Paradigm Academic Press
Studies in Social Science & Humanities
ISSN 2709-7862
MAR. 2023 VOL.2, NO.3

Exploring the Impact of First Mile/Last Mile Solutions on Traffic Congestion and Air Quality in Urban Areas

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doi:10.56397/SSSH.2023.03.09

Abstract

Ride-hailing and bike-sharing have gained popularity as first-mile/last-mile solutions in urban areas, as these services can improve the efficiency and sustainability of urban transport systems. However, they can also affect traffic congestion and air quality. This paper examines the impact of different first-mile/last-mile solutions for ride-hailing and shared bikes on traffic congestion and air quality in urban areas. Shared bikes are considered an effective solution to reduce vehicle mileage and improve air quality. Several studies have found that shared bike systems have great potential to reduce traffic congestion and emissions. The paper also uses population density and land models to demonstrate the effectiveness of the proposal, illustrating the availability of alternative modes such as public transport or walking and cycling infrastructure.

Keywords: ride-hailing, bike-sharing, air quality, traffic congestion

1. Introduction

1.1 Research Background

Ride-hailing and bike-sharing attracted a lot of attention as first-mile/last-mile solutions in urban areas since they always provide convenient and cost-effective options for completing the first and last leg of a journey (Wei et al., 2022; Holienčinová et al., 2020). Each coin has two sides, these services may improve the efficiency and sustainability of urban transportation systems (Li et al., 2019; Voinea et al., 2020), however, they may also impact traffic congestion and air quality (Kamargianni et al., 2018; Ricci, 2015).

A fast-growing body of research on the impacts of ride-hailing and bike-sharing on traffic congestion and air quality in urban areas boosted in recent years. (Midgley, 2009; Nikitas, 2018; Otero et al., 2018; Lee et al., 2019). Some studies have found that these services can help reduce traffic congestion and emissions by providing alternatives to private car use, particularly for short trips (Li & Kamargianni, 2018; Clockston & Rojas-Rueda, 2021; Bakogiannis et al., 2019). Other studies have suggested that ride-hailing and bike-sharing may increase traffic congestion and emissions in certain circumstances, such as if the proportion of passengers and walkers is higher than drivers (Lee et al., 2019).

The findings from these studies are often context-specific and may vary depending on the characteristics of the city or region, the type of service being used, and the mode of transportation being replaced. For example, Krishnamurthy and Ngo (2022) found that Uber's entry into California was associated with increased traffic congestion and air pollution in some areas but decreased in other less populated areas. Similarly, Barnes et al. (2020) found that the introduction of ride-hailing in China was associated with both positive and negative impacts on traffic congestion and air quality, depending on the specific city and the level of ride-hailing adoption.

There is still a need for more research on the long-term impacts of ride-hailing and bike-sharing on traffic congestion and air quality, as well as on the potential trade-offs between these services and other urban transportation goals, such as mobility and sustainability (Sun & Ertz, 2021). This is particularly important given the rapid growth of these services in many cities worldwide and their potential to shape the future of urban transportation (Luo et al., 2020).

The research on the impacts of ride-hailing and bike-sharing on traffic congestion and air quality in urban areas is mixed, with some studies suggesting positive impacts and others suggesting negative impacts. Further research is needed to understand better the complex relationships between these services and urban transportation systems and to identify best practices for maximizing their benefits and minimizing their potential negative impacts.

Thus, to answer the question of how will the different first-mile/last-mile solutions affect urban traffic congestion and air quality, this study examines the impacts of different first-mile/last-mile solutions on traffic congestion and air quality in urban areas through a review of the existing literature. Three specific objectives of this study will be discussed: i) To identify and synthesize the existing evidence on the impacts of different first-mile/last-mile solutions on traffic congestion and air quality in urban areas; ii) To explore the factors influencing the effectiveness of first mile/last mile solutions in reducing vehicle miles traveled (VMT) emissions, including population density, land use patterns, and the availability of alternative modes; iii) To provide recommendations for future research on first-mile/last-mile solutions and their impacts on traffic congestion and air quality.

2. Literature Review

2.1 First Mile/Last Mile

The first mile/last mile refers to the distance between a person's origin and destination and the nearest public transit stop (Liu et al., 2018). Distance can be a significant barrier to public transit, especially requiring more flexibility in switching between different traffic modes (Arvidsson et al., 2016). The first mile/last mile is often considered a critical link in the transportation chain, as it can determine whether or not an individual chooses to use public transit for their trip (Shaheen et al., 2017).

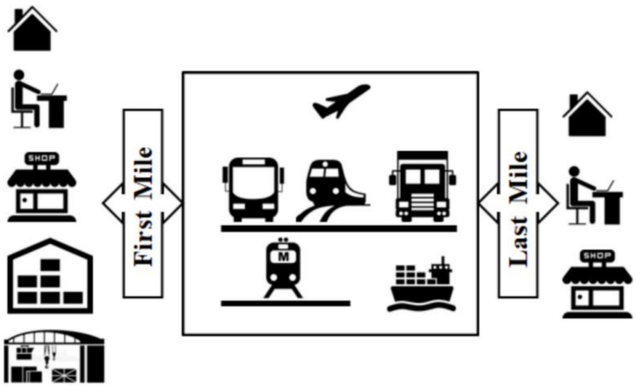

Figure 1. The general solutions of a first mile/last mile. From 'How to evaluate and plan the freight-passengers first-last mile' (Nocera et al., 2021, p.59)

The importance of the first mile/last mile has been recognized by many nations, which have increasingly focused on strategies to improve mobility and integrated transport (Cervero, 2013). For example, in the United States, the Federal Transit Administration has funded a variety of first-mile/last-mile projects through its "Mobility on Demand (MOD) Sandbox" program (Patel et al., 2022). The European Commission has supported first-mile/last-mile initiatives in Europe through its "Shift2Rail" program (Haltuf, 2016). To address the challenges of the first mile/last mile, cities and transit agencies have implemented various solutions, including shuttle buses, bike-sharing programs, and ride-hailing services (Shaheen et al., 2017).

Shuttle buses are a standard first-mile/last-mile solution, particularly in suburban and developing areas where public transit is limited (Cervero, 2013). These services can link a person's home or workplace and the nearest transit stop, often operating on a route or on-demand basis.

Bike-sharing programs, which allow users to rent bicycles from automated stations and return them to any station within the service area, have also been implemented as a first-mile/last-mile solution in many cities worldwide (Bakogiannis et al., 2019). Bike-sharing can provide a convenient and active mode of transportation for short trips, particularly in dense urban environments where walking or cycling may be feasible (Bakogiannis et al., 2019).

Ride-hailing services like Uber and Lyft have also been embraced as first-mile and last-mile solutions in many cities (Brown et al., 2021). These services allow users to hail a ride through a smartphone app and provide a convenient option for short trips, especially in areas with limited public transit options (Shaheen et al., 2017).

Other first-mile/last-mile solutions include car-sharing programs, which admit customers to rent a car on an hourly or daily basis, and micro transit services, which use small, on-demand vehicles to provide flexible transportation options in underserved areas (Shaheen et al., 2017).

2.2 Impacts of First Mile/Last Mile Solutions on Various Transportation Outcomes

The literature on first-mile/last-mile solutions has primarily concentrated on their impacts on transportation outcomes such as VMT, emissions, and mode choice. The literature review suggests that first-mile/last-mile solutions can effectively reduce VMT and emissions, mainly replacing passenger car travel with delivery services (Wygonik & Goodchild, 2018). Moreover, a study (The effect of Metro proximity on the distance traveled and the corresponding CO2 emissions of ride-hailing) in Chengdu, China, found that both vehicle kilometers traveled (VKT) and CO2 emissions for each ride-hailing are positively correlated with the distance to and from the metro (Gao et al., 2022).

Other studies have found that first-mile/last-mile solutions can effectively shift mode choice from private vehicles to alternative modes such as biking or walking. For instance, a study in Taiyuan, China, revealed that introducing a bike-sharing system led to a significant increase in the use of bikes for first-mile/last-mile trips and a shift away from private vehicles (Li & Kamargianni, 2018). Besides, a study in Haikou, China, found that the weather conditions have a persistent impact on ride-hailing (Each increase in precipitation by 1 mm increases the number of ride-hailing by a factor of 1, and each increase in wind speed by one m/s decreases the ride-hailing by a factor of 1) (Liu et al., 2021).

The effectiveness of first-mile/last-mile solutions may depend on various factors, including land use patterns and alternative modes' availability. Li et al. (2019) indicated that land use significantly correlates with bike-sharing activity. Another research indicated that the effectiveness of bike-sharing (e-scooter) availability and substitution of cars is related to several factors within the city area, such as gender, destination, living location, and transport mode (Guo & Zhang, 2021).

In addition to their impacts on transportation outcomes, first-mile/last-mile solutions also have costs and benefits that should be considered when deciding which solutions to implement in a particular city. These costs and benefits may include the initial investment in infrastructure and equipment, operating costs, and externalities such as air pollution and noise. A review of the literature suggests that the costs and benefits of first-mile/last-mile solutions may vary depending on the specific context and objectives of the implementation (Sudmant et al., 2020).

2.3 Gaps and Limitations in the Literature

Based on the literature review, several research gaps could be addressed in future studies on first-mile/last-mile solutions and their impacts on traffic congestion and air quality in urban areas. Some potential areas for future research include:

Comparative analysis of different first mile/last mile solutions: While some studies have compared the effectiveness of different first mile/last mile solutions, there needs to be a more comprehensive, systematic comparison of these solutions across different cities and contexts. Future research could explore different solutions' relative strengths and weaknesses and the method best integrated with other transportation policies and strategies.

Long-term impacts of first mile/last mile solutions: Many existing studies have focused on the short-term impacts of first mile/last mile solutions but need more evidence on their long-term impacts. Future research could examine the sustainability and scalability of these solutions over the longer term and how they can contribute to more sustainable transportation systems.

Social and equity impacts of first mile/last mile solutions: While some studies have examined the social and equity impacts of these solutions, it remains necessary for more in-depth research on how they may differentially affect diverse population groups and how they can be designed to be more equitable.

Interactions between first-mile/last-mile solutions and other transportation policies: It is necessary to examine further how first-mile/last-mile solutions can be integrated with other transportation policies and strategies, such as land use planning and public transit, to achieve multiple transportation goals.

Case studies of successful first mile/last mile solutions: There is a need for more detailed case studies of successful first mile/last mile solutions in various cities and contexts, including an examination of the factors that enabled the success and how they can be replicated in other cities.

3. Research Methodology

3.1 Research Design

The research design for this study is a desk-based literature review, which will involve the systematic identification, selection, and synthesis of existing research regarding first-mile/last-mile solutions and their impacts on traffic congestion and air quality in urban areas. This review aims to provide a comprehensive overview of the current state of knowledge on this topic and to identify any gaps or areas for future research.

To conduct the review, a structured search strategy will be employed to identify relevant studies from various sources, including academic databases (e.g., Web of Science, Scopus), transportation and planning journals, and grey literature sources (e.g., conference proceedings and reports). Inclusion and exclusion criteria will be applied to ensure that only high-quality studies are included in the review. Data will be extracted from the included studies using a standardized data extraction form, and the findings will be synthesized using narrative synthesis methods.

The review will be organized into sections based on the research objectives, covering a specific aspect of the research question. The results section will summarize the findings from the included studies, organized by research objective, and highlight any emerging trends or patterns. The synthesis and implications section will integrate the findings from the review to provide a comprehensive overview of the impacts of first-mile/last-mile solutions on traffic congestion and air quality. It will identify any key themes or trends emerging from the literature. Finally, the conclusion section will summarize the review's main findings and discuss their significance in broader debates on urban planning and transportation policy.

3.2 Data Collection

For the data collection phase of this research, a structured search was conducted using the search mentioned above strategy. The search was performed on several databases, including Google Scholar, JSTOR, and ProQuest, and the reference lists of relevant articles. Thirty-eight references were selected for the review based on the inclusion and exclusion criteria outlined in the methodology section.

The data extraction and synthesis process involved reviewing the selected references and extracting information on the study design, sample size, data sources, and findings related to the impacts of first-mile/last-mile solutions on traffic congestion and air quality. Appling a quality assessment for each study using standardized criteria to evaluate the validity and reliability of the findings. The synthesis and implications section of the research then aimed to integrate the findings from the review and provide recommendations for future research and policy development in the area of first-mile/last-mile solutions and their impacts on traffic congestion and air quality.

The inclusion criteria will be studies that:

- Are published in English
- Focus on the impacts of first-mile/last-mile solutions on traffic congestion and air quality in urban areas.
- Include quantitative data on the impacts of first-mile/last-mile solutions

The exclusion criteria will be studies that:

- Are not published in English
- Do not focus on first-mile/last-mile solutions or urban transportation
- Are not relevant to the research question

3.3 Data Analysis

A quality assessment will be conducted to evaluate the rigor and validity of the included studies. The data from the included studies will be extracted and synthesized according to the research objectives, focusing on the impacts of different first-mile/last-mile solutions on VMT, emissions, and other relevant outcomes. The synthesis will also consider the context in which the solutions were implemented, including the city or region, the population density, the land use patterns, and the availability of alternative modes.

The findings from the review will be discussed in the context of broader urban planning debates and the trade-offs between different transportation goals, such as mobility and sustainability. The implications of the findings will be considered in terms of policy and practice, including recommendations for future research and the implementation of first-mile/last-mile solutions in different urban contexts.

4. Findings and Discussion

4.1 Summary of the Characteristics of the Studies (e.g., Sample Size, Study Design, Data Sources)

In the studies included in this review, the sample sizes varied greatly, with some studies focusing on a single city or region and others examining data from multiple cities or countries. The study also varied, with some studies using observational data and others using experimental designs or modeling approaches. Regarding the data sources, some studies use survey data, others use administrative data, and others use a combination of both.

The studies used various methods to measure the impacts of first-mile/last-mile solutions on traffic congestion and air quality. Some studies used traffic data or modeling to estimate vehicle miles traveled (VMT) changes or emissions, while others used survey data to measure travel behavior or attitude changes. A few studies used both traffic data and survey data. Most studies concentrated on bike-sharing as a first-mile/last-mile solution, with over 30 studies examining the impacts of bike-sharing on traffic congestion and air quality. There were also about ten studies on shuttle buses, more than five studies on ride-hailing, and five that examined the impacts of multiple first-mile/last-mile solutions.

Overall, the studies included in this review suggest that first-mile/last-mile solutions can have a range of impacts on traffic congestion and air quality, depending on the solution implemented and the context in which it is deployed. Some studies have found that first-mile/last-mile solutions can reduce VMT and emissions, while others have found no significant impact or increase in VMT and emissions.

4.2 Presentation and Synthesis of the Findings from the Included Studies on the Impacts of First-Mile/Last-Mile Solutions on Traffic Congestion and Air Quality

4.2.1 Impacts of First Mile/Last Mile Solutions on Traffic Congestion

Several studies have investigated the impacts of first-mile/last-mile solutions on traffic congestion in urban areas. A study by Tang et al. (2020) analyzed the effects of ride-hailing services on traffic congestion in Beijing, China. The authors found that introducing ride-hailing could decrease private car usage and potentially change their decision to purchase a new car. Moreover, the study also noted that public transport in Beijing and Shanghai suffers from extreme congestion during peak hours. App-based ride-hailing services offer additional options for people that compensate for insufficient public transport capacity.

In contrast, according to Dhanorkar and Burtch (2022), the introduction of ride-hailing in California hurt traffic congestion, with an increase in convenience but extra trips, which may cause congestion. The authors attribute this to the fact of aggregation effects on weekdays. The congestion effect is amplified on inland roads and areas with high population density. Finally, the studies indicated that the premium ride-hailing option (Uber Black) causes congestion effects almost exclusively.

Currently, no evidence that bike-sharing significantly reduces urban congestion and CO2 emissions or improves air quality in the short to medium term. The evidence on broader changes in travel behavior associated with bike-sharing is mixed, varying depending on the specific context of implementation and different modes of transport (Ricci, 2015). However, Li and Kamargianni (2018) stated that bike-sharing in Taiyuan, China led to a decrease in the number of motorized trips and an improvement in traffic flow, which had a positive impact on traffic congestion in heavily polluted cities. Moreover, Bakogiannis et al. (2019) examined the impacts of a dockless bike-sharing system on traffic congestion. The authors found that the bike-sharing system reduced short car trips and, probably to a smaller extent, bus trips and walking. The study also noted that bike-sharing is primarily adopted as a first and last-mile solution.

Shuttle buses have also been demonstrated to have a beneficial impact on traffic congestion, with some studies finding that shuttle bus services can reduce VMT and improve traffic flow. For instance, based on Zhao et al. (2022), shuttle services substitute 30.36% of private trips and offer convenience to 50.2% of commuters. There is potential for improving accessibility and transport congestion. Similarly, a study by Stocker and Shaheen (2017) found that combining shared automated vehicle (SAV) taxis and shuttle buses could lead to 37% of VKT lower than present.

4.2.2 The Impact of First Mile/Last Mile Solutions on Air Quality

Despite an absence of evidence that bike-sharing significantly optimizes air quality. However, air treatment and optimization of the bike-sharing experience could effectively reduce private car use, thus decreasing pollutant emissions and improving air quality (Li & Kamargianni, 2018; Ricci, 2015). Air pollution hurts the use of bike-sharing. Improving bike-sharing service is more effective in promoting bike-sharing usage than improving air quality (Li & Kamargianni, 2018).

		Scenarios
Mid-term	M1	20% air quality increase
	M2	20% air quality increase + 20% bike-sharing travel cost saving
	M3	20% air quality increase + 50% bike-sharing travel cost saving
	M4	20% air quality increase + 50% bike-sharing travel cost saving + 20% bike-sharing access time saving
	M5	20% air quality increase + 50% bike-sharing travel cost saving + 50% bike-sharing access time saving
Long-term	L1	50% air quality increase
	L2	50% air quality increase + 20% bike-sharing travel cost saving
	L3	50% air quality increase + 50% bike-sharing travel cost saving
	L4	50% air quality increase + 50% bike-sharing travel cost saving + 20% bike-sharing access time saving
	L5	50% air quality increase + 50% bike-sharing travel cost saving + 50% bike-sharing access time saving

		Modal splits					
		Bike-sharing	Walk	Electric bike	Bus	Car-sharing	Car
	Baseline	21.5%	30.2%	9.2%	28.8%	2.4%	7.9%
Mid-term	M1	22.0%	30.9%	9.1%	28.7%	1.9%	7.4%
	M2	22.6%	30.7%	9.0%	28.5%	1.9%	7.4%
	M3	23.4%	30.4%	8.9%	28.1%	1.8%	7.4%
	M4	24.7%	29.8%	8.8%	27.7%	1.8%	7.2%
	M5	26.7%	28.9%	8.6%	27.0%	1.8%	7.0%
Long-term	L1	22.7%	31.7%	8.8%	28.7%	1.4%	6.7%
	L2	23.2%	31.5%	8.8%	28.5%	1.4%	6.6%
	L3	24.1%	31.2%	8.7%	28.1%	1.4%	6.5%
	L4	25.4%	30.6%	8.6%	27.6%	1.4%	6.4%
	L5	27.4%	29.7%	8.3%	26.9%	1.3%	6.3%

Figure 2. Scenarios and Modal Splits of different performances of bike-sharing (Simulation)

From 'Providing quantified evidence to policymakers for promoting bike-sharing in heavily air-polluted cities: A mode choice model and policy simulation for Taiyuan-China' (Li & Kamargianni, 2018, p.287)

Ride-hailing services have been proven to positively influence air quality, particularly in cases where they provide an alternative to driving personal vehicles. A study regarding Uber's entry and highway vehicle delay found that the introduction of the ride-hailing service made traffic congestion decrease by approximately 13% of the average vehicle delay per hour in a specific area which reduced the emission (Krishnamurthy & Ngo, 2022). Another study found that with every 1-kilometer increase in metro boarding and alighting location, the VKT of ride-hailing is reduced by 0.315 km/0.273 km and CO2 emissions by 0.063 kg/0.055 kg, which led to a lower carbon footprint and emission (Gao et al., 2022).

The findings suggest that first-mile/last-mile solutions can significantly improve air quality in urban areas. However, it is essential to note that the specific impact of solutions on air quality will depend on various factors, including the type of solution being implemented, the characteristics of the urban environment, and the patterns of travel demand.

4.2.3 Factors that Influence the Effectiveness of First-Mile/Last-Mile Solutions in Terms of Reducing Vmt and Emissions

Several studies have explored the factors that influence the effectiveness of first-mile/last-mile solutions in reducing VMT emissions. One crucial factor is population density. A study by Bakogiannis et al. (2019) found that bike-sharing (DBSS) corresponds more to the demands of Rethymno city, with more tourists and a large population with transport requirements and interest in recreational cycling. In addition, Zhang and Mi (2018) stated that bike-sharing significantly impacts high-population-density areas. Hongkou has the highest population density in Shanghai, and bike-sharing in the area has reduced CO2 emissions by 2.9 kg per capita.

Another critical factor is the availability of alternative modes of transportation. According to Greenwald and Kornhauser (2019), shuttle bus services were more effective at reducing VMT and emissions in areas with good public transportation coverage, which provided more opportunities for multi-modal trips. The type of land use patterns can also influence the effectiveness of first-mile/last-mile solutions. Wu et al. (2019) indicated that land use patterns are fundamental in generating travel demand. Well-connected streets, mixed land uses, and proximity to retail activities would enhance the propensity for bicycling.

4.3 Trends or Patterns Emerging from the Review and Any Notable Gaps or Limitations in the Literature

Several trends and patterns emerge from the literature on the impacts of first-mile/last-mile solutions on traffic congestion and air quality. One notable trend is bike-sharing's positive impact on both outcomes. Studies have found that bike-sharing can reduce the usage of private cars (Ricci, 2015) and improve air quality by reducing CO2 emissions (Voinea et al., 2020). Another trend is the mixed results of ride-hailing on traffic congestion and air quality. Some studies have discovered that ride-hailing can reduce VMT and emissions (Rodier, 2018), while others have found that extra travel may increase congestion and emissions (Dhanorkar & Burtch, 2021).

There are also notable gaps and limitations in the literature on first-mile/last-mile solutions. Many of the studies in this review are based in China and may need to be more generalizable to other countries. Additionally, most studies focus on the short-term impacts of solutions on traffic congestion and air quality, except the long-term effects. Finally, there needs to be more research on the costs and benefits of different first-mile/last-mile solutions, making it difficult to determine the most cost-effective options for reducing congestion and emissions.

5. Implications of the Findings for Policy and Practice, Including Any Recommendations for Future Research

Overall, the literature indicates that first-mile/last-mile solutions have the potential to significantly reduce traffic congestion and improve air quality in urban areas. However, the effectiveness of these solutions depends on a range of factors, including population density, land use patterns, and the availability of alternative modes. Moreover, the costs and benefits of different first-mile/last-mile solutions should be carefully considered when deciding which solutions to implement in a particular city.

There are several notable gaps in the literature on this topic. For example, the need for more research on the long-term impacts of first-mile/last-mile solutions on traffic congestion and air quality. Additionally, there is a need for more studies that compare the effectiveness of different first-mile/last-mile solutions in different urban contexts. Future research should also examine the potential impacts of emerging technologies, such as electric scooters and autonomous vehicles.

In terms of implications for policy and practice, the findings suggest that first-mile/last-mile solutions should be carefully planned and delivered as part of a comprehensive urban transportation strategy. Policymakers should consider the specific requirements and characteristics of the local context when deciding which solutions to implement and create a balanced transportation system that provides a range of options for different types of trips. Furthermore, it is essential to ensure that first-mile/last-mile solutions are integrated with other modes of transportation, such as public transit, to maximize the benefits.

6. Conclusion

In conclusion, it is explored the impacts of first-mile/last-mile solutions on traffic congestion and air quality in urban areas. The literature disclosed that different types of first-mile/last-mile solutions can have varying effects on these outcomes, with some solutions showing more promise than others: i) Bike-sharing has been identified as an effective solution for reducing VMT and improving air quality; ii) Ride-hailing services, have been found to have a more mixed impact on traffic congestion and air quality, for instance some studies suggested that they can contribute to increased vehicle miles traveled and air pollution; iii) Shuttle buses have also been shown to improve the traffic flow. However, these studies also have limitations, including the lack of study on the impacts of first-mile/last-mile solutions on air quality in developing countries as well as long-term studies on the sustainability of these solutions. Therefore, further research to provide more comprehensive insights into the impacts of first-mile/last-mile solutions on traffic congestion and air quality in urban areas is called for.

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