frequency decreased during PAR.



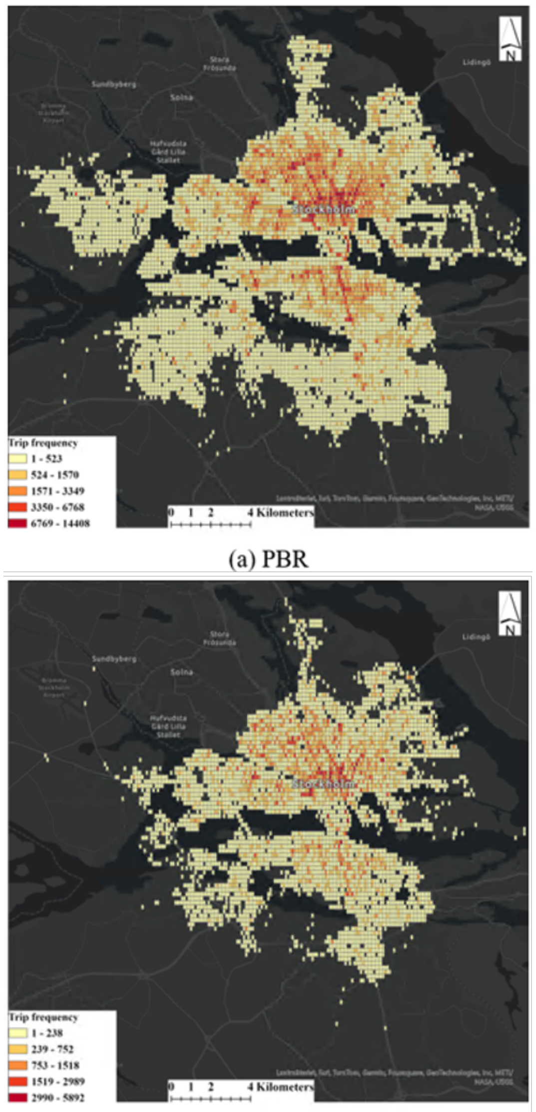
(a) PBR

(b) PAR

Figure 1. Temporal distribution of trip frequency on an hourly basis during (a) PBR and (b) PAR.

B. Service area

In this subsection, the service areas during PBR and PAR were calculated, respectively, as shown in Figure 2. It can be observed that the service area during PAR shrank in the peripheral area of Stockholm. In addition, the trip frequencies at the cell level in terms of the number of origins and destinations were visualized during the two periods, which were classified into five classes with the natural breaks (Jenks) method. The red cells represent the areas with high trip frequency, which were mainly concentrated in the central area of Stockholm. We also calculated the global Moran's I based on the spatial distribution of trip frequency, which are 0.57 and 0.38, respectively, during the two periods. The high Moran's I values also indicated the clustering characteristics of trip frequency. By comparing the two periods, it can also be seen that the number of red cells decreased during PAR. These results demonstrated the lower popularity of shared e-scooter usage after the introduction of parking regulations.



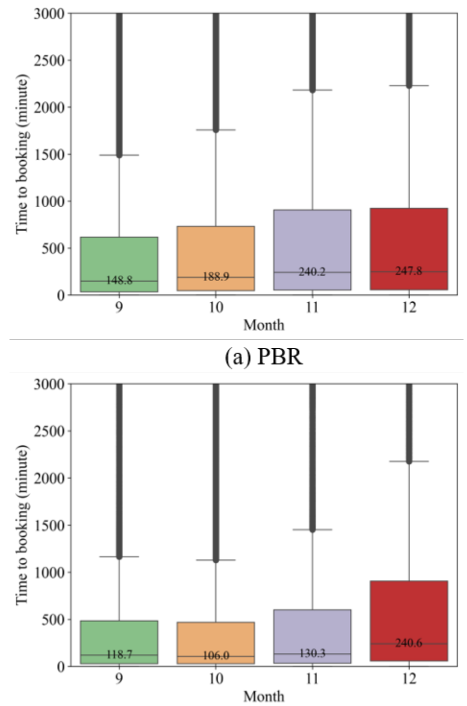
(a) PBR

(b) PBR

Figure 2. Service areas and spatial distribution of trip frequency during (a) PBR and (b) PAR.

C. Usage efficiency

In this subsection, the time to booking values at the trip level were calculated based on the trips during the two periods. Figure 3 displays the statistical distribution of time to booking on a monthly basis in terms of a boxplot during PBR and PAR, respectively. The numbers in each boxplot represent the median of Ttb in the specific month during the two periods. It can be seen that the median values of Ttb decreased in each month accordingly after the introduction of parking regulations, indicating the improvement of usage efficiency of shared e-scooters.



(a) PBR

(b) PAR

Figure 3. Statistical distribution of time to booking on a monthly basis during (a) PBR and (b) PAR.

Figure 4 presents the spatial distributions of Ttb medians at the DeSO level during PBR and PAR. The Ttb medians were categorized into five classes with the natural breaks method. Since the Ttb medians are visualized with the same classification scheme, the two maps are comparable to each other. In the maps, the yellowish DeSOs represent the areas with low Ttb values and high usage efficiency of shared e-scooters. It can be observed that the number of yellowish DeSOs increased dramatically during PAR. It may conclude that the usage efficiency of shared e-scooters is lower, even if the number of e-scooter trips is higher than that after the introduction of parking regulations. It could be due to the oversupply of shared e-scooters before the introduction of parking regulations.

D. Integration between shared e-scooter and public transport

According to the method described in subsection III-C, the e-scooters were classified into complementary, competitive, and other categories. The complementary trips were further divided into the ones for the first-mile and last-mile connection. The proportions of complementary trips during PBR and PAR are very close, which are 32.0% and 32.2% respectively.

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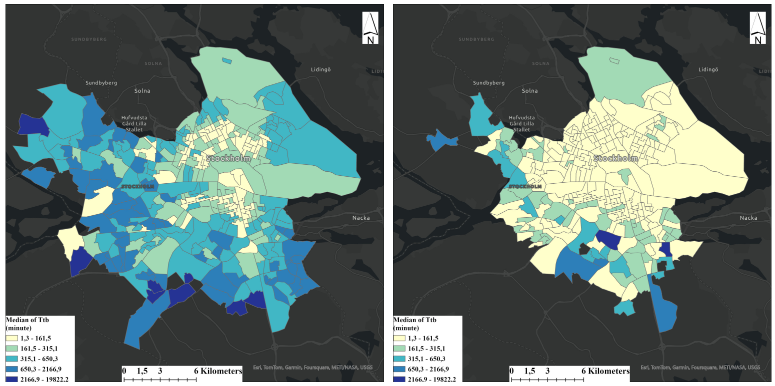
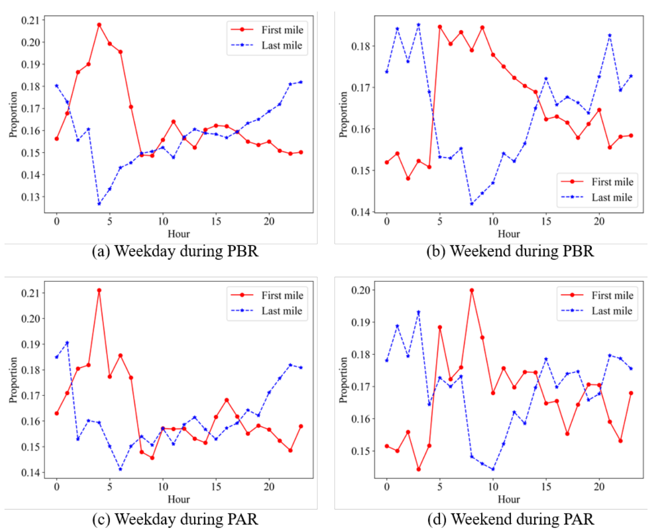


Figure 4. Spatial distribution of time to booking during (a) PBR and (b) PAR.

Likewise, we also aggregated and averaged the proportions of the first-mile and last-mile trips on an hourly basis during PBR and PAR. Figure 5 displays the temporal variations of the proportions during the two periods. It can be observed that the patterns of the integration between shared e-scooters and public transport are similar before and after the enforcement of parking regulations. The first mile trips occupied a major portion in the morning on weekday and weekend compared with the last mile trips, and then the last mile trip became dominant in the evening. The findings are consistent with the study by Li et al. [20].



(a) Weekday during PBR
(b) Weekend during PBR
(c) Weekday during PAR
(d) Weekend during PAR

Figure 5. Temporal distribution of proportions of first mile and last mile trips on an hourly basis during (a) PBR and (b) PAR.

V. Conclusion and Future Work

Shared e-scooters offer a sustainable and flexible alternative to traditional transport modes. Considering the regulatory challenges caused by their widespread adoption, parking regulations have been introduced to tackle them in many cities worldwide. However, less is known about how the parking regulations influence shared e-scooter usage in urban areas. In this paper, we explore how shared e-scooter usage changed before and after the enforcement of parking regulations in terms of three usage indicators and their integration with public transport by conducting a case study in Stockholm, Sweden. The main findings of this study are summarized as follows.

First, the trip frequency decreased dramatically after the introduction of parking regulations. This could also be due to the permit constraint on the number of shared e-scooters in urban areas, in addition to the parking regulations. However, the temporal usage patterns were similar before and after the parking regulations. Second, the service areas of shared e-scooters shrank after the introduction of parking regulations, which were mainly concentrated in the peripheral areas of Stockholm. The areas with high trip frequency were still focused on central Stockholm. Third, the usage efficiency of shared e-scooters in terms of time to booking displays improvement after the introduction of parking regulations. Lastly, the changes in the integration between shared e-scooters and public transport in terms of the proportions of the first mile and last mile trips are tiny before and after the introduction of parking regulations.

Overall, the research findings are beneficial for urban planners and policy-makers to develop evidence-based parking regulations and practices for regulating shared micro-mobility. The following aspects deserve to be studied in future work. First, more analyses will be implemented to investigate how the parking regulations influence the integration between shared e-scooters and public transport from the perspectives of accessibility and equity, especially in the context of multiple cities. Second, it is also interesting to see whether the parking regulations affect the relationships between the integration patterns and influence factors, such as the urban built environment and socio-demographics.

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