



Delft University of Technology

## Is Crowdshipping A Sustainable Last-Mile Delivery Solution? A Case Study Of Rome

Salehi, Salar; Cebeci, Merve Seher; de Bok, Michiel; Tey, Mahsa; Rinaldi, Marco; Gentile, Guido

**Publication date**  
2025

### Citation (APA)

Salehi, S., Cebeci, M. S., de Bok, M., Tey, M., Rinaldi, M., & Gentile, G. (2025). *Is Crowdshipping A Sustainable Last-Mile Delivery Solution? A Case Study Of Rome*. Paper presented at 104th Annual Meeting of the Transportation Research Board (TRB), Washington DC, District of Columbia, United States.

### Important note

To cite this publication, please use the final published version (if applicable).  
Please check the document version above.

### Copyright

Other than for strictly personal use, it is not permitted to download, forward or distribute the text or part of it, without the consent of the author(s) and/or copyright holder(s), unless the work is under an open content license such as Creative Commons.

### Takedown policy

Please contact us and provide details if you believe this document breaches copyrights.  
We will remove access to the work immediately and investigate your claim.

*This work is downloaded from Delft University of Technology.  
For technical reasons the number of authors shown on this cover page is limited to a maximum of 10.*

1 **IS CROWDSHIPPING A SUSTAINABLE LAST-MILE DELIVERY SOLUTION? A  
2 CASE STUDY OF ROME**

3

4

5

6 **Salar Salehi**

7 Department of Civil, Constructional and Environmental Engineering

8 Università di Roma La Sapienza, Roma, Italy

9 Salar.salehi@uniroma1.it

10

11 **Merve Seher Cebeci**

12 Department of Transport and Planning

13 Delft University of Technology, Stevinweg 1, 2628CN Delft, the Netherlands

14 M.S.Cebeci@tudelft.nl

15

16 **Michiel De Bok**

17 Department of Transport and Planning

18 Delft University of Technology, Stevinweg 1, 2628CN Delft, the Netherlands

19 M.a.debok@tudelft.nl

20

21 **Mahsa Tey**

22 Department of Civil, Constructional and Environmental Engineering

23 Università di Roma La Sapienza, Roma, Italy

24 Tey.1953064@studenti.uniroma1.it

25

26 **Marco Rinaldi**

27 Department of Transport and Planning

28 Delft University of Technology, Stevinweg 1, 2628CN Delft, the Netherlands

29 M.Rinaldi@tudelft.nl

30

31 **Guido Gentile**

32 Department of Civil, Constructional and Environmental Engineering

33 Università di Roma La Sapienza, Roma, Italy

34 Guido.Gentile@uniroma1.it

35

36

37 Word Count: 5747 words + 7 table(s) × 250 = 7497 words

38

39

40

41

42

43

44 Submission Date: July 29, 2024

**1 ABSTRACT**

2 Last-mile delivery, one of the most polluting segments of the supply chain, is the focus of numerous  
3 studies. There are various innovative delivery methods aimed at mitigating its adverse effects. This  
4 study explores whether crowdshipping (CS) could serve as a sustainable urban logistics solution  
5 for Rome, assessing its environmental viability. It poses the question: Can Rome adopt CS, and if  
6 so, how sustainable would it be? Using real-world data, we employed the MASS-GT simulation  
7 tool to simulate parcel demand for various parcel companies in Rome's urban areas. Additionally,  
8 we considered real data on trips made by employees to offices within the study area and their modes  
9 of transport. The analyses include predicting parcel demand and forming parcel schedules, both  
10 with and without CS. We also assessed employees' willingness to make detours for parcel pickups.  
11 Our findings suggest that CS can reduce emissions depending on users' willingness to adjust travel  
12 routes, which can be incentivized through monetization. Furthermore, by considering the fleet  
13 composition of parcel companies, we quantified the potential emissions savings achievable through  
14 CS. The results indicate that CS is applicable in Rome and could significantly reduce emissions by  
15 approximately 1.3 tonnes of CO<sub>2</sub> per day, equivalent to 93 euros in the EU's Emissions Trading  
16 System. This approach aligns with European emissions plans and validates the feasibility of CS  
17 in Rome through practical research. It offers valuable insights for policymakers, emphasizing the  
18 importance of encouraging user participation and supporting CS platforms.

19

20 *Keywords:* Crowdshipping, Sustainable urban logistics, Urban freight simulation, Agent-based  
21 model, Sustainability

## 1 INTRODUCTION

2 In recent decades, delivery and e-commerce services have grown, offering innovative solutions in  
3 the last-mile logistics (LML) sector. However, due to the interface with final customers, it strongly  
4 relates to the satisfaction level of users. Moreover, it still has challenges and is often described  
5 as one of the supply chain's most expensive and polluting elements (1). With the growing e-  
6 commerce trend worldwide, intelligent solutions are needed to meet the increasing demand. For  
7 instance, Global e-commerce is projected to grow at a compound annual growth rate of 9% through  
8 2027 (2), or the parcel delivery market in Italy has shown rapid expansion in Europe, boasting a  
9 compound annual growth rate of 8.5% over the last five years (3). One practical approach in-  
10 volves integrating passenger and freight transport systems to maximize the utilization of passenger  
11 transport capacity, which can be considered a form of CS. This approach enhances flexibility and  
12 optimizes resource utilization, and may improve delivery efficiency. CS became well-known in  
13 2015 after its adoption by Amazon (4). Moreover, one of the recent studies addressing the problem  
14 of urban deliveries revolves around crowd logistics as well (5). One of the challenges in incorpo-  
15 rating CS is matching supply and demand, a process that depends on the willingness of users to  
16 participate in the system (6, 7). However, integrating CS with innovative last-mile delivery solu-  
17 tions, for instance, parcel lockers, could minimize the extra distance traveled by crowdshippers,  
18 thereby lowering CO<sub>2</sub> emissions (8). Although some studies include CS as a sustainable delivery  
19 solution (9), some argue that the benefits of such a service are highly dependent on the CS busi-  
20 ness model. Some examples include peer-to-peer (10), retailer-oriented (11) and reverse logistics  
21 (12) CS. The literature on CS has primarily focused on survey-based stated preference experiments  
22 due to the lack of operational data, with limited emphasis on real data analysis, with the notable  
23 exception of (13). In this manuscript, we innovate an approach by employing a multi-agent-based  
24 simulator. This simulator not only calculates the available supply level—identifying potential CS  
25 drivers willing to join the system—but also efficiently matches parcel demand with the available  
26 supply. It also explores the potential for integrating CS into existing employee commuting patterns  
27 to enhance sustainability, including their chosen modes of transport, such as bicycles in Rome.  
28 Hence, CS services can reduce environmental impact by leveraging existing trips instead of creat-  
29 ing dedicated ones. This approach minimizes drawbacks like longer travel times and higher fuel  
30 consumption typically associated with additional vehicle trips (14). However, this approach also  
31 has tradeoffs, such as potential labor impacts, increased workload for employees serving as CS  
32 drivers, and the need for proper incentivization. Despite its significant environmental benefits,  
33 addressing these challenges is crucial for developing a sustainable and equitable CS system. For  
34 instance, Li et al. (15) found a tradeoff between a taxi company's profit and the acceptance rate  
35 of parcels for delivery in taxi-based CS systems. The objective of this research is to investigate  
36 the potential environmental benefits of CS by considering real employee commuting pattern data.  
37 To do this, we used a simulation tool to investigate different CS scenarios. In contrast to previ-  
38 ous studies focusing on public transport or non-employee crowdshippers in Rome (11, 16, 17),  
39 our approach emphasizes the utilization of real data and leads to behaviorally realistic findings.  
40 This distinction allows us to provide novel insights into the potential environmental impacts and  
41 market feasibility of CS in urban settings in Rome. The paper is organized as follows: Section  
42 2 introduces the study's concept and objectives. Section 3 offers a detailed literature review on  
43 crowdshipping (CS). Section 4 outlines the methodology used in the study. Section 5 presents the  
44 findings and results of our analysis. Finally, Section 6 provides a discussion of the results and  
45 draws conclusions.

## 1 LITERATURE REVIEW

2 Several studies have investigated various aspects of LML, particularly crowdshipping (CS). These  
3 investigations have covered a wide range of topics, delving into the operational efficiency, cost-  
4 effectiveness, and environmental impacts of CS compared to traditional delivery methods. Re-  
5 searchers have further examined the social and economic benefits for involved participants. For  
6 instance, (7) focused on the logistics, demand, operational strategies, and management of CS ser-  
7 vices in freight transportation. Furthermore, (18) explored the feasibility and potential of CS in  
8 urban areas and investigated conditions under which individuals would be willing to participate,  
9 emphasizing the need for more qualitative and quantitative research with real-world data. (19)  
10 highlighted the need to explore the sustainability implications of CS, especially toward achieving  
11 zero-emission targets. Additionally, (20) focused on understanding factors influencing the imple-  
12 mentation of crowd logistics, acknowledging the roles of credit risk for crowd workers and plat-  
13 form reliability, both crucial yet often overlooked elements. Moreover, (21) studied the integration  
14 of crowdsourcing options into existing last-mile delivery platforms using floating population data  
15 to optimize operations, noting a lack of research combining crowdsourcing with existing platforms,  
16 particularly regarding pricing strategies varying by geographic area. (22) developed a comprehen-  
17 sive CS mathematical optimization model for last-mile delivery services, aiming to balance prof-  
18 itability, delivery quality, and environmental sustainability. However, the study also highlighted  
19 gaps in integrating crowdsourcing with existing delivery platforms. Additionally, Tapia et al. (13)  
20 underscored the potential of CS in urban freight transport to reduce environmental pollution. The  
21 study revealed higher vehicle kilometers and CO<sub>2</sub> emissions for certain delivery types, suggest-  
22 ing the need for complex analyses considering various urban environments and delivery scenarios.  
23 Building on this foundation, our study introduces an innovative approach by analyzing employee  
24 commuting patterns to integrate CS. This novel method aims to further optimize environmental  
25 benefits by leveraging existing commuting trips, thereby reducing the need for additional vehi-  
26 cle journeys and enhancing the sustainability of urban freight transport. From an environmental  
27 perspective, leveraging trips already made by commuters prevents additional emissions associated  
28 with freight vehicles (23, 24). This benefit is amplified when CS is achieved by using environmen-  
29 tally friendly modes of transport such as bikes, contributing to emissions reduction. Furthermore,  
30 (25) found that CS will be environmentally beneficial if it primarily utilizes sustainable transport  
31 methods. Moreover, (6, 26, 27) proposed an innovative approach to last-mile delivery by integrat-  
32 ing CS but highlighted a research gap in real-world data availability. On the one hand, studies  
33 focusing on occasional couriers' (OC) behavior are limited (28); on the other hand, recent research  
34 has shown that OCs are willing to travel longer distances depending on the compensation offered  
35 by CS services. Another behavioral study (29) demonstrated the commercial potential of bicy-  
36 cle CS, considering supply and demand dynamics. Miller et al. (30) found that the fundamental  
37 premise of minimizing driver detours forms the basis for CS participation. This means that an  
38 OC's decision to pick up a delivery depends on whether the location is convenient to their home,  
39 workplace, or other destinations. Beside, trust is also a crucial factor when using CS platforms; For  
40 instance, (31) highlighted the influence of trust, which is related to the reputation of the delivery  
41 company and affects the adoption of CS. Delivery time directly influences service choice but does  
42 not affect trust. Moreover, (32) examined the potential for CS to generate new trips rather than  
43 consolidating existing ones, revealing a higher probability of low-income individuals initiating de-  
44 livery trips from their homes. According to the research by (9), providing users with the flexibility  
45 to schedule delivery dates and times could incentivize them to use CS services more frequently.

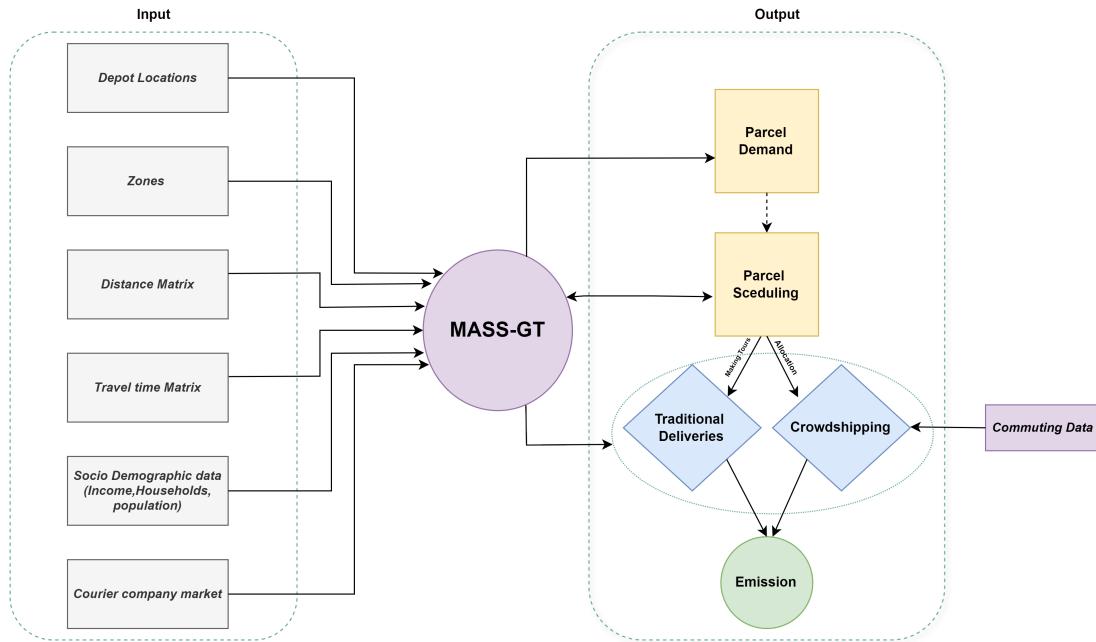
1 Beside that, wholesale shops are experimenting with having their employees deliver packages to  
2 nearby homes at the end of their workday (33). Furthermore, Bajec and Tuljak-Suban (22) found  
3 that existing CS optimization models do not specifically address the reduction of negative environ-  
4 mental impacts, whether considered alone or in conjunction with other objectives. In addition, (34)  
5 examined the emissions produced by delivery tasks with and without the involvement of crowd-  
6 shippers. Despite this, their proposed CS model for allocating delivery tasks did not incorporate  
7 environmental considerations. Other studies evaluate the impacts of public transport-based CS  
8 platforms. For instance, (17) aimed to assess the economic, environmental, and social benefits of  
9 last-mile delivery solutions in Copenhagen using public transport-based CS. Similarly, (11) an-  
10 alyzed sustainable and economic impacts by studying demand levels, vehicle kilometers saved,  
11 and externality reductions. (35) evaluated the potential impacts of implementing CS services on  
12 traffic congestion and pollution in urban areas, specifically in Rome, modeling traditional delivery  
13 services and two alternative CS frameworks one car-oriented and one public-transit-oriented. Like-  
14 wise, (9) argued that CS holds promise for reducing pollution from last-mile deliveries in urban  
15 areas by utilizing metro networks and smart lockers located inside or outside stations. Addition-  
16 ally, (16) examined the willingness of individuals, specifically students, to serve as crowdshippers  
17 for B2C e-commerce deliveries via public transportation systems in Rome. Their study, which  
18 did not use a simulator, considered a payment of 5–10 euros per delivery and a maximum detour  
19 distance of 2.4 km. Not all studies report positive outcomes regarding the potential impacts of CS.  
20 According to (35), CS is often described as a 'double-edged sword' when considering its effects on  
21 sustainable logistics operations. Major service providers like Uber and Lyft (36) view CS services  
22 as a potential extension to their business models, leveraging idle capacity and time. However, it's  
23 unclear if these services will result in more trips for people who can pick up and deliver items.  
24 Crowd logistics remains an emerging field with significant challenges, particularly in understand-  
25 ing the factors influencing business adoption. Previous research has not conclusively demonstrated  
26 whether a multi-channel delivery system offers improved efficiency and reduced emissions com-  
27 pared to a single-channel system. Our study utilizes a multi-agent-based simulator to examine these  
28 dynamics in detail. Compared to previous simulations with this simulator, (13), our innovation is  
29 to include observed commuting data from employees using bikes and personal cars from Rome  
30 in the analysis. Our data analysis reveals how different commuting modes impact efficiency and  
31 emissions. By providing insights into these factors, our study contributes to the empirical evidence  
32 of the likely impacts of CS and offers valuable guidance for businesses considering multi-channel  
33 logistics strategies.

## 34 METHODOLOGY

35 This section outlines the data sources, methodology, and model utilized in this study to assess the  
36 environmental and economic effects of implementing a CS platform. In this study, we explore  
37 through established modeling and simulation approaches, whether CS would be market-feasible in  
38 the municipality of Rome, as well as whether it could contribute to the city's emission reduction  
39 targets. The detailed methodology is illustrated in Figure 1, which provides an overview of the  
40 workflow. Each step is explained in detail below.

## 41 Data Collection

42 To ensure a comprehensive and robust analysis, we collected data from a diverse array of sources.  
43 These included primary sources such as industry publications, market research studies, and gov-



**FIGURE 1** Methodology outline

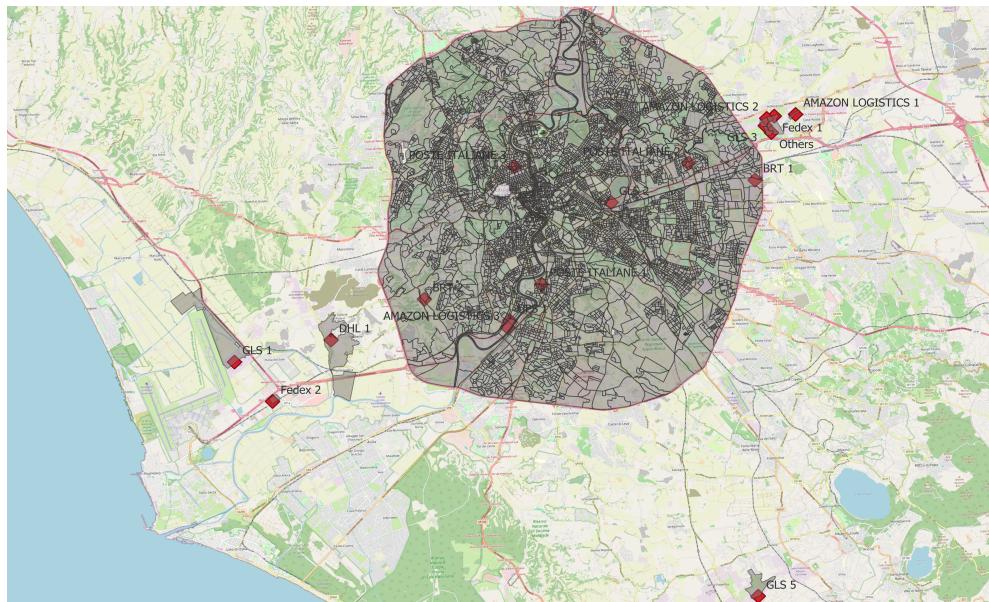
1 government databases to enhance the accuracy, depth, and validity of our findings.

2 **Depot Locations:** These refer to the specific geographical sites within the city of Rome  
3 where parcel depots are established for the storage, sorting, and distribution of goods and packages  
4 within the logistics network. In this study, we identified and mapped the locations of the major  
5 courier companies' depots across Rome Using OpenStreetMap (37). This data was then integrated  
6 into our analysis to understand the spatial distribution of logistics operations.

7 **Zones:** Zones are introduced as smaller segments of the network. For the purpose of  
8 detailed analysis in our case study, we utilized the city geographic zones derived from the 2021  
9 census data provided by the Italian Statistics Institute ISTAT (38). ISTAT provided the census  
10 data at the provincial level, which we then refined to focus solely on the urban areas of Rome.  
11 This process resulted in 8,658 cells. Each cell contains information such as region ID, population  
12 categorized by age and gender, and the number of households, among other Socio-Demographic  
13 variables. These divisions are based on a detailed cell structure within Rome, as illustrated in  
14 Figure 2.

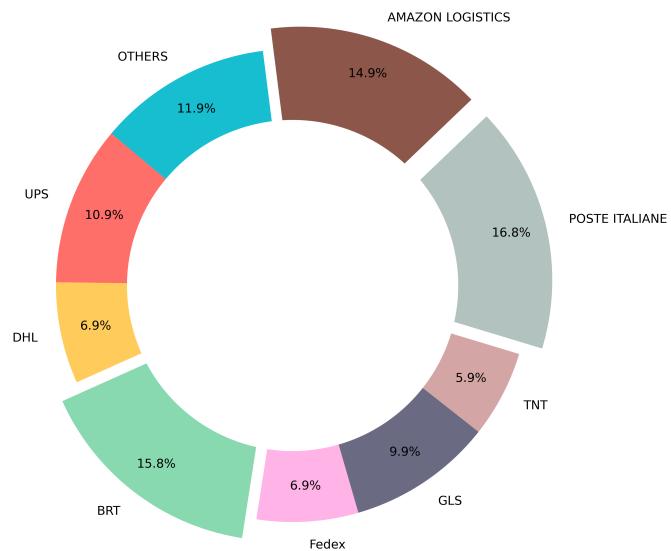
15 **Distance Matrix:** To create the distance matrix, we used the centroids of each zone as  
16 starting points. Python and the OSMNX library (39) were employed to calculate road distances  
17 between these points, rather than using Euclidean distances. Due to the project's scale, we util-  
18 ized the Blue Delft supercomputer server (40) to handle the computational demands of solving  
19 around 74 million instances of Dijkstra's algorithm, as implemented by OSMnx. This parallelized  
20 approach efficiently managed the calculations for our large 8658 x 8658 matrix.

21 **Travel Time Matrix:** To develop a travel time matrix, we used the centroids of each zone  
22 as reference points. By assigning travel speeds, specifically, an average free-flow speed of 50  
23 km/h to the network edges, OSMNX (39) estimates travel times between these centroids, which  
24 represent each zone.



**FIGURE 2 Study area with depot locations**

1      **Courier Market Shares:** We obtained valuable insights from Statista (41) regarding the  
 2 market shares of parcel delivery companies operating in Italy. According to the data, as of 2021,  
 3 Poste Italiane held the largest market share at 17%. This information was critical in shaping our  
 4 strategic considerations for a case study focused on parcel delivery logistics in Rome, as detailed  
 5 in Figure 3.



**FIGURE 3 Market share of the leading parcel shipping providers in Italy 2021**

1 **The Home-Work Travel Plan Data:**

2 The Home-Work Travel Plan, known as Piano Spostamento Casa Lavoro (PSCL) in Italian, is  
 3 a strategic document that analyzes company mobility to promote sustainable transportation by  
 4 reducing reliance on private vehicles. Utilizing PSCL data, we studied commuter trips within  
 5 Rome, crucial for modeling CS scenarios, in collaboration with Movesion company (42). This rich  
 6 dataset includes information on employees commuting to work across Italy, covering aspects such  
 7 as trip modes, origin and destination coordinates, and modes of transport. We filtered this dataset  
 8 to focus on the study area of Figure 2, specifically examining trips made via private vehicles and  
 9 bikes (including scooters). Subsequently, we generated Table 1 to present detailed information  
 10 on employees' trips to their workplaces; These commuting patterns were then matched with our  
 11 designated zones, allowing us to determine the number of trips originating from each zone and  
 12 their destinations within the city.

**TABLE 1 PSCL data**

Variables	PSCL data	This study
Mode	Bike, Private Car, public transport, walking	Car, bike
Offices	552	317 (car), 45 (bike)
Employees	50059	30652 (car), 4598 (bike)

13 **Agent-Based Model Platform: MASS-GT**

14 MASS-GT (Multi-Agent Simulation System for Goods Transport) is an agent-based modeling plat-  
 15 form developed specifically for simulating a wide range of transportation and logistics scenarios.  
 16 It leverages multi-agent systems to accurately model the behavior and interactions of individual  
 17 entities such as vehicles, parcels, and infrastructure components within transportation networks  
 18 (43). MASS-GT consists of three interconnected modules: the shipment synthesizer, the tour for-  
 19 mation model, and the network model, as referenced in (43). Within the shipment synthesizer,  
 20 the parcel demand module generates the demand for parcels, while the parcel scheduling module  
 21 assigns parcels to vehicles and organizes delivery routes. Household data across various zones and  
 22 the average parcel demand per household serve as inputs for the parcel demand module, result-  
 23 ing in a set of parcels with designated origins and destinations. These parcels are then processed  
 24 by the scheduling module, which simulates the creation of distribution tours for parcel delivery.  
 25 This scheduling module is essential for assessing the impact of conventional freight transport de-  
 26 livery methods. MASS-GT is set up to replicate real-world conditions. This includes defining  
 27 agent behavior, setting operational constraints, and simulating scenarios to analyze and optimize  
 28 delivery logistics. The MASS-GT platform has been utilized in various cities and projects (13, 43–  
 29 46), confirming its practical applicability and robustness. Our study aims to leverage this model  
 30 for practical analysis rather than focusing on the detailed verification of its methodology. In the  
 31 model, the most suitable parcels are determined by the detour distance relative to the parcel trip  
 32 distance. This detour should be minimized to ensure sustainable crowdshipping. The equation for  
 33 this relative detour can be found in the equation below.

34

$$35 \text{ relative detour } rd_{p,t}(-) = \frac{\text{traveler's detour (km)} - \text{parcel trip distance (km)}}{\text{parcel trip distance (km)}} \quad (1)$$

1 Specifically, we will use MASS-GT to analyze two distinct scenarios: the traditional delivery  
 2 model by vans, as provided by MASS-GT according to parcel demand, and a scenario incorpo-  
 3 rating employee commuting data, which integrates this new mode into the Non-CS scenario. Our  
 4 objective is to evaluate the environmental impact, particularly in terms of CO<sub>2</sub> emissions, based on  
 5 the kilometers traveled in each scenario. When the model input is loaded, and processing begins,  
 6 the 'crowd shipping' phase, as illustrated in Figure 1, initiates. In this phase, travelers input their  
 7 trips into the platform, which then iterates over available transportation modes (car and bike) and  
 8 their users. For each trip, the platform generates a list of potential parcels by applying several fil-  
 9 ters: parcels already claimed are excluded, parcels must have either the origin or destination within  
 10 the same municipality as the traveler's route, and the parcel's trip must be at least half the length of  
 11 the traveler's trip. These filters help reduce computation time and ensure that only relevant parcels  
 12 are considered. For each remaining parcel, we calculate the relative detour using the given equa-  
 13 tion. Parcels with a relative detour below a threshold have their compensation calculated and are  
 14 stored as potential options. After evaluating all parcels, the three with the lowest relative detours  
 15 are selected and presented to the traveler. The traveler then calculates the utility of each offered  
 16 parcel using equation **below** and selects the one with the highest utility. If this utility exceeds  
 17 a predetermined threshold, the traveler chooses to carry the parcel, informs the platform of their  
 18 decision, and becomes an occasional carrier. The platform records this match, and the process for  
 19 this traveler concludes.

20

$$21 \text{ utility}_{p,t} \left( \frac{\epsilon}{h} \right) = \frac{\text{provided compensation}_p(\epsilon)}{\text{detour time}_{p,t}(h) + 2 \cdot \text{drop-off time}_t(h)} \quad (2)$$

22  
 23 This procedure is repeated for all willing travelers. Ultimately, this results in some travelers choos-  
 24 ing to ship parcels while others do not. The platform tracks these outcomes, and parcels that remain  
 25 unclaimed are forwarded to conventional carriers for delivery.

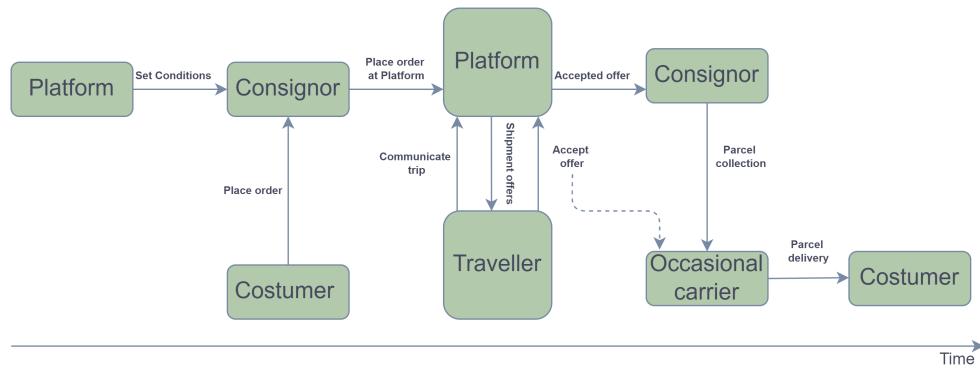
## 26 Scenario Analysis

27 We analysed two main scenarios in this study:

28       **Traditional Parcel Market:** This scenario represents conventional parcel delivery meth-  
 29 ods without CS, using standard last-mile routes with company-owned or contracted vehicles. These  
 30 vehicles follow predetermined routes, delivering parcels directly from depots to recipients. Our  
 31 analysis focused on several key aspects: the number of delivery tours required to meet parcel de-  
 32 mand efficiently, the total distance traveled by delivery vehicles, and the emissions produced. We  
 33 also examined the distribution of tours among vans and calculated the total kilometers covered,  
 34 aiming to optimize operations, ensure timely deliveries, and explore opportunities for emissions  
 35 reduction.

36       **CS Parcel Market:** The process starts with the customer placing an order on the platform.  
 37 The platform sets the strategy, collects orders, and calculates the best orders and compensations.  
 38 Travelers share their trip details with the platform, which then offers them shipments. Once a  
 39 traveler accepts an offer, they make the trip themselves or act as occasional carriers as detailed in  
 40 Figure 4 from (47).

41       In this study, we consider each crowdshipper delivering a single package, with an aver-  
 42 age weight of 3 kg and a van capacity of 180 parcels. Since willingness drives CS participation  
 43 and due to a lack of data for a similar case study, we assume a rough willingness percentage of



**FIGURE 4 Overview of CS process**

1 30%. This estimate accounts for the difference in willingness between employees and students, as  
 2 evidenced by the 87% willingness rate reported for students in the same case study by public trans-  
 3 port (16). The lower percentage for employees reflects their different motivations and constraints  
 4 compared to students. Sensitivity analysis may further validate this assumption by examining the  
 5 impact of varying willingness rates on our results. Travelers are expected to select parcels based  
 6 on specific preferences, including pickup/drop-off times and a value-of-time (VOT) metric for de-  
 7 tours compensated in euros. The Car VOT for Italy is estimated at 6 euros/h in (48), while a Bike  
 8 VOT of 5.75 euros/h is assumed for bicycles, which is in line with other work in the literature  
 9 (47). Moreover, the acceptance of travelers in CS platforms hinges significantly on the compen-  
 10 sation offered. Higher pay tends to lead to more accepted orders from travelers. However, for  
 11 CS to remain economically feasible, the payment to travelers must be less than what consignors  
 12 pay for conventional delivery services. According to (49), the average cost of parcel delivery in  
 13 the business-to-consumer market was 3.35 euros in 2020. To compete effectively with traditional  
 14 delivery services, CS services should ideally set their maximum price at this level. Travelers are  
 15 compensated based on the distance they travel to deliver parcels. The maximum compensation for  
 16 the longest trip is set at 3.35 euros, aligning with the consignor's payment. For shorter trips, the  
 17 compensation is structured to cover the traveler's time for pick-up and drop-off tasks. Despite a  
 18 lack of specific research on the minimum desired compensation for travelers, a baseline of 1.50  
 19 euros has been established for this study, according to (47). To formulate the compensation struc-  
 20 ture, we design a mechanism that exhibits desirable properties such as generous compensation  
 21 for shorter trips and diminishing returns for longer trips. To achieve this, we propose a simple  
 22 logarithmic model, as shown in Equation 3. This approach ensures that shorter trip lengths are  
 23 compensated more generously per kilometer to offset the time spent on pick-up and drop-off ac-  
 24 tivities.

25  $\log((\text{parcel distance}) + 5)$  (3)

26

27 According to (50), drop-off times are estimated at 2 minutes per parcel for delivery vans, halved  
 28 for bicycles primarily due to quicker parking. we assume that parcel pickup times are symmetric  
 29 with respect to drop-off times. Table 2 summarizes our chosen model parameters.

**TABLE 2 Specifications and numbers**

Specification	Numbers
Number of zones	8658
Van max parcel capacity	180
Average parcel weight	3 kg
Bike max parcel load	1
Car max parcel load	1
Bike willingness to ship	30%
Car willingness to ship	30%
Bike VOT	5.75 €/h
Car VOT	6 €/h
Unloading Bike	0.016 h
Unloading Car	0.033 h
Unloading Van	0.033 h

1           **Emission calculation** In this section, we detail the methodology used to calculate emissions for both CS and non-CS scenarios. We specifically focus on tailpipe emissions, which are negligible for electric vehicles (EVs). Lifecycle emissions are beyond the scope of this analysis. 2 We focused on Poste Italiane, the leading parcel delivery company in Italy (41), to base our assumptions on an electric fleet to calculate non-electric fleet emissions for our scenario. According 3 to the operator's reported fleet composition data (51), as shown in Table 3, we estimate that 60% of 4 their fleet in 2022 consisted of traditional internal combustion engine (ICE) vehicles. We adopted 5 this percentage as a proxy for other companies in the industry in our simulation analysis. For 6 commuter vehicles in the CS case, we can assume a small proportion to be EV users. According 7 to (52), 6% of individuals in Rome use electric cars, a figure we integrated into our calculations. 8 These assumptions are necessary due to the lack of precise data on the percentage of electric 9 vehicles used by each parcel company or the number of employees driving EVs in our PSCL data. 10 While these are rough approximations, the substantial difference in EV penetration rates between 11 freight and CS allows us to draw meaningful qualitative conclusions. We calculated emissions 12 based on the distance traveled by vehicles in both scenarios. In the non-CS scenario, emissions 13 are computed considering the kilometers traveled by vans alone. In the CS scenario, emissions 14 are calculated from the combined distance traveled by both vans and private cars, including eventual 15 detours. The calculations follow Equation 4:

$$19 \text{ Total emission} = (\beta \times \text{KM}_{\text{van}} \times \text{EF}_{\text{van}}) + (\gamma \times \text{KM}_{\text{car}} \times \text{EF}_{\text{car}}) \quad (4)$$

20           Where:

21  $\beta = 0.6$  (non-electric van fleet ratio),

22  $\gamma = 0.94$  (non-electric car ratio),

23  $\text{KM}_{\text{van}}$  = kilometers traveled by van,

24  $\text{KM}_{\text{car}}$  = kilometers traveled by car,

25  $\text{EF}$  = emission factor for each type.

1 This linear relationship assumes that emissions increase proportionally with distance traveled,  
 2 which simplifies the model and allows for more robust and faster computations. Although there  
 3 are emission models in the literature that are typically nonlinear, we opted for a linear model to  
 4 enhance computational efficiency.

**TABLE 3 Corporate fleet data of Poste Italiane**

	2020	2021	2022
Total vehicles	32,791	31,645	30,850
<b>of which:</b>			
traditional vehicles	28,133	26,747	<b>19,441</b>
alternative vehicles	4,658	4,898	11,409
<b>of which:</b>			
bicycles	324	324	333
electric vehicles	1,448	1,805	3,654
hybrid motor vehicles	79	79	5,782
petrol-natural gas-fueled vehicles	1,727	1,615	1,410
petrol-LPG-fueled vehicles	1,080	1,075	230
diesel-natural gas-fueled vehicles	0	0	0
LPG-fueled vehicles	0	0	0
percentage of alternative vehicles (%)	14.2	15.5	37

5 Emission factors (EF) for vans are derived from (53), which provides average fleet data  
 6 for road transport of bulk/packaged goods. This study considers well-to-wheel emissions, offering  
 7 detailed emission coefficients for different van types. For normal vehicles, the calculation is based  
 on car emission factors from (54–56). These factors are detailed in Table 4.

**TABLE 4 Emission factors**

Emission Type	van EF (g/km)	car EF (g/km)
CO <sub>2</sub> -eq (Carbon dioxide equivalent)	<b>857.3</b>	<b>180</b>
SO <sub>2</sub> (Sulfur dioxide)	0.89	0.03
PM <sub>c</sub> (Coarse PM)	0.08	0.005
NO <sub>x</sub> (Nitrogen oxides)	3.1	0.3
PM <sub>w</sub> (Fine PM)	0.044	0.02

8

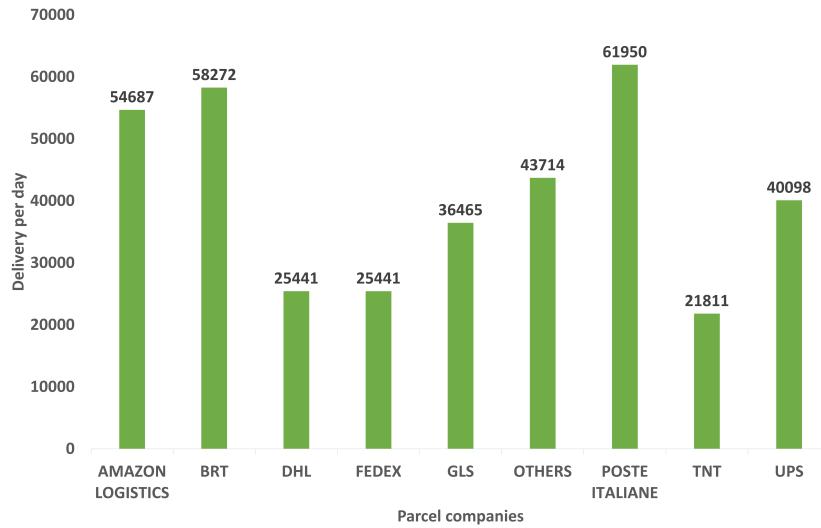
## 9 RESULTS AND DISCUSSION

### 10 Demand share of parcels

11 We calculated parcel demand across Rome's urban areas based on socio-demographic charac-  
 12 teristics and household structure of the population, employing MASS-GT's parcel demand and  
 13 scheduling modules. The model integrates data to calculate parcel demand by considering two  
 14 main factors: socio-demographic characteristics, network and supply data. The former includes  
 15 the anticipated parcel demand based on aggregate population and household characteristics such

1 as population size and income levels. The latter includes zoning structure of the network, depot  
 2 locations of couriers and the courier market shares, as detailed in Section 4.1. With these data,  
 3 the parcel demand of the courier companies is simulated per zone in the network, providing the  
 4 destination zone of the parcels. Following this, the parcels are assigned to the closest depot of the  
 5 courier to the destination zone of the parcel.

6 Figure 5 illustrates the distribution of parcel demand across different parcel couriers in  
 Rome, which is derived from MASS-GT Demand module. The results show variability in parcel



**FIGURE 5 Number of parcel delivery for different companies in Rome per day**

7  
 8 demand among different companies, with Poste Italiane dominating the market share. This high-  
 9 lights Poste Italiane's strong presence and customer base in Rome's urban logistics. Our simulation  
 10 estimates an average daily demand of about 360,000 parcels in Rome, aligning with national statis-  
 11 tics which reported that in 2022, Italy saw a 3.5% increase in parcel volume, reaching 1.5 billion  
 12 parcels from 1.4 billion in 2021. The average number of parcels per person rose to 25, with house-  
 13 holds averaging 57 parcels each (57). Considering Rome's population and delivery trends, this  
 14 daily estimate reflects the city's urban freight demand accurately.

## 15 **Parcel scheduling**

16 Parcel scheduling involves creating delivery tours based on simulated parcel demand for each  
 17 courier. This module allocates parcels to vehicles, typically vans with a capacity of 180 parcels per  
 18 tour, and plans the delivery routes accordingly. Table 5 summarizes the key performance indicators  
 19 of this scenario:

20 Analyzing traditional parcel scheduling in a large urban network like Rome reveals key in-  
 21 sights. Frequent tours are essential for meeting delivery demands efficiently, while numerous stops  
 22 indicate the need for substantial coordination. The long distances covered by vans and the signif-  
 23 icant time investment highlight the complexity and time-consuming nature of last-mile delivery.  
 24 These findings underscore the need for optimization in network planning.

**TABLE 5 Parcel scheduling without CS**

<b>KPIs</b>	<b>Value</b>
Number of parcels	367879
Number of tours	2053
Number of trips	65311
Vans VKT	244203.6
Vans Travel Time(h)	4884.06

**1 Parcel scheduling with CS**

2 The demand module of the platform generates parcel demands for 8658 zones in Rome. However,  
 3 due to the data, CS could only be simulated in 4000 of these zones, where travelers' origins and  
 4 destinations are available through PSCL data. Therefore, out of the total parcel demand in the  
 5 reference case, a total of 80,606 parcels were ordered within the system. Of these, 2449 parcels  
 6 were eligible for CS. Among the eligible parcels, 1256 were successfully delivered through CS,  
 7 resulting in a delivery rate of 51.28%. For the remaining parcels, van delivery is employed. The  
 8 average distance traveled for CS parcel trips was 3.65 km, with an average detour of 2.39 km  
 9 for delivered parcels. The CS deliveries contributed an additional 3004.43 kilometers of travel.  
 10 Detours were distributed across modes as follows: 503 parcels by bike, totaling 1050 km (average  
 11 2.01 km per detour), and 753 parcels by car, totaling 1950 km (average 2.59 km per detour).  
 12 Occasional carriers received an average compensation of 2.11 euros per delivery detailed in Table  
 13 6. The distribution of detours is discussed further.

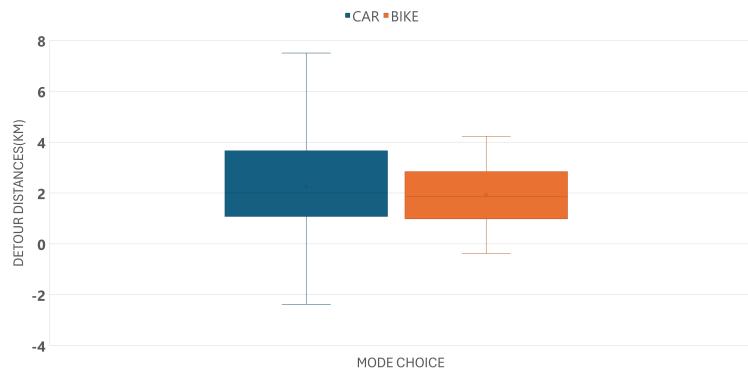
**TABLE 6 CS Metrics**

<b>Metric</b>	<b>Value</b>
Total Parcels Ordered	80,606
Parcels Eligible for CS	2,449
Parcels Delivered through CS	1,256
% of Eligible Parcels Delivered through CS	51.28%
Average Distance of CS Parcel Trips	3.65 km
Average Detour for Delivered Parcels	2.39 km
Total Extra Kilometers Driven for CS Deliveries	3,004.43 km
Detours by Mode	
- Bike	503 parcels, 1,050 km total (2.01 km average)
- Car	753 parcels, 1,950 km total (2.59 km average)
Average Compensation for Occasional Carriers	2.11 euros

14 Traveler availability and willingness to carry parcels are crucial. Ideally, parcels should be  
 15 placed in areas with accessible traveler data, aligning with their routes. Parcels far from common  
 16 routes or in low-traffic areas may be less suitable. Future studies will include detailed sensitivity  
 17 analysis to improve these decisions.

## 1 Mode choice

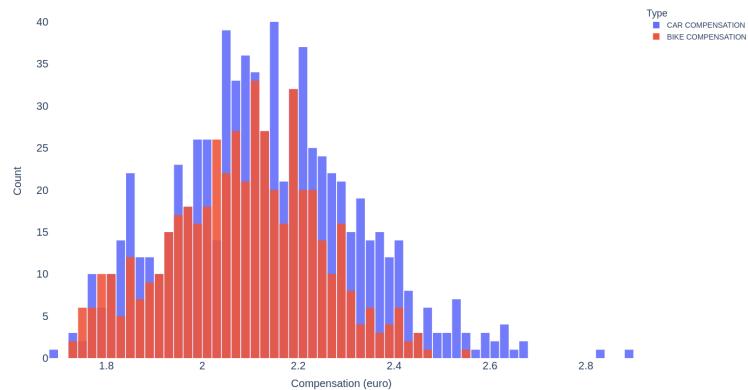
2 When examining the distribution of detours made by cars, we observe that some occasional carriers  
 3 experience negative detours, with the minimum detour recorded at -2.25 km as in Figure 6. This  
 4 phenomenon implies that, in some instances, less distance is covered when a traveler delivers a  
 5 parcel. The underlying reason for this is that travelers often prefer the fastest route available rather  
 6 than the shortest. Consequently, when these occasional carriers engage in parcel deliveries, they  
 7 may find themselves traveling shorter distances even though the route may take longer to complete  
 8 which is align with (47) result. This highlights the complexity of route optimization.



**FIGURE 6 Caption**

## 9 Compensation

10 Histogram analysis of car and bike compensation amounts Figure 7 shows distinct patterns. Both  
 11 types range from 1.7 to 3 euros. Car claims peak at 2.2-2.4 euros and above 2.6 euros, while  
 12 bike claims are concentrated between 1.8 and 2.2 euros. There is overlap from 1.8 to 2.4 euros:  
 13 bike claims are more frequent in the lower segment (1.8-2.1 euros), while car claims increase with  
 14 higher amounts. Bike compensation has a symmetric distribution around 2 euros, whereas car  
 15 compensation peaks at 2.1 and 2.3 euros. Cars also show outliers beyond 2.6 euros, unlike bikes.



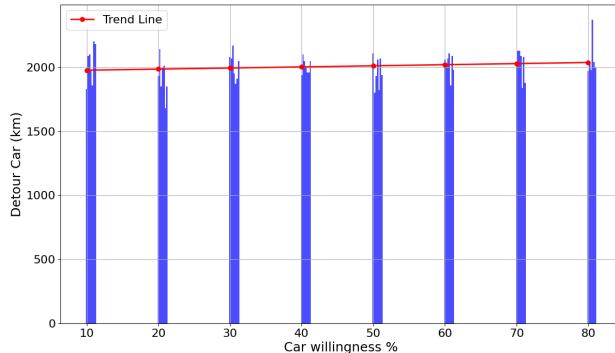
**FIGURE 7 Compensation distribution of Car and Bike**

16 Higher car compensation amounts, especially above 2.6 euros, encourage longer detours

1 due to logarithmic VOT valuation. However, if detours require excessive time, drivers may find  
 2 the compensation insufficient. Bike claims, generally between 1.8 and 2.4 euros, rarely exceed  
 3 2.6 euros, indicating less incentive for detours. This highlights how compensation and transport  
 4 mode affect travel behavior and the complexity of compensation structures. Since both modes used  
 5 the same formula, further testing with alternative compensation methods like linear or flat rates is  
 6 needed for a comprehensive comparison.

## 7 **Sensitivity analysis**

8 The type of sensitivity analysis used in our analysis involves parameter sensitivity analysis and the  
 9 primary focus is on understanding how variations in car usage, while keeping bike usage between  
 10 10% and 80% of employees, impact the detour distance of cars according to Figure 8. To address  
 11 emissions concerns, our analysis shows that as car crowdshippers' willingness increases, detour  
 12 distances rise more significantly for cars than bikes. This trend impacts environmental sustainabil-  
 13 ity, particularly CO<sub>2</sub> emissions, as longer detours lead to higher emissions. This pattern persists  
 14 regardless of the proportion of bikes and cars. A possible reason for this trend is incomplete zone  
 15 coverage. Future research should include a transport model that covers all trips within each zone  
 16 for better system insights. This finding could inform future research on CS compensation mecha-  
 17 nisms and proactive policymaking.



**FIGURE 8 sensitivity analysis**

## 18 **Emission**

19 This section compares CO<sub>2</sub> emissions between non-CS and CS scenarios. The table 7 displays  
 20 total emissions and savings for each emission type in kilograms. The CS scenario shows reduc-  
 21 tions across all emission types, with CO<sub>2</sub> emissions being the highest. The CS scenario achieves a  
 22 savings of 1,310.94 kg of CO<sub>2</sub>, valued at 93 euros under the EU's Emissions Trading System (58).  
 23 Although the CO<sub>2</sub> savings here might seem relatively small, it is important to recognize the signif-  
 24 icance of these reductions within the context of the current study. The amount of savings is limited  
 25 by the fact that not all zones were covered due to data constraints from the PSCL dataset. If we  
 26 had comprehensive coverage of all zones, the potential for increased savings would be substantial.  
 27 This is because extending the analysis to additional zones would likely reveal more opportunities  
 28 for reducing emissions through the integration of CS. Moreover, the results might not fully capture  
 29 the potential benefits due to the use of a linear model for emissions analysis. Employing a more ad-

1 vanced modeling approach, such as the built-in emission calculation in MASS-GT network model  
 2 (45) or COPERT, could provide a more nuanced understanding of emissions and potentially high-  
 3 light more significant impacts. This suggests that the actual benefits of the CS scenario could be  
 4 greater than the current analysis indicates.

**TABLE 7 Emission Comparison**

<b>Emission Type</b>	<b>Total Non-CS Emissions(kg)</b>	<b>Total CS Emissions(kg)</b>	<b>Save (kg)</b>
CO <sub>2</sub> – <i>eq</i>	125613.31	124302.37	1310.94
SO <sub>2</sub>	130.40	128.75	1.65
PM <sub>c</sub> (Coarse PM)	11.72	11.57	0.15
NO <sub>x</sub>	454.21	448.84	5.37
PM <sub>w</sub> (Fine PM)	6.44	6.30	0.14

## 5 CONCLUSION

6 This study demonstrates the potential of CS as a sustainable last-mile delivery solution for Rome  
 7 under certain conditions, such as the use of environmentally friendly vehicles and leveraging ex-  
 8 isting trips. Using real-world data and advanced simulation techniques, we evaluated the possible  
 9 impacts of CS in the city of Rome. By integrating parcel deliveries with employees' existing travel  
 10 routes, our research highlights contributions and areas for future exploration. We demonstrated  
 11 the feasibility of CS in Rome using the MASS-GT simulator and real-world OD trip data from  
 12 employees-to-office. Our case study shows that CS can be effectively integrated into the city's ur-  
 13 ban logistics framework. By evaluating daily parcel delivery demand and optimizing scheduling,  
 14 we achieved efficiency gains by utilizing existing commuter routes for parcel delivery. A com-  
 15 parative analysis indicated that CS could reduce CO<sub>2</sub> emissions in Rome. While the CO<sub>2</sub> savings  
 16 presented may appear modest, their significance within the scope of this study cannot be over-  
 17 looked. Consider the potential impact if these efforts were scaled up to encompass larger zones;  
 18 the reductions in emissions could be more substantial. This reduction supports European emissions  
 19 goals and underscores the environmental benefits of CS. We improved our CS model's accuracy  
 20 by using socio-demographic data to estimate delivery demand, demonstrating the value of detailed  
 21 data in optimizing logistics solutions.

22 In Rome, a city predominantly driven by private vehicles and facing significant environ-  
 23 mental issues with high CO<sub>2</sub> emissions; CS presents a promising solution. Policymakers should  
 24 consider supporting the development of CS platforms and incentivizing individuals and companies  
 25 to participate. Encouraging employees who engage in CS reflects a commitment to sustainability  
 26 and environmental responsibility. Our study highlights the need to compensate travelers for detours  
 27 as crucial for CS success. Future research should develop incentive structures to boost participa-  
 28 tion and use richer employee-to-office data to refine models and outcomes. While our analysis  
 29 addresses tailpipe emissions, it overlooks the lifecycle emissions of electric vehicles, which could  
 30 provide a fuller environmental impact assessment. Future studies should consider lifecycle emis-  
 31 sions and explore the impact of switching to sustainable transport modes like bicycles, potentially  
 32 aligning with (25).

**1 ACKNOWLEDGEMENTS**

2 We would like to acknowledge TU Delft and the FL Lab for hosting and collaborating on this  
3 study. We also used ChatGPT-4 for assisting in enhancing the text, correcting grammatical errors,  
4 and ensuring clarity in the text.

**5 AUTHOR CONTRIBUTIONS**

6 **S.S.**: Conceptualization, Methodology, Software, Validation, Analysis, Investigation, Data cu-  
7 ration, Writing original draft; **M.C.**: Conceptualization, Resources, Writing reviews & editing;  
8 **M.D.**: Methodology, Resources, Writing reviews; **M.T.**: Writing Draft & Edited draft; **M.R.**:  
9 Supervision, Writing reviews; **G.G.**: Supervision, Resources.

1 **REFERENCES**

2 1. Gevaers, R., E. Van de Voorde, and T. Vanelslander, Cost Modelling and Simulation of  
3 Last-mile Characteristics in an Innovative B2C Supply Chain Environment with Implications  
4 on Urban Areas and Cities. *Procedia - Social and Behavioral Sciences*, Vol. 125,  
5 2014, pp. 398–411, eighth International Conference on City Logistics 17-19 June 2013,  
6 Bali, Indonesia.

7 2. Boston Consulting Group, *E-Commerce Will Reach 6.3Trillionby2026*, 2023, accessed :  
8 2024 – 07 – 20.

9 3. Scaramella, R., J. D'Inca, and E. Raffaele, *The Last Mile Is Determining E-Commerce's*  
10 *Winners*, 2022, accessed: April 2024.

11 4. Halzack, S., *Amazon Flex: The Retailer's Uber-like Effort to Bring You Packages*.  
12 [https://www.washingtonpost.com/news/business/wp/2015/09/29/  
amazon-flex-the-retailers-uber-like-effort-to-bring-you-packages/](https://www.washingtonpost.com/news/business/wp/2015/09/29/amazon-flex-the-retailers-uber-like-effort-to-bring-you-packages/?noredirect=on)?noredirect=on, 2015, accessed: 2023-06-04.

13 5. Devari, A., A. G. Nikolaev, and Q. He, Crowdsourcing the last mile delivery of online  
14 orders by exploiting the social networks of retail store customers. *Transportation Research*  
15 *Part E: Logistics and Transportation Review*, Vol. 105, 2017, pp. 105–122.

16 6. Rougès, J.-F. and B. Montreuil, Crowdsourcing delivery: New interconnected business  
17 models to reinvent delivery. In *1st international physical internet conference*, Québec City  
18 (Canada) IPIC, 2014, Vol. 1, pp. 1–19.

19 7. Le, T. V., A. Stathopoulos, T. Van Woensel, and S. V. Ukkusuri, Supply, demand, operations,  
20 and management of crowd-shipping services: A review and empirical evidence.  
21 *Transportation Research Part C: Emerging Technologies*, Vol. 103, 2019, pp. 83–103.

22 8. Farizky Wijanarko, F., *Potential Impact of Car-Based Crowdshipping on Vehicle Mileage*  
23 *and Carbon Dioxide Emission: An Agent-Based Modelling Study Case*. Master's thesis,  
24 Delft University of Technology, nl, 2022.

25 9. Gatta, V., M. Nigro, S. Patella, and S. Serafini, Public Transport-Based Crowdshipping for  
26 Sustainable City Logistics: Assessing Economic and Environmental Impacts. *Sustainability*,  
27 Vol. 11, 2018, p. 145.

28 10. Le, T. V., A. Stathopoulos, T. Van Woensel, and S. V. Ukkusuri, Supply, demand, operations,  
29 and management of crowd-shipping services: A review and empirical evidence.  
30 *Transportation Research Part C: Emerging Technologies*, Vol. 103, 2019, pp. 83–103.

31 11. Gatta, V., E. Marcucci, M. Nigro, S. M. Patella, and S. Serafini, Public Transport-Based  
32 Crowdshipping for Sustainable City Logistics: Assessing Economic and Environmental  
33 Impacts. *Sustainability*, Vol. 11, No. 1, 2019.

34 12. Pan, S., C. Chen, and R. Y. Zhong, A crowdsourcing solution to collect e-commerce  
35 reverse flows in metropolitan areas. *IFAC-PapersOnLine*, Vol. 48, No. 3, 2015, pp. 1984–  
36 1989.

37 13. Tapia, R. J., I. Kourounioti, S. Thoen, M. de Bok, and L. Tavasszy, A disaggregate model  
38 of passenger-freight matching in crowdshipping services. *Transportation Research Part A:*  
39 *Policy and Practice*, Vol. 169, 2023, p. 103587.

40 14. Paloheimo, H., M. Lettenmeier, and H. Waris, Transport reduction by crowdsourced deliveries – a library case in Finland. *Journal of Cleaner Production*, Vol. 132, 2015.

41 15. Li, B., D. Krushinsky, H. A. Reijers, and T. Van Woensel, The Share-a-Ride Problem:

1 People and parcels sharing taxis. *European Journal of Operational Research*, Vol. 238,  
2 No. 1, 2014, pp. 31–40.

3 16. Serafini, S., M. Nigro, V. Gatta, and E. Marcucci, Sustainable crowdshipping using public  
4 transport: a case study evaluation in Rome. *Transportation Research Procedia*, Vol. 30,  
5 2018, pp. 101–110, eURO Mini Conference on "Advances in Freight Transportation and  
6 Logistics".

7 17. Fessler, A., M. Thorhauge, S. Mabit, and S. Haustein, A public transport-based crowdshipping  
8 concept as a sustainable last-mile solution: Assessing user preferences with a stated  
9 choice experiment. *Transportation Research Part A: Policy and Practice*, Vol. 158, 2022,  
10 pp. 210–223.

11 18. Le Pira, M., C. S. Carrocci, V. Gatta, and E. Pieralice, Connected shared mobility for  
12 passengers and freight: Investigating the potential of crowdshipping in urban areas, 2017,  
13 pp. 839–843.

14 19. Sina Mohri, S., H. Ghaderi, N. Nassir, and R. G. Thompson, Crowdshipping for sustainable  
15 urban logistics: A systematic review of the literature. *Transportation Research Part  
16 E: Logistics and Transportation Review*, Vol. 178, 2023, p. 103289.

17 20. Bin, H., F. Zhao, G. Xie, L. Huang, H. Wang, R. Zhu, and L. Jiang, Crowd-Sourcing a  
18 Way to Sustainable Urban Logistics: What Factors Influence Enterprises' Willingness to  
19 Implement Crowd Logistics? *IEEE Access*, Vol. 8, 2020, pp. 225064–225075.

20 21. Kim, J., S. J. Kweon, S. W. Hwang, and S. Lee, Crowdsourcing integration on the last mile  
21 delivery platform considering floating population data. *Expert Systems with Applications*,  
22 Vol. 248, 2024, p. 123312.

23 22. Bajec, P. and D. Tuljak-Suban, A Strategic Approach for Promoting Sustainable Crowd-  
24 shipping in Last-Mile Deliveries. *Sustainability*, Vol. 14, No. 20, 2022.

25 23. Rai, H. B., S. Verlinde, J. Merckx, and C. Macharis, Crowd logistics: an opportunity for  
26 more sustainable urban freight transport? *European Transport Research Review*, Vol. 9,  
27 No. 3, 2017, p. 39.

28 24. Paloheimo, H., M. Lettenmeier, and H. Waris, Transport reduction by crowdsourced de-  
29 liveries – a library case in Finland. *Journal of Cleaner Production*, Vol. 132, 2016, pp.  
30 240–251, absolute Reductions in Material Throughput, Energy Use and Emissions.

31 25. Pourrahmani, E. and M. Jaller, Crowdshipping in last mile deliveries: Operational chal-  
32 lenges and research opportunities. *Socio-Economic Planning Sciences*, Vol. 78, 2021, p.  
33 101063.

34 26. Buldeo Rai, H., S. Verlinde, and C. Macharis, Shipping outside the box. Environmental  
35 impact and stakeholder analysis of a crowd logistics platform in Belgium. *Journal of  
36 Cleaner Production*, Vol. 202, 2018, pp. 806–816.

37 27. Gdowska, K., A. Viana, and J. P. Pedroso, Stochastic last-mile delivery with crowdship-  
38 ping. *Transportation Research Procedia*, Vol. 30, 2018, pp. 90–100, eURO Mini Confer-  
39 ence on "Advances in Freight Transportation and Logistics".

40 28. Le, T. V. and S. V. Ukkusuri, Modeling the willingness to work as crowd-shippers and  
41 travel time tolerance in emerging logistics services. *Travel Behaviour and Society*, Vol. 15,  
42 2019, pp. 123–132.

43 29. Wicaksono, S., X. Lin, and L. A. Tavasszy, Market potential of bicycle crowdshipping:  
44 A two-sided acceptance analysis. *Research in Transportation Business Management*,  
45 Vol. 45, 2022, p. 100660, urban logistics: From research to implementation.

1 30. Miller, J., Y. Nie, and A. Stathopoulos, Crowdsourced Urban Package Delivery: Modeling  
2 Traveler Willingness to Work as Crowdshippers. *Transportation Research Record: Journal*  
3 *of the Transportation Research Board*, Vol. 2610, 2017, pp. 67–75.

4 31. Cebeci, M. S., R. Tapia, M. Kroesen, and L. Tavasszy, The effect of trust on crowdshipping  
5 service choice, 2022.

6 32. Cebeci, M. S., R. Tapia, A. Nadi, M. de Bok, and L. Tavasszy, Does Crowdshipping of  
7 Parcels Generate New Passenger Trips? Evidence from the Netherlands. *Transportation*  
8 *Research Record: Journal of the Transportation Research Board*, Vol. 2678, 2023.

9 33. Lore, M., *Serving Customers in New Ways: Walmart Begins Testing Associate De-*  
10 *livery.* [https://corporate.walmart.com/newsroom/innovation/20170601/](https://corporate.walmart.com/newsroom/innovation/20170601/servingcustomers-innewways-walmartbeginstestingassociatedelivery)  
11 *servingcustomers-innewways-walmartbeginstestingassociatedelivery*, 2017, accessed: 2024-07-13.

12 34. Ghaderi, H., P.-W. Tsai, L. Zhang, and A. Moayedikia, An integrated crowdshipping  
13 framework for green last mile delivery. *Sustainable Cities and Society*, Vol. 78, 2022,  
14 p. 103552.

15 35. Simoni, M., V. Gatta, and C. Claudel, Potential last-mile impacts of crowdshipping ser-  
16 vices: a simulation-based evaluation. *Transportation*, Vol. 47, 2020.

17 36. Frenken, K. and J. Schor, Putting the sharing economy into perspective. *Environmental*  
18 *Innovation and Societal Transitions*, Vol. 23, 2017, pp. 3–10, sustainability Perspectives  
19 on the Sharing Economy.

20 37. OpenStreetMap contributors, *Planet dump retrieved from https://planet.osm.org* . <https://www.openstreetmap.org>, 2017.

21 38. Istituto Nazionale di Statistica (ISTAT), *Dati per sezioni di censimento.* <https://www.istat.it/notizia/dati-per-sezioni-di-censimento/>, 2021, accessed: 2024-07-  
22 10.

23 39. Boeing, G., Modeling and Analyzing Urban Networks and Amenities with OSMnx, 2024,  
24 working paper.

25 40. Delft High Performance Computing Centre (DHPC), *DelftBlue Supercomputer (Phase 2).*  
26 <https://www.tudelft.nl/dhpc/ark:/44463/DelftBluePhase2>, 2024.

27 41. Statista, *Parcel shipping providers market share in Italy.* <https://www.statista.com/statistics/1275101/parcel-shipping-providers-market-share-italy/#:~:text=In%202021%2C%20the%20Poste%20Italiane,market%20share%20at%2016%20percent.>, 2021, accessed: 2024-07-11.

28 42. Movesion, *PSCL - Piano Spostamenti Casa-Lavoro.* [https://www.movesion.com/landing\\_pscl\\_piano\\_spostamenti\\_casa\\_lavoro](https://www.movesion.com/landing_pscl_piano_spostamenti_casa_lavoro), 2024, accessed: 2024-06-11.

29 43. de Bok, M. and L. Tavasszy, An empirical agent-based simulation system for urban goods  
30 transport (MASS-GT). *Procedia Computer Science*, Vol. 130, 2018, pp. 126–133, the 9th  
31 International Conference on Ambient Systems, Networks and Technologies (ANT 2018) /  
32 The 8th International Conference on Sustainable Energy Information Technology (SEIT-  
33 2018) / Affiliated Workshops.

34 44. de Bok, M., I. Bal, L. Tavasszy, and T. Tillema, Exploring the impacts of an emission  
35 based truck charge in the Netherlands. *Case Studies on Transport Policy*, Vol. 8, No. 3,  
36 2020, pp. 887–894.

1 45. Thoen, S., M. d. Bok, and L. Tavasszy, Shipment-based urban freight emission calculation.  
2 In *2020 Forum on Integrated and Sustainable Transportation Systems (FISTS)*, 2020, pp.  
3 372–377.

4 46. Thoen, S., L. Tavasszy, M. de Bok, G. Correia, and R. van Duin, Descriptive modeling  
5 of freight tour formation: A shipment-based approach. *Transportation Research Part E: Logistics and Transportation Review*, Vol. 140, 2020, p. 101989.

7 47. Berendschot, M., An agentbased approach to simulate strategical effects of crowdshipping  
8 in the Netherlands, 2021.

9 48. Commission, E., D.-G. for Mobility, Transport, H. Essen, D. Fiorello, K. El Beyrouty,  
10 C. Bieler, L. Wijngaarden, A. Schroten, R. Parolin, M. Brambilla, D. Sutter, S. Maffii, and  
11 F. Fermi, *Handbook on the external costs of transport – Version 2019 – I.1*. Publications  
12 Office, 2020.

13 49. Autoriteit Consument & Markt, *Post- en Pakkettenmonitor 2019*, 2020, accessed: 2024-  
14 07-12.

15 50. McLeod, F., T. Cherrett, T. Bektas, J. Allen, A. Martinez-Sykora, C. Lamas-Fernandez,  
16 O. Bates, K. Cheliotis, A. Friday, M. Piecyk, and S. Wise, Quantifying environmental and  
17 financial benefits of using porters and cycle couriers for last-mile parcel delivery. *Transportation Research Part D: Transport and Environment*, Vol. 82, 2020, p. 102311.

19 51. Poste Italiane S.p.A., *Sintesi Bilancio Integrato 2022*, 2022, accessed: 2024-07-13.

20 52. Statista, *Electric Vehicles in Italy - Statistics & Facts*. <https://www.statista.com/outlook/mmo/electric-vehicles/italy#unit-sales>, 2024, accessed: 2024-07-13.

22 53. Kleijn, A., D. Hilster, M. Otten, and P. Scholten, *STREAM Freight Transport 2020*. CE  
23 Delft, Netherlands, 2020, available at <http://www.cedelft.eu/>.

24 54. European Environment Agency, *Monitoring of CO<sub>2</sub> emissions from passenger cars – Regulation (EU) 2019/631*, 2019, accessed: 2024-07-13.

26 55. Façanha, C., K. Blumberg, and J. Miller, *Global transportation energy and climate roadmap*. International Council on Clean Transportation, 2012.

28 56. Hsu, D. D., *Life Cycle Assessment of Gasoline and Diesel Produced via Fast Pyrolysis and Hydroprocessing*. United States, 2011.

30 57. Pitney Bowes, *Global Parcel Shipping Index 2023*. [https://www.pitneybowes.com/content/dam/pitneybowes/us/en/shipping-index/23-mktc-03596-2023\\_global\\_parcel\\_shipping\\_index\\_ebook-web.pdf](https://www.pitneybowes.com/content/dam/pitneybowes/us/en/shipping-index/23-mktc-03596-2023_global_parcel_shipping_index_ebook-web.pdf), 2023, accessed: 2024-07-13.

33 58. OpenCO2.net, *CO<sub>2</sub> Converter*. <https://www.openco2.net/en/co2-converter>, 2024, accessed: 2024-06-15.