Impact of Parcel Lockers as Transfer Points on Crowdshipping Services: Carriers' Perspective

Crowdshipping

Impact of Parcel Lockers as Transfer Points on Crowdshipping Services: Carriers' Perspective

by

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Cover Image: Parcel lockers, Source (https://my-pup.com/our-offer/pick-up-points/)
An electronic version of this thesis is available at http://repository.tudelft.nl/.

Preface

After over seven months of hard work, this report is finally presented here as the last step to obtaining a master's degree in Transport, Infrastructure and Logistics at Delft University of Technology. During the project, I went through the initial confusion of the project, hesitations in method selection, and anxiety over repeated revisions. I also experienced the satisfaction of learning new knowledge, the joy of problem-solving, and the excitement of challenging myself. After completing everything, I am proud of myself regardless of the outcome. Also, I would like to express my gratitude to all the people who have helped and supported me.

First and foremost, I would like to thank all the committee members, including Prof. Tavasszy, Dr. Duin, MSc Cebeci and MSc Wardt. Initially, I had several discussions with Prof. Tavasszy, who introduced me to the innovative concept of crowdshipping, ultimately leading me to choose this field for research. Throughout the project, Prof. Tavasszy pointed out the issues and provided new directions in our meetings, which was immensely helpful to me. In several discussions with Dr. Duin, he provided useful suggestions on the report, especially in the stakeholder analysis part. Although this section was removed in the final version of the report, it greatly assisted me in understanding crowdshipping. For the project experiment involving parcel lockers, MSc Wardt provided me with a lot of assistance in this regard. He also offered many of his own insights into the practical application of crowdshipping, helping me expand my ideas. Finally, I want to extend special thanks to MSc Cebeci. Whenever I was confused and hesitant, she was always there to actively help me resolve my doubts and provide valuable advice.

I am very grateful to my parents. During my two years of studying in the Netherlands, they have consistently provided me with as much help as possible and offered me valuable life advice, which has become my precious wealth in life. I'd also like to thank my friends, especially my best friends in Delft, Haoyu, Chen, Ximing, and Xinran. With you guys, life in the Netherlands became more enjoyable. Wishing all my friends a successful future!

At this moment, it's just one month until I return to China. I'm heading home with these wonderful memories from here!

Rui Su
Delft, October 2023

Summary

With the rapid growth in online shopping demand, there has been a gradual increase in the need for parcel deliveries. Particularly for last-mile transportation, meeting customer demands in this context can be time-consuming and costly. Furthermore, traditional logistics service providers typically use dedicated cargo vehicles for last-mile transportation. While this approach may achieve some economies of scale, it also generates negative impacts, such as noise, increased traffic, occupation of sidewalks, and emissions. Especially in the context of striving for zero emissions in cities in the future, finding new logistics methods is of paramount importance. Inspired by the concept of the Physical Internet, a parcel transportation method called ”crowdshipping” has begun to gain attention.

In crowdshipping, individuals or ”occasional carriers” who are already planning to travel from one place to another offer to transport packages or items for others along their route. This can be done for a fee or as a community service, depending on the platform and arrangement. In this study, after completing a parcel transportation task, occasional carriers can receive compensation provided by the task initiator through the platform. The crowdshipping platform, acting as an intermediary, charges a certain fee for its services. Currently, research on crowdshipping primarily focuses on the service type where parcels are transported directly from the origin to the destination without intermediate stops (direct crowdshipping), i.e., without the use of transfer points like parcel lockers. Studies on the integration of parcel lockers as transfer points within crowdshipping (joint crowdshipping) remain limited, especially in terms of investigating the impact of parcel lockers on crowdshipping. Examples of direct crowdshipping and joint crowdshipping are shown in figure 1.

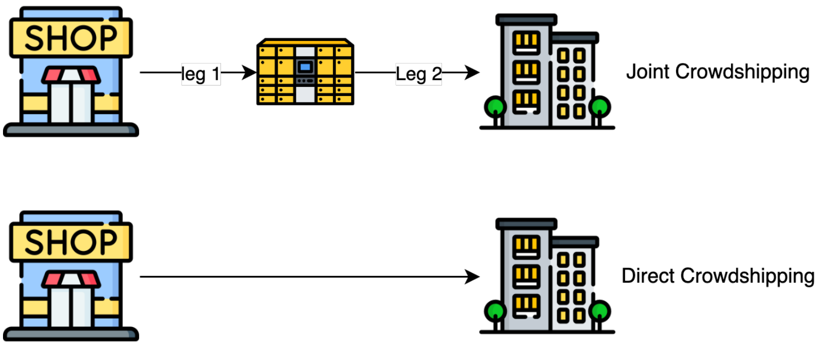

Figure 1: Direct crowdshipping and joint crowdshipping

Furthermore, since crowdshipping is still primarily a conceptual model and lacks widespread practical application, the majority of research relies on stated preference experiments (SP) through survey questionnaires to collect data related to crowdshipping, while the collection of revealed preference (RP) data is significantly lacking. To address these gaps, this study adopts a combination of RP and SP data to explore how parcel lockers influence crowdshipping from the supply side. The main research question is as follows:

How does the presence of parcel lockers shape carriers’ participation?

In order to gain a deeper understanding of crowdshipping, a stakeholder analysis was conducted. In crowdshipping, stakeholders include the sender and receiver (customers), the crowd, logistics service providers, municipalities, parcel locker providers, and crowdshipping platforms. Through perspective analysis and interaction analysis, crowdshipping has the potential to revolutionize last-mile delivery and create a collaborative and sustainable ecosystem that benefits all stakeholders involved. Then, to address the main research question, two approaches have been employed: the establishment of a choice model and a simulation model. These models investigate the impact of applying parcel lockers on occasional carriers' participation from both individual and group perspectives. First, a literature review was conducted to identify factors that can influence carriers' choices. These factors include remuneration, total travel time, parcel characteristics (weight, size, and quantity), the decision to use parcel lockers, delivery booking mode and bank credit mode. Considering the project's objectives and feasibility, the following attributes from table 1 were ultimately selected for further validation.

Table 1: Factors to be tested in this study

Factor	Explanation
Remuneration (euro)	The amount of compensation offered for completing tasks.
Parcel Quantity (pcs)	The number of parcels to be delivered in a single task.
Whether to Use Parcel Locker or Not (Y/N)	The decision to use a parcel locker as part of the delivery process or not.
Total Delivery Time (min)	The total time required to complete the delivery task.
Travel Time (min)	The time spent traveling from the starting point to the destination.

Following this, an RP experiment was designed utilizing parcel lockers provided by MyPup within TU Delft and several addresses in Delft, Den Haag, and Rotterdam as parcel pickup or delivery points. Participants were recruited to physically carry out parcel transportation tasks, providing data. Due to the limited availability of RP data, supplemental SP data was collected through survey questionnaires. Ultimately, the results of the choice model, which indicate that remuneration, travel time, and total delivery time are significant factors influencing choice behavior, demonstrate that the application of parcel lockers does not result in additional utility. However, this also might be because of two reasons: 1) Insufficient data collection, and 2) People might under/overestimate the alternatives in the SP experiment. The utility functions obtained are as follows:

$$V_{Pickup} = -0.17631 * TDT + 0.96582 * Rem \tag{1}$$

$$V_{Notpickup} = -0.17631 * TT \tag{2}$$

Where TDT, TT and Rem stand for the total delivery time, travel time and Remuneration. In this scenario, it is assumed that all carriers use bicycles as their mode of transportation. Therefore, the time can be calculated by dividing the distance between two locations by the average bicycle speed of 4.2 m/s.

For the simulation model, the results from the choice model were used as inputs. By setting the parcel pickup and delivery points, the locations of parcel lockers, and the value of remuneration, the model generated choices from carriers on the randomly selected routes. In the case study, Delft was selected as the experimental area, with new students purchasing home accessories. The starting point was set at IKEA, and the endpoint was five selected student apartments. Three parcel lockers operated by MyPup were used as transfer points to explore the impact of parcel lockers on the crowdshipping system. The remunerations for leg 1 and leg 2 are defined by the following equations:

$$Rem\_leg1 = \frac{Distance\_leg1}{Distance\_leg1 + Distance\_leg2} Rem\_total[euro] \tag{3}$$

$$Rem\_leg2 = \frac{Distance\_leg2}{Distance\_leg1 + Distance\_leg2} Rem\_total[euro] \tag{4}$$

Which is valid where Rem_leg1 is the remuneration for the first leg of joint crowdshipping, Rem_leg2 is the remuneration for the second leg of joint crowdshipping, $Distance\_leg1$ is the distance from IKEA to the parcel locker, $Distance\_leg2$ is the distance from the parcel locker to the student apartment building and Rem_total is the remuneration for direct crowdshipping.

In the first scenario, different destination locations were tested. The results indicated that the application of parcel lockers had a positive effect on increasing the number of accepted tasks and reducing detours. This is because parcel lockers increase the ways in which carriers can participate in crowdshipping. However, it also led to a decrease in the number of fulfilled tasks due to the imbalance of task acceptance between leg 1 and leg 2 in joint crowdshipping and the low efficiency caused by joint crowdshipping. In addition, a notable usage of parcel lockers was observed. In the second scenario, different remuneration levels were tested. As remuneration increases, the number of accepted tasks increases. However, the proportion of fulfilled joint crowdshipping in the total task completion decreases, as more individuals opt for direct crowdshipping. In addition, the average detour within the system increases. It can be concluded that the positive effects of parcel lockers were more pronounced when remuneration levels were lower. In this context, parcel lockers effectively reduced detours and increased the number of fulfilled tasks.

Even though there are some research limitations, it is still possible to deduce promising conclusions from this research. Firstly, the application of parcel lockers does not result in the additional utility of picking up a parcel for carriers. Secondly, the use of parcel lockers can reduce detours and increase the number of individuals accepting crowdshipping tasks by expanding the coverage of the crowdshipping system. However, if the goal is to improve the fulfillment rate, the crowdshipping platform should place a focus on pricing and matching strategy to ensure that the completion status of leg 1 and leg 2 in joint crowdshipping is at the same level. Additionally, the selection of parcel locker locations should be done properly based on demand and volume. In order to improve the findings of this study, some future research directions were provided. Firstly, it is necessary to consider a broader range of attributes, such as parcel size and weight, and conduct analyses for different modes of transportation and travel. Secondly, it is essential to conduct further RP experiments to acquire more data for a higher level of accuracy. Thirdly, it will be valuable to examine the demand side to validate whether the use of parcel lockers can make it easier for consumers to adopt crowdshipping services. Fourthly, there is a need for further exploration of pricing strategy and matching strategy for a crowdshipping system that incorporates parcel lockers. Lastly, exploring optimal parcel locker placement within the crowdshipping system to maximize their utilization and reduce the additional time carriers spend on task execution is a valuable direction for further study.

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Nomenclature

Abbreviations

Abbreviation	Definition
ASC	Alternative Special Constant
CS	Crowdshipping
DC	Direct Crowdshipping
DCM	Discrete Choice Model
JC	Joint Crowdshipping
Min	Minute
MNL	Multinomial Logit
Pcs	Pieces
PI	Physical Internet
PL	Parcel Locker
RP	Revealed Preference
RUM	Random Utility Maximization
SP	Stated Preference
VoT	Value of Time

1
Introduction

1.1. Background

Over the next three decades, there will be a sustained global urbanization process. According to the World Cities Report, the urban population is expected to grow from 56% in 2021 to 68% in 2050 (Habitat, 2022). This signifies a projected rise of 2.2 billion urban residents, placing pressure on urban services. People in urban areas need regular access to essential goods, and e-commerce currently plays a significant role in retailing worldwide. Moreover, the delivery of goods in cities is particularly important. In 2015, e-commerce accounted for nearly 7.5% of global retail sales, while the forecast indicates that, by 2026, it will account for nearly 25% of retail sales worldwide (Coppola, 2022). In the Netherlands, the annual revenue from e-commerce sales has been steadily increasing over time. As can be seen in Figure 1.1, it has grown from 2.82 billion euros in 2005 to 30.6 billion euros in 2021.

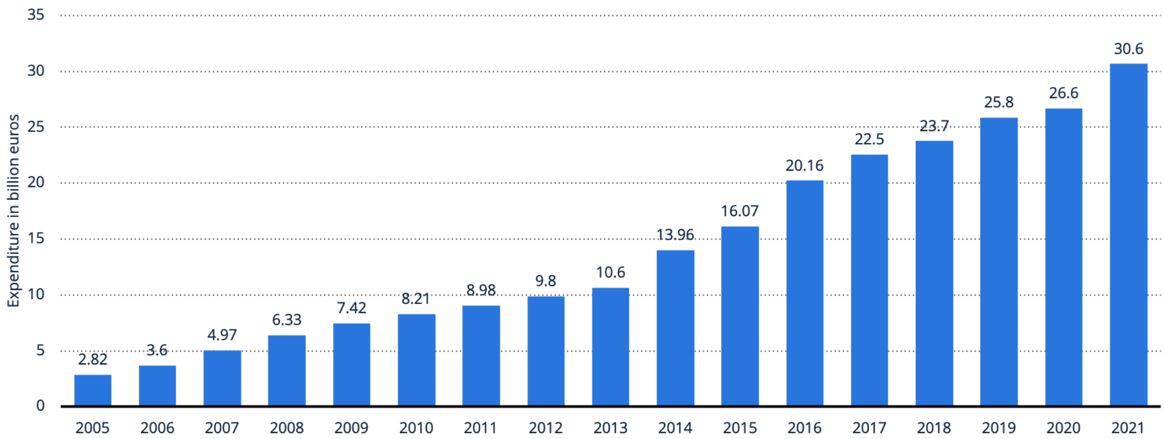


Figure 1.1: Total revenue of e-commerce sales in the Netherlands from 2005 to 2021 (Statista, 2022)

With the increase in e-commerce, there has been rapid growth in home deliveries. As shown in Figure 1.2, the parcel market volume in the Netherlands is experiencing significant growth, increasing from 343 million in 2014 to 954 million in 2021. This means that there is a significant volume of packages being transported between and within cities on a daily basis. However, with the increasing demand for last-mile delivery, traditional courier companies such as DHL, PostNL and FedEx face immense pressure and challenges. The courier companies deliver the parcels to the doors so consumers can easily collect the parcels. However, there are several issues regarding this way of delivery. First, customers are not always available at home to receive packages, which may cause failed deliveries (Song et al., 2009; Morganti et al., 2014; Wang et al., 2016). Second, the high volume of delivery tasks requires more complex last-mile delivery, generating negative impacts. These impacts include, but are not limited to, GHG emissions, congestion, noise and road safety (Nogueira et al., 2022; Buldeo Rai et al., 2017). To ensure a sustainable future for urban areas, it is essential to plan for environmentally friendly transportation and mobility both within cities and beyond, with the aim of reducing energy consumption, air pollution, noise, and greenhouse gas (GHG) emissions. Therefore, an innovative solution is required to tackle these issues.

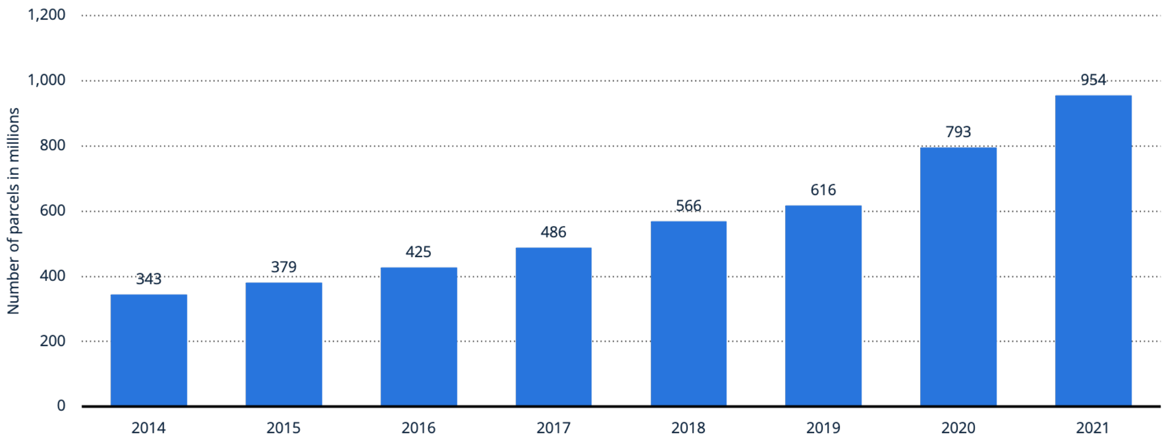


Figure 1.2: Courier, express and parcel (CEP) market volume in the Netherlands from 2014 to 2021 (Statista, 2022)

To build more efficient last-mile delivery systems, the vision of the Physical Internet (PI) was proposed as an innovative solution. It emphasizes several key concepts, including standardized containerization, shared resources, intelligent systems and sustainability. According to Peng et al. (2020), the PI exhibits significant advantages over traditional models, with its flexibility, efficiency in transportation, and Pareto solutions offering a holistic approach to improving sustainability in logistics. One of the applications proposed in PI is crowdshipping in which passenger mobility and last-mile delivery operations can be combined (Crainic & Montreuil, 2016). The main idea is that users can become carriers when their destinations are not far from those of the parcels. The large-scale implementation of such a service can help reduce the infrastructure and operational costs, as well as courier-generated traffic (Rougès & Montreuil, 2014; Ghaderi et al., 2022). Thanks to the bicycle-friendly environment and convenient public transportation in the Netherlands, carriers can utilize environmentally friendly modes of transportation to facilitate the delivery of parcels. For instance, an individual can carry a package and deliver it to the intended location on the daily commute, creating additional value on both the supply side and the demand side. In this way, crowdshipping can make better use of the current transportation capacity, achieving faster, cheaper and more sustainable deliveries (Miller et al., 2017; Pourrahmani & Jaller, 2021; Arditi & Toch, 2022). However, crowdshipping services are also facing several challenges in practice. According to Wang et al. (2016), in crowdshipping each task is independent and the task is performed on a one-to-one communication basis. As a result, there are few consolidation effects. Rougès & Montreuil (2014) state that the feasibility and efficiency of large-scale crowdshipping depend on carriers' proximity to the origins and destinations of parcels. If the flow between the parcel origin and destination is low, then the efficiency of crowdshipping services can be influenced. Therefore, one of the most significant challenges in the establishment of crowdshipping is to guarantee reliable and scalable delivery procedures (Boysen et al., 2022).

In recent years, the use of parcel lockers has been popular (Iwan et al., 2016). Parcel lockers are groups of strategically situated lockers, located in urban areas, that can be emptied and filled 24/7, so people are able to collect or return their parcels at a moment that fits their agenda best. Various business models are in existence when employing parcel lockers. Vertically integrated courier companies invest in developing their own network of lockers, while certain specialized operators provide on-demand locker services catering to both individuals and businesses. Of particular note is that the use of parcel lockers provides a flexible solution to transfer goods between different modes and actors for collaborative delivery (Ghaderi et al., 2022; Pan et al., 2021). The utilization of parcel lockers in a crowdshipping network can improve the performance of crowdshipping services by reducing the trip detour and achieving better coverage (Ghaderi et al., 2022). Therefore, it is possible to explore the integration of parcel lockers in crowdshipping, enabling multiple occasional carriers to complete one task. Parcel delivery tasks served by crowdshipping are no longer limited to a single origin and destination, allowing people more options and increasing the feasibility of crowdshipping services.

1.2. Problem Definition

Currently, there is an increasing number of researchers engaged in the topic of crowdshipping. As an innovative delivery method, crowdshipping is projected to alleviate the burdens associated with traditional distribution and delivery approaches, resulting in faster, more cost-effective, and environmentally sustainable parcel delivery (Bajec & Tuljak-Suban, 2022).

Based on the literature analysis on crowdshipping, several studies have been conducted to optimize the crowdshipping system and determine the system's outcomes. Ghaderi et al. (2022) proposed a novel model for determining the locations of parcel lockers and allocating delivery tasks in a crowdshipping network. By conducting numerical analyses on large instances, it has been demonstrated that joint delivery can enhance the success rate of deliveries by up to 5%. Barbosa et al. (2023) developed a dynamic compensation scheme through the integration of logistic regression and optimization methods. The authors determine the optimal reward for occasional carriers, which maximizes the acceptance of being an occasional carrier. To simultaneously maximize the number of matched deliveries and take into account the employees' minimum expected earnings, Boysen et al. (2022) offered an effective solution procedure based on classic Benders decomposition. Kızıl & Yıldız (2023) formulated and optimized a new last-mile delivery model composed of automated service points, crowdshipping, public transit network and backup transfers. Many studies have evaluated the outcomes of the crowdshipping system in terms of its economic, environmental, and societal benefits. According to Tapia et al. (2023), introducing crowdshipping with the use of cars and bicycles for L2L deliveries results in an increase in both vehicle kilometers and CO2 emissions. However, the authors suggest that crowdshipping services can be efficient in less dense areas. According to Ballare & Lin (2020), the delivery paradigm of microhubs with crowdshipping was proved to significantly reduce the number of trucks, vehicle miles traveled, total daily operating costs and total fuel consumption compared with the traditional hub-and-spoke paradigm for the same demand. Nevertheless, trucks are still involved in this type of crowdshipping to transport goods among hubs, and occasional carriers are only responsible for the trips between hub and consumer. Farizky WIjanarko (2022) concluded that car-based crowdshipping services would not have benefits on vehicle mileage and carbon dioxide emission, while public transport-based crowdshipping can lead to a reduction in particulates and carbon dioxide (Gatta et al., 2018). However, these findings are concluded based on the assumption that there is sufficient acceptance and adoption of crowdshipping from both the demand and supply sides.

Regarding the acceptance and adoption of crowdshipping, a considerable amount of research has been conducted. According to Marcucci et al. (2017), a majority of students, 87%, expressed their readiness to participate in crowdshipping, although this figure declines with larger delivery boxes and lower pay rates. Conversely, 93% of respondents would be open to receiving goods through a crowdshipping platform, but this number would significantly drop if there was no way for customers to communicate with the crowdshipping company. Meanwhile, about half of the sample expresses a positive attitude toward the success of crowdshipping services by public transport (Gatta et al., 2018; Serafini et al., 2018). According to Miller et al. (2017), crowdshipping could be an attractive alternative for particular urban commuters and, if properly handled, may offer a more eco-friendly and efficient shipping choice for individuals, private firms, and government entities. And high-income group is not likely to perform the delivery. As to the consumers of crowdshipping services, trust plays an important role (Cebeci, Tapia, Kroesen, et al., 2023; Pourrahmani & Jaller, 2021). Consumers are likely to trust and use crowdshipping services with a strong reputation and low damage risk, and direct communication between couriers and consumers is necessary during the delivery process. However, all the conclusions from the aforementioned studies are based on respondents' choices in hypothetical scenarios and therefore lack empirical evidence from practical implementation. The expansion of crowdshipping services relies heavily on a large pool of participants. If the crowd cannot effectively cover the service areas, the quality of the service will be significantly influenced, and consumers may not choose this new service model.

There have been some studies that have started to link crowdshipping with parcel lockers, aiming to optimize the performance of crowdshipping services through the unique characteristics of parcel lockers. According to Pan et al. (2021), parcel lockers offer a flexible and convenient solution for transferring goods between different modes and actors in collaborative delivery models. The utilization of parcel lockers in a crowdshipping network can improve the performance of crowdshipping services in several ways, including reducing trip detours and achieving better coverage (Ghaderi et al., 2022). Fessler et al. (2023) conducted a full-scale test of a public transport-based crowdshipping concept. 28 parcel lockers were placed at public transport stations in Denmark, and participants were required to carry parcels among the public transport stops. Viability was validated from a user perspective, with a high degree of acceptance. However, the study did not further explore the factors that influence the acceptance of parcel delivery tasks by users. Ghaderi et al. (2022) explored how to optimize a crowdshipping network with parcel lockers as exchange points. Numerical analyses conducted on large instances have demonstrated that implementing joint delivery can enhance the success delivery rate by up to 5%. This improvement can be accomplished by strategically placing a small number of parcel lockers at highly dense locations. Kızıl & Yıldız (2023) developed and optimized a novel last-mile delivery model that integrates automated service points, crowdshipping, public transit network, and backup transfers. Based on the aforementioned studies, the integration of parcel lockers in crowdshipping is considered a viable direction. However, these studies are mostly optimization-based, and there is still insufficient theoretical support regarding the impact of parcel lockers on crowdshipping services, particularly due to the lack of analysis based on relatively empirical data. Hence, behavioral studies are still lacking.

The aim of this research is twofold. First, it is important to identify the factors that influence carriers' choices, especially when incorporating this service with parcel lockers. Second, it is necessary to comprehend the impact of parcel lockers on crowdshipping which is the main aim of this study since the role that parcel lockers can play in crowdshipping services remains unknown, especially from the supply side. Parcel lockers could potentially impact carriers' choices, thereby influencing the flow of crowdshipping and finally the utilization of parcel lockers themselves.

1.3. Research Gap and Motivation

As mentioned in Section 1.2, there are several research gaps that have been found in the literature. While there have been numerous studies analyzing the acceptance of crowdshipping from both the supply and demand sides, the research has primarily relied on hypothetical scenarios. This implies that the conclusions are based on assumptions and lack empirical evidence from practical data. Other studies focusing on optimizing the crowdshipping network and evaluating the system performance often reference the conclusions of research that lack empirical evidence. This reliance on idealized conclusions may lead to results that are overly optimistic or not fully reflective of real-world conditions. In addition, there is still limited research on the application of parcel lockers in crowdshipping services, and the impact of parcel lockers on the crowdshipping system remains unknown. Research on the supply side of crowdshipping is crucial as it determines whether a sufficient number of individuals are attracted to participate in parcel delivery. Therefore, this study aims to gather empirical data to understand the supply side of crowdshipping in individual choice behavior and then analyze the crowd behavior in crowdshipping with parcel lockers, filling the research gaps shown in Figure 1.3.

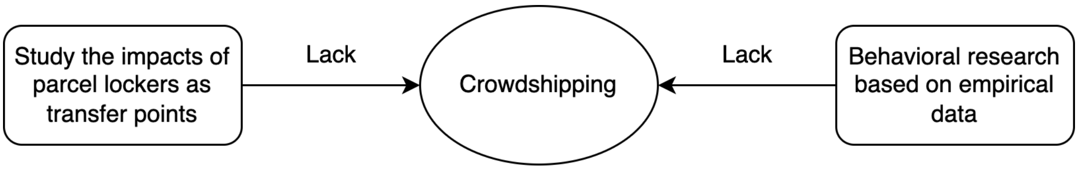


Figure 1.3: Research gaps

This thesis topic has been selected by a student pursuing a Master of Science in Transport, Infrastructure, and Logistics at Delft University of Technology (TU Delft). The author's motivation has originated from his own interest in last-mile delivery, behavioral research and innovative and customized logistics services. This research aims to shed light on the factors that individuals consider when actively participating in crowdshipping, as well as the potential impacts of parcel lockers on this service. As a company that operates parcel delivery and parcel locker services, My Pick-up Point (MyPup) wishes to investigate the potential role of parcel lockers in future logistics models from this research. The company's operational philosophy revolves around sustainability and environmental friendliness, and the concept of crowdshipping aligns with these principles. Therefore, the company is highly interested in the potential and development direction of crowdshipping and hopes to see relevant conclusions in this research project. As a result, this research may provide MyPup with a new idea for operating parcel lockers in the future.

1.4. Research Objectives and Questions

Originally, crowdshipping services were achieved by employing carriers to directly deliver the parcels to destinations. After implementing the concept of parcel lockers as transfer points, it is possible to separate one crowdshipping task into several sub-tasks, which is called joint delivery. This way of crowdshipping operation can provide more flexibility for occasional carriers. According to Ghaderi et al. (2022), the success rate can be increased through joint delivery with parcel lockers. Fessler et al. (2023) concluded that there is a high degree of acceptance for commuters taking public transport to carry parcels through 28 parcel lockers located at stations. Therefore, the use of parcel lockers in crowdshipping services can be feasible and effective. Nevertheless, using parcel lockers as transfer points might change carriers' choice behavior, and this potential change is unknown to us. According to the literature review, there is no study researching the impacts of parcel lockers as transfer points on crowdshipping services from the perspective of carriers. Moreover, there is currently a lack of collection and analysis of empirical data. This research aims to analyze carriers' behaviors and understand the change in their choices in different crowdshipping scenarios, especially with or without parcel lockers as transfer points, contributing to the further implementation of this field. Based on the research objective, the research questions are proposed below:

How does the presence of parcel lockers shape carriers' participation?

The following sub-questions can jointly answer the main research question:

1. **What are the attributes affecting willingness to become carriers?**
   Before initiating an experimental plan, it is essential to conduct a literature review to define the attributes that influence willingness to become carriers. This helps in planning which factors need to be tested in the experiment and then provides a prediction according to model estimation.
2. **How do parcel lockers as a transfer point influence willingness to become carriers?**
   To answer this sub-research question, a choice model will be developed. The analysis helps in understanding the effects of parcel lockers and provides insights into the rationale behind carriers' choices. The utility functions obtained from the model estimation were used as the input of the simulation model for the next research question.
3. **What is the potential impact of parcel lockers on crowdshipping from the supply side in an urban area?**
   After comprehending the impact of parcel lockers on carriers' decision-making behavior, it is necessary to explore the broader perspective of how they can potentially reshape crowdshipping practices. Delft was selected as the experimental area, and a simulation approach was employed to compare the status of the crowdshipping system with and without parcel lockers as transfer points from the supply side under different scenarios. This comparison can enable us to draw conclusions about the potential outcomes.

1.5. Scientific and Societal Relevance

This study contributes to the existing body of knowledge by utilizing empirical data and investigating the factors influencing the acceptance of crowdshipping from the perspective of carriers. Moreover, the impact of parcel lockers as a transfer point is investigated. The study aims to fill the gaps found in the current literature by providing empirical evidence and simulating the crowdshipping system with and without parcel lockers.

The findings of this research have significant implications for the logistics industry and society as a whole. Understanding the factors that influence individuals' decisions to participate in crowdshipping can help shape future strategies and policies to promote sustainable and efficient delivery models. The integration of parcel lockers in crowdshipping services can potentially enhance the convenience, reliability, and environmental sustainability of last-mile deliveries. By addressing the research questions, this study contributes to the development of innovative and sustainable logistics solutions that can potentially improve overall transportation efficiency, reduce congestion, and minimize environmental footprints.

1.6. Structure

The structure of the paper and the chapters corresponding to the research questions are depicted in Figure 1.4. Chapter 2 primarily addresses sub-question 1 and summarizes the attributes studied in this project, which serve as input for Chapter 3. Chapter 3 provides a detailed description of the research methodology, forming the framework to support the case study in Chapter 4. Chapter 4 analyzes and summarizes the results of the choice model and simulation experiments, serving as a basis for Chapter 5. Ultimately, Chapter 5 combines the findings from all the previous chapters to present the project's conclusions and recommendations.

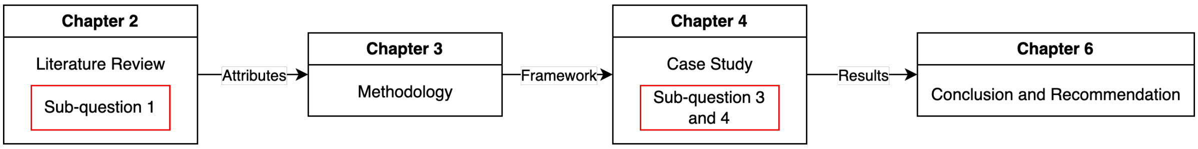


Figure 1.4: Structure

2 Literature Review

This literature review is used to understand the concepts of parcel locker and crowdshipping as well as the various research directions in this field. Simultaneously, an analysis of perspectives among stakeholders associated with crowdshipping services was conducted to determine the prospects for the development of this new service. In addition, it is significant to identify the factors that play a role in users' choice behavior toward being carriers in crowdshipping services, then they can be considered as research subjects in the experiment. First, the concept of crowdshipping is introduced followed by the parcel locker. Then, the relevant factors will be summarized through a literature review. To search for appropriate sources, the very first step is to open www.sciencedirect.com and www.scopus.com. The relevant articles are searched using the following keywords: ”crowdshipping”, ”parcel locker”, ”crowdshipper” and ”occasional carrier”. In these studies, references to other relevant literature will be included, and through this ”snowballing” search approach, a substantial body of literature that intersects with this research can be identified, thereby serving as references for this study. Then, all the relevant papers are classified into different categories based on their research directions.

2.1. Crowdshipping

In order to continuously improve the quality and efficiency of last-mile delivery, the vision of Physical Internet (Crainic & Montreuil, 2016) was proposed. It envisions a globally interconnected, efficient, and sustainable logistics system. Its core concept is to establish a networked and open architecture for freight transportation, enabling the seamless transportation and exchange of standardized containers and modular units among various carriers and transportation modes. By enabling shared and coordinated logistics, the Physical Internet aims to improve the utilization of resources, reduce carbon emissions, lower costs, and enhance overall sustainability in freight transportation. According to Zhu et al. (2023), it is feasible to integrate freight transportation into passenger transportation, which is called co-modality. By adopting this approach, the surplus capacity of passenger transportation can be efficiently utilized, reducing the need for dedicated freight transportation.

Inspired by Physical Internet, crowdshipping is a novel logistics concept that shares similarities with co-modality. According to Gdowska et al. (2018), crowdshipping involves ordinary people in the process of package delivery to other customers. It capitalizes on the concept of the sharing economy, where individuals who are already traveling from one location to another can take on additional packages for delivery along their route. These individuals, often referred to as ”occasional carriers,” voluntarily participate in crowdshipping for corresponding compensations by signing up for platforms or apps that connect them with package senders in need of delivery services.

Crowdshipping services typically involve three key components. Taking the Nimber platform as an example, individuals with parcel delivery needs can submit requests on the platform, specifying pickup location, destination, desired delivery time, and compensation. Users who have registered as bringers can then browse and accept tasks based on their preferences. They are responsible for picking up the package and delivering it to the specified destination within the agreed-upon timeframe. The crowdshipping platform plays a crucial role as an intermediary, ensuring that bringers can easily browse and access relevant tasks based on their location preferences. Additionally, the platform can utilize historical data of bringers to provide them with task recommendations that align with their preferences and past performance. Crowdshipping may serve two business models: Business-to-Consumer (B2C) and Consumer-to-Consumer (C2C) (Gatta et al., 2019; Marcucci et al., 2017). Both B2C and C2C models can benefit from crowdshipping services, enabling more flexible and convenient package delivery options for businesses and individuals alike.

There are already many successful crowd logistics services such as Uber and DiDi Hitch, but the majority of their carriers engage in it as either a full-time or part-time occupation. This approach does not optimally leverage existing resources and can be seen as primarily addressing capacity shortages through a large workforce rather than resource efficiency. In addition to that, there are also some platforms that implement the crowdshipping concept such as Nimber. In Norway, the Nimber platform has gained increasing interest and participation in crowdshipping. However, in the Netherlands, crowdshipping remains a relatively unfamiliar concept for the majority of the population. In order to establish crowdshipping as a viable and successful commercial model in the future, it is imperative to gain deeper insights into individuals' perceptions, attitudes, and preferences toward this service. Conducting pilot studies would be instrumental in examining the factors influencing individuals' willingness to participate in crowdshipping and identifying strategies to optimize the service. By conducting rigorous research and analysis, we can effectively tailor the crowdshipping model, facilitating its acceptance and integration into the existing logistics landscape.

2.2. Application of Parcel Lockers

Parcel lockers are secure storage units designed to receive and store packages for convenient pickup 24/7 by recipients. They are commonly used in residential buildings, apartment complexes, offices, and retail locations. Parcel lockers typically consist of a series of individual compartments or lockable boxes, each assigned to a specific recipient. When a package is delivered to a parcel locker, the recipient receives a notification, usually through a mobile app, email, or text message, containing a unique pickup code or QR code. The recipient can then visit the parcel locker, enter the code or scan the QR code, and retrieve their package from the designated compartment. Compared to traditional home delivery, parcel lockers have several advantages. First, parcel lockers can solve the not-at-home issue. During weekdays, people are occupied with work, studying, or shopping, resulting in many instances where there is no one at home. Unfortunately, delivery attempts often coincide with these periods of absence, leading to a high number of failed deliveries (Visser et al., 2014; Deutsch & Golany, 2018). Reattempting deliveries adds to the cost of the delivery process and contributes to more GHG emissions. The application of parcel lockers can solve this issue, as people can retrieve their packages from the lockers at any time during the day. Second, the use of parcel lockers can achieve better parcel consolidation for courier companies. According to da Silva et al. (2019); Deutsch & Golany (2018), the greater concentrations of deliveries to a small number of points can result in a more efficient allocation of vehicles, taking advantage of consolidation opportunities. Home delivery often involves more complex route planning. To complete daily tasks within the expected time frame, courier companies have to deploy more vehicles to deliver parcels. From an environmental perspective, the use of parcel lockers can reduce at most 67% of the emissions than home delivery (M. Giuffrida et al., 2016). Compared to the service point, parcel locker can avoid labor costs, occupy smaller physical space, and is not restricted by opening hours.

Currently, the functionality of parcel lockers is relatively limited, primarily offering consumers parcel retrieval and return services to enhance last-mile transportation efficiency. Consequently, research on parcel lockers primarily focuses on the acceptance of parcel lockers, optimization of parcel locker networks, and the development of new transportation models that leverage parcel lockers. According to Collins (2015); Molin et al. (2022), price and delivery moment are taken as the main attributes for using home delivery while opening hours and distance/time from home are determined as the factors for choosing parcel locker and service point. The results also show that price is a significant factor that considerably influences consumers' preferences. In order to determine the locations of parcel locker, Moslem & Pilla (2023) adopted a multi-criteria decision-making (MCDM) approach called AHP in a Spherical Fuzzy environment. Enthoven et al. (2020) formulated a two-echelon vehicle routing problem to optimize parcel delivery with cargo bikes and parcel lockers. It is concluded that the use of parcel lockers has great potential to reduce driving distance. However, there is currently a lack of research on how emerging logistics technologies may impact parcel lockers. For instance, it is worth exploring whether the development of crowdshipping services would affect the utilization of existing parcel lockers. This is a valuable topic for companies offering parcel locker services.

PostNL has implemented over 400 parcel lockers in various locations across the country, and the objective is to expand this number to 1,500 by 2024 (PostNL, 2022). This indicates that the parcel locker market is continuously expanding, and there will be a growing presence of parcel lockers in our surroundings. However, the potential of parcel lockers should not be limited to merely facilitating package pick-up and return processes. It is worthwhile to investigate the effective utilization of idle locker units to unlock their potential value.

2.3. Stakeholders' Perspectives

According to Buldeo Rai et al. (2017), there are five main stakeholders involved in crowdshipping, including sender and receiver, crowd, logistics service provider, municipality, and crowdshipping platform. In addition, the locker provider is also considered a stakeholder because this study focuses on the use of parcel lockers in crowdshipping. Understanding the perspectives of various stakeholders facilitates the continuation and success of the service. Through literature review and the interviews with the MyPup managing director, a policy advisor at the municipality of The Hague and a logistics expert, the following sections provide a detailed explanation of each stakeholder's perspective.

2.3.1. Sender and Receiver (Customers)

The parcel sender and receiver are the potential customers of crowdshipping services. By leveraging crowdshipping, parcel senders can tap into a vast network of individuals who are willing to deliver packages while they are traveling. In the Netherlands, where public transportation and cycling networks are highly developed, people can quickly and conveniently travel to various locations, providing a solid foundation for crowdshipping services. Meanwhile, these modes of transport are not only eco-friendly but also enable the people who join the service to navigate through congested areas more effectively. Therefore, crowdshipping is likely to offer customers fast, reliable and sustainable deliveries. Especially for the business-to-consumer model, the quick and efficient crowdshipping service can help improve consumers' overall satisfaction and loyalty to the business, which, in turn, can lead to positive word-of-mouth recommendations.

2.3.2. Crowd

Crowd, as one of the stakeholders, can be analyzed from two perspectives. First, individuals can choose to become carriers themselves, creating opportunities to earn money. According to the feedback from the experiment implemented in this project, participants are willing to get remuneration through this method. Participation allows individuals to actively engage in the crowdshipping ecosystem, contributing to its growth while reaping financial benefits. Second, citizens' quality of life can be improved by the implementation of crowdshipping. Compared to traditional home delivery, the crowdshipping services emphasized in this study, which primarily rely on active modes, do not contribute to additional traffic volume, thereby reducing negative social and environmental impacts. The environmental impacts mainly include greenhouse gas emissions, air pollution and noise, while road safety and traffic congestion contribute to the social impacts (Buldeo Rai et al., 2017). As the number of participants increases, the quality of crowdshipping services will improve, leading to further support and expanding its positive impact.

2.3.3. Logistics Service Provider

Traditional logistics providers, such as DHL, PostNL, and UPS, are expected to maintain their dominant position in last-mile delivery services (Tapia et al., 2023). In the short term, the development of crowdshipping may rely on the assistance of these traditional logistics providers, especially when the number of crowdshippers is insufficient to offer flexible and high-quality services (Erickson & Trauth, 2013). Traditional logistics providers can collaborate with crowdshipping platforms to utilize surplus capacity for parcel delivery tasks on the platform, without increasing transportation costs (Le & Ukkusuri, 2019b). As market dynamics evolve, the co-existence and collaboration between crowdshipping and traditional logistics can contribute to more efficient and sustainable urban transportation solutions.

2.3.4. Municipality

According to the interview with a policy advisor at the municipality of The Hague, effectively utilizing existing infrastructure to meet the growing demands of people is an important task. With the rapid growth of e-commerce, there is an increasing need for parcel transportation. To meet this demand, more vehicles are allocated to ensure timely delivery, especially for last-mile transportation. However, this puts additional pressure on urban traffic, requiring the municipal departments responsible for mobility and transportation to constantly seek new solutions. Crowdshipping services, being a novel approach to parcel transportation, can handle a portion of delivery tasks without increasing the overall traffic volume when utilizing bikes, pedestrians and public transport. Meanwhile, municipalities are responsible for achieving zero emissions within the city. In the long term, crowdshipping can provide a direction to share and use fleets and assets to the maximum, achieving logistics decarbonization (Liesa, 2019). Therefore, municipal research departments are willing to focus on the potential development of crowdshipping.

2.3.5. Locker Provider

Parcel lockers, serving as excellent transit tools, are expected to be applied in crowdshipping services. For parcel locker providers, the use of parcel lockers in crowdshipping services can be a new business for the future. First, locker providers would like to know the feasibility of this new model. Based on an interview with the founder of MyPup, it has been revealed that they are eager to explore further possibilities for the expansion of their parcel locker services. If crowdshipping services can become a successful model, locker providers will be responsible for leveraging the locations of parcel lockers, making the trips between lockers as affordable and convenient as possible. The preferred locations can be universities, business clusters, public transportation stations, etc. In this way, people will be more likely to become carriers, while parcel locker providers are able to generate more profits. In summary, parcel locker providers can play an essential role in the future development of crowdshipping services.

2.3.6. Crowdshipping Platform

The crowdshipping platform is a key stakeholder with the most significant power and interest. While generating revenue, it has the responsibility of promoting the service, optimizing mechanisms, and managing package losses. The fundamental role of the platform is to publish tasks and facilitate reasonable task matching, with their primary source of income being the service fees paid by package senders. Increasing revenue necessitates expanding the scale and improving the quality of crowdshipping services. Therefore, the platform needs to operate effectively while seeking ways to enhance service capabilities, such as implementing parcel lockers to reach broader users and improve task responsiveness. As an intermediary, the platform must consider the needs of both the demand and supply sides, motivating both parties to ensure service utilization. In essence, the crowdshipping platform needs active coordination with other stakeholders to ensure the feasibility of the service and create substantial value.

2.4. State of the Art

There has been an increasing number of studies on crowdshipping recently, and the studies can be divided into four types, including the optimization of crowdshipping systems (Ghaderi et al., 2022; Barbosa et al., 2023; Boysen et al., 2022), the evaluation of crowdshipping services in terms of economic, environmental and societal benefits (Tapia et al., 2023; Ballare & Lin, 2020; Arditi & Toch, 2022; Farizky WIjanarko, 2022), the acceptance of crowdshipping from demand and supply sides (Gatta et al., 2018; Serafini et al., 2018; Fessler et al., 2023; Le & Ukkusuri, 2019b; Miller et al., 2017; Wicaksono et al., 2022; Cebeci, Tapia, Kroesen, et al., 2023) and the integration of crowdshipping with other technologies (Ghaderi et al., 2022; Le Pira et al., 2021; Zhu et al., 2023). In this section, these perspectives of crowdshipping are specified.

Regarding the optimization of crowdshipping systems, there are several papers discussing the network of parcel lockers, job-to-carrierr assignment strategy and pricing strategy. Ghaderi et al. (2022) proposed a novel model for determining the locations of parcel lockers and allocating delivery tasks. By conducting numerical analyses on large instances, it has been demonstrated that joint delivery can enhance the success rate of deliveries by up to 5%. Barbosa et al. (2023) developed a dynamic compensation scheme through the integration of logistic regression and optimization methods. It will determine the optimal reward to be provided to occasional carriers, which maximizes the acceptance of being an occasional carrier. In order to simultaneously maximize the number of matched shipments and take into account the employees' minimum expected earnings, Boysen et al. (2022) offered an effective solution procedure based on Benders decomposition. In summary, research on optimization problems involves almost every step of crowdshipping services. In addition, the optimization of the parcel locker network is a new trend since the use of parcel lockers has the potential to improve the performance of crowdshipping services.

Concerning the performance of crowdshipping, it is evaluated by many studies in terms of economic, environmental and societal benefits. According to Tapia et al. (2023), introducing crowdshipping with the use of cars and bicycles for L2L deliveries results in an increase in both vehicle kilometers and CO2 emissions. However, it suggests that crowdshipping services can be efficient in less dense areas. According to Ballare & Lin (2020), the delivery paradigm of Microhubs with crowdshipping was proved to significantly reduce the number of trucks, truck VMT, total daily operating costs and total fuel consumption compared with the traditional hub-and-spoke paradigm for the same demand. But trucks are still involved in this type of crowdshipping to transport goods among hubs, and occasional carriers are only responsible for the trips between hub and consumer. Farizky WIjanarko (2022) concluded that car-based crowdshipping services would not have benefits on vehicle mileage and carbon dioxide emission, while public transport-based crowdshipping can lead to a reduction in particulates and carbon dioxide (Gatta et al., 2018). To summarize, the impacts of crowdshipping services vary depending on the type of service and city characteristics.

The acceptance of crowdshipping has been analyzed by many studies in terms of the demand and supply sides. According to Marcucci et al. (2017), a majority of students, 87%, expressed their readiness to participate in crowdshipping, although this figure declines with larger delivery boxes and lower pay rates. Conversely, 93% of respondents would be open to receiving goods through a crowdshipping platform, but this number would significantly drop if there was no way for customers to communicate with the crowdshipping company. Meanwhile, about half of the sample expresses a positive attitude toward the success of crowdshipping services by public transport (Gatta et al., 2018; Serafini et al., 2018). According to Miller et al. (2017), crowdshipping could be an attractive alternative for particular urban commuters and, if properly handled, may offer a more eco-friendly and efficient shipping choice for individuals, private firms, and government entities. And high-income group is not likely to perform the delivery. As to the consumers of crowdshipping services, trust plays an important role (Cebeci, Tapia, Kroesen, et al., 2023; Pourrahmani & Jaller, 2021). Consumers are likely to trust and use crowdshipping services with a strong reputation and low damage risk, and direct communication between couriers and consumers is necessary during the delivery process. From the above overview, it can be seen that research on the acceptance of crowdshipping is quite complete. The use of parcel lockers is mentioned in some of the studies. However, there is no explanation of the potential impacts of parcel lockers, which can be a topic for further research.

Regarding the integration of crowdshipping with other technologies, related research is limited. Le Pira et al. (2021) proposed a concept integrating freight transport into a Mobility as a Service (MaaS) environment. Crowdshipping can be involved in this process to improve the system's efficiency. According to Ghaderi et al. (2022), parcel lockers can be used as exchange points in crowdshipping to reduce detours and achieve better geographical coverage, improving the performance of crowdshipping.

2.5. Attributes Definition

In order to determine the attributes to be tested in the experiment, conducting a literature review is necessary to summarize potential factors that may influence carriers' acceptance of tasks. Based on the conclusions drawn from the literature review and considering their practical applicability in the experiment, relevant attributes will be selected for the analysis of experimental data.

According to Gatta et al. (2019), age, location of parcel locker (PL), remuneration, delivery booking and bank credit mode are significant attributes that influence the willingness to become carriers. By designing a stated choice (SC) experiment and collecting data through online surveys, Fessler et al. (2022) found that the utility of bringing a parcel is positively associated with the monetary compensation offered to individuals, while it is negatively correlated with the detour, as well as the weight, size, and quantity of parcels. To explore the heterogeneity in preferences amongst those who might become carriers, Cebeci, Tapia, Nadi Najafabadi, et al. (2023) designed a stated preference experiment, which revealed that total travel time, the use of parcel locker and remuneration are significant factors. Tapia et al. (2023) incorporated the total travel time including the detours to pick up the parcel, travel cost and remuneration into the utility function for analyzing the willingness of the carriers to carry each parcel. Additional travel time, remuneration, and package weight can significantly influence the propensity to perform crowdshipping tasks (Wicaksono et al., 2022). Both travel time and remuneration earned have a significantly diminishing effect on utility in this decision context (Miller et al., 2017). The monetary incentive is a crucial factor in recruiting and maintaining carriers in the crowdshipping system (Le & Ukkusuri, 2019a; Galkin et al., 2021). In addition, Marcucci et al. (2017) found that package size and compensation fee are considered by carriers, while (Le & Ukkusuri, 2018) proposed trip time (including detour time), profit, package weight and the number of packages to deliver.

Table 2.1: Significant variables for occasional carrier

Variables	**Source**
Remuneration	Gatta et al. (2019); Fessler et al. (2022); Cebeci, Tapia, Nadi Najafabadi, et al. (2023); Tapia et al. (2023); Wicaksono et al. (2022); Miller et al. (2017); Le & Ukkusuri (2019a); Galkin et al. (2021); Marcucci et al. (2017); Le & Ukkusuri (2018)
Detour/total travel time	Fessler et al. (2022); Cebeci, Tapia, Nadi Najafabadi, et al. (2023); Tapia et al. (2023); Wicaksono et al. (2022); Miller et al. (2017); Le & Ukkusuri (2018)
Parcel characteristics (weight, size and quantity)	Fessler et al. (2022); Wicaksono et al. (2022); Marcucci et al. (2017); Le & Ukkusuri (2018)
Whether to use parcel locker or not	Gatta et al. (2019); Cebeci, Tapia, Nadi Najafabadi, et al. (2023)
Other (delivery booking and bank credit mode)	Gatta et al. (2019)

Table 2.1 summarizes all the factors mentioned in the literature above that may influence carriers' task selection. Based on the table, it can be observed that remuneration and detour (travel time) are the most significant factors considered by carriers in their task selection. Additionally, parcel characteristics and the use of parcel lockers also have some influence on carriers' choices. According to Gatta et al. (2019), when controlling all variables to zero, carriers tend to lean towards not accepting any tasks, suggesting the possible presence of an

alternative special constant (ASC) in the utility function for ”non-acceptance”. Furthermore, some other factors such as delivery booking and bank credit mode can also impact carriers' selection. Considering the feasibility of the experiment, only the quantity of parcels will be selected for validation concerning parcel characteristics. Since Delivery booking and bank credit modes require specific platform technologies, they will not be tested in this experiment. Therefore, this study ultimately selects remuneration, detour, parcel quantity and the use of parcel locker as the primary factors influencing carriers' acceptance of tasks and incorporates them into the utility function. Further validation of these attributes will be conducted in the model estimation derived from experimental data.

Based on the results of the literature review, five factors have been selected as the validation objects for this study, including remuneration, parcel quantity, whether to use a parcel locker or not, total delivery time and travel time. The explanations for each factor are shown in Table 2.2. These factors will be examined and validated in the context of the study.

Table 2.2: Factors to be tested in this study

Factor	Explanation
Remuneration	The amount of compensation offered for completing tasks.
Parcel Quantity	The number of parcels to be delivered in a single task.
Whether to Use Parcel Locker or Not	The decision to use a parcel locker as part of the delivery process or not.
Total Delivery Time	The total time required to complete the delivery task.
Travel Time	The time spent traveling from the starting point to the destination.

2.6. Conclusion

The literature review in this study is primarily divided into five sections: an overview of crowdshipping research, an introduction to parcel locker applications, the latest developments in crowdshipping, the stakeholder perspectives and the most significant summary of factors influencing carriers' choice behavior in crowdshipping. The last section has addressed one of the research sub-questions: What are the attributes affecting willingness to become carriers? According to the results of the literature review, crowdshipping has the potential to revolutionize last-mile delivery and create a collaborative and sustainable ecosystem that benefits all stakeholders involved. However, the development of crowdshipping is still limited, particularly in the need for more real-world data to support this emerging logistics concept. While a few studies have explored the use of parcel lockers in crowdshipping, further research is required to confirm the impact of parcel lockers on crowdshipping services. This study aims to fill these gaps by using data from the real world to investigate the effects of parcel lockers on crowdshipping from the supply side, and Section 3 will provide a more detailed overview.

3 Research Methodology

This chapter first introduces the conceptual framework adopted in this study, followed by an explanation of the data collection and data processing methods employed in establishing the choice model to address the second research sub-question. Lastly, the simulation model is explained for the subsequent case study.

3.1. Conceptual Model

It is worth noting that there is currently a lack of research investigating the impact of parcel lockers on crowdshipping from the perspective of individual choice behavior. Additionally, there is a lack of further understanding of how crowdshipping services may vary based on individual choice behavior in the presence or absence of parcel lockers. The conceptual model for this research is given in Figure 3.1. The focus of the conceptual model is to understand the key elements of this research and the interactions between these elements.

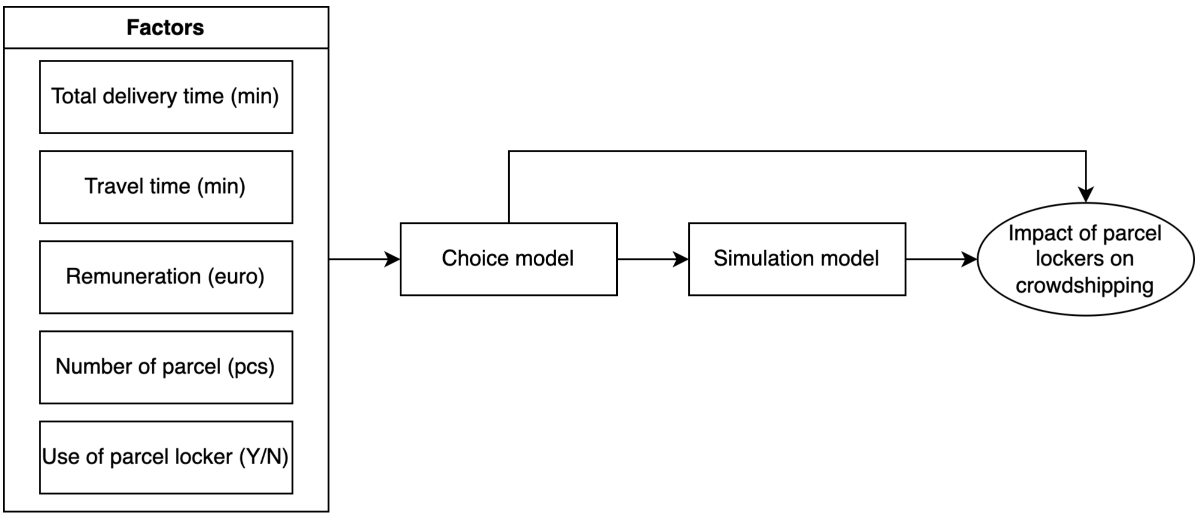


Figure 3.1: Conceptual model

Based on the literature review, five factors have been identified as influencing carriers' choice behavior, including remuneration, detour, travel time, total delivery time, parcel quantity and the use of parcel locker. In this study, the use of parcel lockers is one of the leading research objectives. Therefore, the experiment involves the practical use of parcel lockers. Ultimately, through the analysis of carriers' choice behavior and the application of the simulation model in a case study, theoretical support is provided for understanding the impact of parcel lockers on crowdshipping from a supply-side perspective.

The experiment collected carriers' choice data and fitted it to a choice model that incorporates the research factors. This allows for an assessment of the impact of each factor on choice behavior. The data obtained from the revealed preference experiment can reflect carriers' behavior in the real world, enhancing the persuasiveness of the model estimation. Due to the time constraints as well as technical problems in the crowdshipping platform used in the experiment, insufficient data were obtained. To ensure reliable results, an available SP survey from another research was used to collect SP data, but most SP data was retrieved from the same research. This data was then combined with the RP data to obtain the final results. Eventually, the utility function representing carriers' choice behavior was used as input to establish a supply-side simulation model, providing insights into the impact of parcel lockers on crowdshipping.

3.2. Revealed Preference Experiment

Revealed preference methods are a set of techniques used in economics and consumer behavior research to infer an individual's preferences and choices based on their observed behavior (Richter, 1966; Houthakker, 1950; Sen, 1971). Revealed preference methods offer non-intrusive, real-world insights into consumer choices, based on observed behavior, with broad applications and policy relevance. Crowdshipping, as a logistics model with potential applications in the future, requires further validation through real-world observational data to genuinely understand the principles underlying carriers' choice behavior. This will lay the foundation for the development of a business model.

3.2.1. Experiment Objectives and Scope

As mentioned in Section 1.2, there is currently no crowdshipping service in operation in the Netherlands. Therefore, the factors influencing individuals' decisions to become carriers, as identified, are predominantly derived from the stated preference experiments conducted at the research level. Furthermore, given the novelty of applying parcel lockers in crowdshipping services, it is essential to gain insights into the impacts of parcel lockers on crowdshipping services. Therefore, the experiment focuses on the collection of revealed preference data, where participants actively engage in crowdshipping tasks and provide feedback based on their real-world experiences.

To reduce the complexity of the experiment, the experiment involves only three regions: Delft, Den Haag, and Rotterdam. Although it is not possible to conduct the experiment throughout the entire Netherlands, these cities are representative and suitable for the purpose since these cities are highly populated (CBS, 2023). These cities provide a significant commuting population, which can provide sufficient support for crowdshipping services with an adequate number of carriers. Moreover, in terms of distance, the trips among these cities represent a variety of distance categories ranging from 3 km to 35 km, offering the possibility of diverse delivery distances. According to N. Giuffrida et al. (2021), universities can be considered as a favorable community for the development of crowdshipping services. University students and staff members are generally more receptive to new developments and innovative solutions, which may make it easier to collect a larger amount of data from this group. Therefore, the parcel lockers used in this experiment are located at the TU Delft Faculty of Civil Engineering and Geosciences, which results in the target audience mainly consisting of students and faculty members.

3.2.2. Experiment Design

Selection of the Origin and Destination for Package Delivery

After deciding to use Delft, Rotterdam, and Den Haag as the research area, it is necessary to select specific addresses within the study area as starting and ending points for parcel delivery. Subsequently, we reached out to our network residing in these cities and individuals who showed interest in participating in the experiment to make use of their addresses. Ultimately, we acquired five addresses in Den Haag, nine addresses in Delft, and three addresses in Rotterdam.

The compensations offered to carriers are calculated based on the distance between the origin and destination. Therefore, it is necessary to know the distance between the addresses. According to Tapia et al. (2023), crowdshipping is likely to increase congestion and GHG emissions. However, there are no constraints on the mode of transportation in his research. In the case of car-based crowdshipping, it is expected that the current situation is not improved in terms of GHG and emissions. Thus, this experiment encourages people to use active modes as a means of reducing the negative impacts associated with parcel delivery. Google Maps is utilized to determine average travel times and distances between the specified origins and destinations.

Design of Crowdshipping Tasks

As mentioned in Section 3.1, the main research attributes of this experiment include detour, total travel time, remuneration, number of parcels, and whether to use parcel lockers. Due to the different modes of transportation used by carriers, there may be significant variations in estimating travel time and consequently the detour between origin and destinations. Therefore, distance is used as a criterion to decide the remunerations instead of time. Detour is measured in time because the post-task questionnaires provide insights into the travel mode of occasional carriers, enabling a relatively accurate estimation of the time spent completing a delivery task.

In the experiment, three levels of remuneration were established for completing a delivery task, which includes 0.5€/km, 1€/km, and 1.5€/km. Then, it is possible to see people's choice behavior toward different pricing. To establish various parcel delivery distances, different addresses were selected as the starting and ending points for parcel delivery. As for the number of parcels, two parcels were made to two destinations from the same origin. The corresponding compensation was set at or above the level of compensation for single-package tasks within the same distance range. Finally, the consideration of parcel locker factors was incorporated by introducing parcel lockers as either the starting or ending point for parcel delivery in some of the tasks.

The crowdshipping platform called Nimber was used in this project. The tasks were created and posted on this platform, and people can download an app called "Nimber for Bringers" to search for tasks based on their preferences. Figure 3.2 shows the interface of the Nimber website (for senders) and the Nimber app (for bringers). After the tasks are posted on Nimber, users can get notifications if they save the preferred locations. The parcel locker utilized in the experiment, located at TU Delft, is provided by MyPup. Codes for opening lockers can be generated by issuing a new item in the system. Figure 3.3 shows the system that is used to manage the parcel lockers. The entire process of the experiment can be summarized as follows:

1. Prior to the experiment, the parcels are handed over to the starting points of the parcel

delivery tasks.

2. According to the plan, crowdshipping tasks are gradually posted on the platform, with approximately ten tasks scheduled per week.
3. Carrier accepts a task if agrees with the offered remuneration. Additionally, bringers have the possibility to bid for a parcel.
4. Carrier picks up the parcels at the designated points. If the origin is at the parcel lockers in TU Delft, the code for opening the locker will be sent to the carrier in the chat box on the Nimber platform. To generate the code MyPuP platform is used, as explained above.
5. Carrier delivers the parcel to the destination. If the destination is the parcel lockers located at TU Delft, the carrier will receive the code generated by MyPup platform to open the locker through the chat box on the Nimber platform.

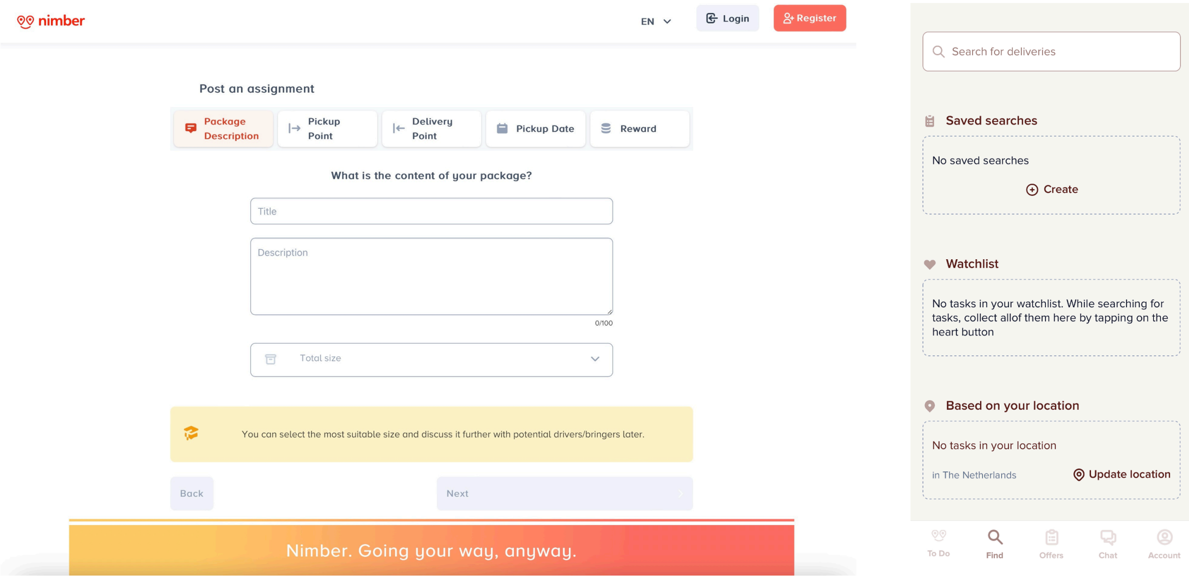


Figure 3.2: Nimber

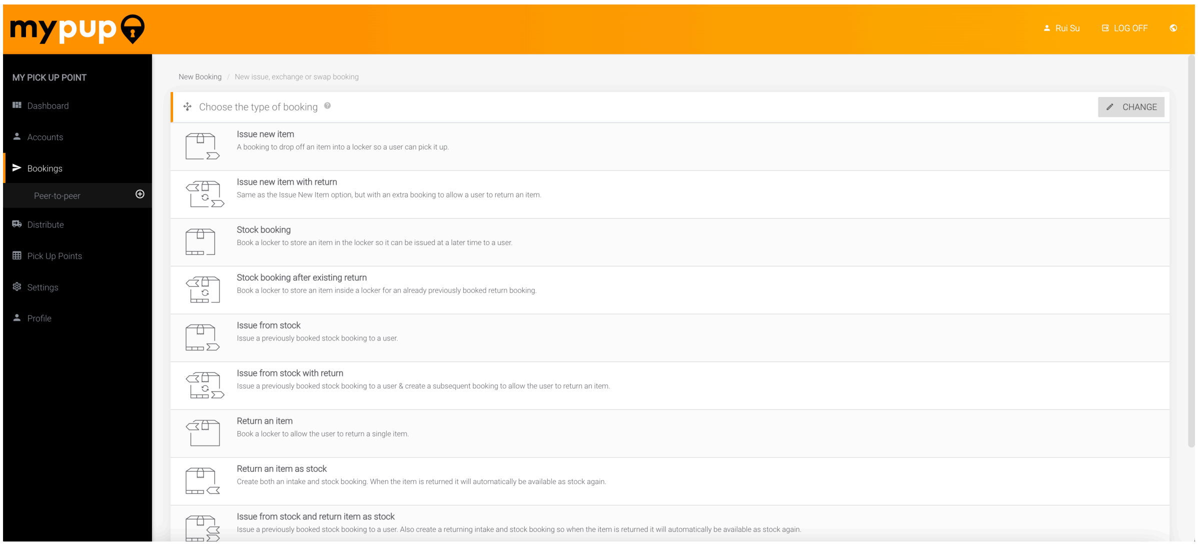


Figure 3.3: MyPup system

The experiment utilized parcels of mailbox size, as illustrated in Figure 3.4, each containing a single book. It is motivated by three main reasons. Firstly, this study focuses primarily on the transportation of small parcels. With the rapid growth of the e-commerce industry, an increasing number of people opt for online shopping. E-commerce platforms typically sell small-sized items such as clothing, shoes, electronics, and food, which are commonly shipped in the form of small parcels. Therefore, the transportation of small parcels is an integral and essential component that cannot be overlooked. Secondly, it simplifies the operational complexity of the experiment, as occasional carriers can simply drop the parcels into the corresponding mailboxes in apartment buildings without the need for practical coordination with the receivers. Reducing task complexity may potentially attract a greater number of experimental participants. Thirdly, it enables occasional carriers to conveniently carry the parcels while cycling or using public transportation, thereby minimizing potential additional emissions by using private cars. This aligns with the values advocated by crowdshipping.

Figure 3.4: Parcel utilized in the experiment

Marketing

In order to promote and encourage participation in the crowdshipping experiment, an informative flyer is designed, that contains the details of the experiment and how to participate, as shown in Appendix A. The promotional material aims to raise awareness among the target audience and provides clear instructions on how individuals can participate as carriers. The flyers were distributed in various locations, such as TU Delft campus, apartment buildings, and public spaces, where they can reach a wide range of potential participants. Unlike surveys, this experiment requires physical participation, and the selection of specific locations may exclude some potential participants. If users cannot find suitable tasks after a few attempts, they are likely to drop their usage of the platform. Therefore, marketing is a crucial step in the execution of the experiment.

3.2.3. Data Collection

In order to calculate the total delivery time and travel time, it is necessary to know the transportation modes used by carriers and carriers' trip origins and destinations. To facilitate the gathering of this information, an electronic questionnaire, shown in Appendix B, has been created and distributed to individuals who have completed parcel delivery tasks.

Based on the transportation mode and travel distance, the total delivery time and travel time were obtained through Google Maps. Total delivery time refers to the overall time it takes for the carrier to travel from the starting point of the journey to the parcel pickup location, then to the parcel delivery location, and finally to the destination point of the journey. Travel time refers to the duration it takes for a person to travel from the starting point to the destination point of a journey, without considering any additional time spent on delivering packages. It represents the time spent solely on the personal transportation aspect of the journey. After collecting this data, it comes to the data preprocessing step. Based on the results of the survey, we can obtain information about the origin and destination of the participants' trips in crowdshipping. In order to obtain data in a format where one person's choices for multiple tasks can be matched with the requirements of data processing, several assumptions were made:

- Carriers' trips occur regularly since the experiment targets individuals who frequently commute to universities.
- Carriers would frequently check for published tasks since the participants demonstrated a high level of acceptance in the post-survey.
- If an individual submits an application for a specific task, it is assumed that the individual has chosen to accept that task, even if each task can only be completed by one carrier.

Based on these assumptions, all tasks posted on the platform can be considered potential choices for each carrier. In the end, the experiment involved the participation of 7 individuals who successfully completed 11 tasks. Therefore, each carrier had 11 choices, resulting in a total of 77 choice sets.

3.3. Choice Data Combination

Due to the involvement of only 7 participants, a total of 77 observations were ultimately obtained. In order to ensure the credibility of the choice model, a stated preference (SP) experiment method was employed to continue data collection. Then, the combination of RP and SP data can be finished to perform choice model estimation. Eventually, the significant factors can be obtained from the interpretation of the model estimation result.

3.3.1. Stated Preference Data

The challenge in conducting RP experiments for crowdshipping lies in the fact that this service is a completely new concept for the public. People are often reluctant to participate in such experiments when they have little or no prior knowledge of the service. On the other hand, SP experiments can assist in collecting data more efficiently and rapidly, as they allow participants to express their preferences and choices without the need for prior real-world experience with the new concept. According to Lavasani et al. (2017), SP experiments are generally useful if there is a need to understand people's responses to new alternatives that have not yet been implemented. In the SP experiment, respondents are requested to make choices within a series of hypothetical scenarios. The data obtained from the SP experiment originated from a study conducted by Cebeci, Tapia, Nadi Najafabadi, et al. (2023). Table 3.1 displays the attributes and their corresponding levels for the SP experiment.

With this information, relevant surveys were designed, and respondents were asked to indicate their acceptance of crowdshipping tasks based on the hypothetical scenarios and provided attribute levels in the questionnaire. A total of 2400 choice sets were ultimately obtained from the SP experiment.

Table 3.1: Summary of the attributes and attribute levels for the SP (Cebeci, Tapia, Nadi Najafabadi, et al., 2023)

Attributes	Number of attribute levels	Levels
Number of Parcels (pieces)	3	1 2 3
Extra travel time (minutes/per parcel)	3	5 10 15 30 40
Delivery point	2	Parcel locker Person-to-person
Remuneration (euros/per parcel)	5	3 5 7 10 15

3.3.2. Mathematical Formulation

According to Bierlaire (1998), discrete choice models (DCMs) were deployed to analyze the decision-making of the respondents. Here, econometric modeling techniques are employed to identify the behavioral preferences of the respondents. The random utility Maximization (RUM) is adopted by DCMs (McFadden, 1974). It assumes that individuals choose the alternative i which has the highest utility (U_i) in the choice set M as shown in the equation below.

$$U_i > U_j \qquad \forall i \neq j \in M \tag{3.1}$$

The utility of alternative i evaluated by individual n can be shown as:

$$U_{in} = V_i + \varepsilon_{in} \tag{3.2}$$

Where V_i is the systematic utility of alternative i and ε_{in} is the error term that captures uncertainty in choice making. The total utility is defined as a linear additive function combined with an error term, which can be shown as:

$$U_{in} = \sum_m \beta_m x_{im} + \varepsilon_{in} \tag{3.3}$$

Where β_m stands for the coefficient of an attribute m and x_{im} is the attribute value. As mentioned in Section 3.1, the factors that are explored in this project are total delivery time, travel time, remuneration, the number of parcels and whether to use a parcel locker. For each task, the potential occasional carriers have two choices: to pick up the package or not to pick up the package. Then, the utility function for picking up and not picking up was created respectively:

$$V_{Pickup} = \beta_{tt\_trip} * TDT + \beta_{rem} * Rem + \beta_{pup} * Locker\_or\_Not + \beta_{num\_p} * (Num\_P - 1) \tag{3.4}$$

$$V_{Notpickup} = \beta_{tt\_trip} * TT + ASC\_NP \tag{3.5}$$

Where TDT, TT, Rem, Num_P, $Locker\_or\_Not$ and ASC_NP stand for the total delivery time, travel time, remuneration, number of parcels, whether to use a parcel locker or not and alternative specific constant for not picking up, respectively.

The Multinomial Logit (MNL) model is a widely used and straightforward approach for modeling discrete choices under the Random Utility Maximization (RUM) assumption. It assumes that the error terms are independent and identically distributed according to the Gumbel distribution. In this type of model, the probability of an individual n choosing alternative i is estimated by the following equation:

$$P_i = \frac{e^{V_i}}{\sum_{i=1}^{I} V_i} \tag{3.6}$$

In this study, each alternative is independent and identically distributed. Therefore, the probability of each alternative can be calculated by Equation 3.6.

3.3.3. Combination of RP and SP

RP and SP data sources have their own strengths and weaknesses, and by using both of them, we can better understand how people make choices and express their preferences (Hensher et al., 1998). In the MNL model, there is typically a single scale parameter, often denoted as λ. It is a positive real number used to adjust the scale parameter of the Gumbel distribution. The MNL model assumes that the error terms for all choices have the same scale parameter λ, meaning that the variances of error terms are equal across all choices. The scale parameter is useful in the process of merging RP and SP data. Here is a detailed description of the data merging process:

1. **Data Preparation:** Organize and prepare RP and SP data for modeling. Ensure that both datasets have a similar structure, including the same choices, attributes, and identification information.
2. **Model Estimation:** For both RP and SP datasets, estimate choice models. These models capture the relationships between attributes, choices, and preferences. The scale parameter is an essential part of these models, helping to scale the utility values.
3. **Scale Adjustment:** Adjust the scale parameter for the SP dataset, to align it with the scale of the RP dataset. This adjustment is necessary because the scale parameters may differ between the two datasets due to differences in data collection methods and response behaviors. The scale parameter is estimated using Maximum Likelihood Estimation. According to Hess & Palma (2023), the scale adjustment was performed through R (Apollo).

3.3.4. Data Analysis and Interpretation

There are multiple choices regarding the estimation of MNL models, such as R (Apollo), Python (statsmodels), Stata and MATLAB. In this study, R (Apollo) is used to estimate the MNL model. According to Hess & Palma (2023), the combination of RP and SP data was implemented. After inputting the data into the estimation tool, the model calculates the coefficients and their corresponding standard errors, t-values and p-values, which provide information about the statistical significance of each variable in the model. These coefficients represent the estimated effects of the independent variables on the choice probabilities. By analyzing these coefficients, we can understand the influence of each variable on the decision-making process and the relative importance of different factors in determining the choices made by individuals.

The interpretation of the results starts by examining the signs (+/-) of the estimated coefficients. A positive coefficient indicates a positive effect on the probability of choosing a particular alternative, while a negative coefficient indicates a negative effect. The magnitude of the coefficient represents the size of the effect. Then, it is necessary to assess the statistical significance of the estimated coefficients. The p-value associated with each coefficient indicates the probability of observing the estimated coefficient if there is no true effect in the population. Generally, coefficients with p-values less than a predefined significance level (e.g., 0.05) are considered statistically significant, indicating high confidence in the estimated effect. In order to identify the most influential factors in the choice model, compare the magnitude and statistical significance of the coefficients. Coefficients with larger magnitudes and smaller p-values generally have a stronger impact on the choice probabilities. The results of the data analysis will reveal whether the inclusion of parcel lockers has an impact on carriers' individual choice behavior.

3.4. Simulation Model

To gain a deeper understanding of the potential impact of parcel lockers on crowdshipping, this section explains how, based on the individual choice model, a simulation model was developed to simulate the choices of carriers regarding crowdshipping tasks. This enhances the comprehensiveness of the research.

3.4.1. Generation of Carriers

Based on the context of this study, carriers make their parcel delivery choices based on their existing travel plans. Therefore, it is necessary to generate starting and ending points for carriers' trips in the model. The travel routes of people are set to be random in the model. In each path, several carriers are set, and the model will output their choice behaviors. The model is run multiple times to compare the output data to ensure the reliability of the results.

3.4.2. Crowdshipping Task

To generate crowdshipping tasks, the first step is to define the starting and ending points of the tasks within the network. Then, the locations of parcel lockers need to be determined within the network. The locations of the starting point, ending point, and parcel lockers will affect the travel time for carriers, and travel time is one of the factors influencing carriers' decisions. Afterward, it's necessary to consider attribute levels that influence carriers' choice behavior, such as the level of remuneration, the number of parcels, etc. However, in this context, only the significant factors obtained from the model estimation need to be considered. The values of these attributes can directly influence the task choices made by carriers.

3.4.3. Choice Behavior of Carriers

The choice behavior of each carrier depends on the utility functions mentioned in Section 3.3.2. By setting the values of significant factors derived from the choice model estimation, the utilities for each leg in joint crowdshipping, direct crowdshipping and declining a task within a parcel delivery task can be derived. Then, it is possible to determine the corresponding probabilities for carriers to choose each alternative by Equation 3.6. The larger the probability associated with an alternative, the more likely a carrier is to select that alternative, and conversely, the smaller the probability, the less likely they are to choose that alternative. For instance, in a crowdshipping network with only one parcel locker, let's assume a carrier's probabilities for different choices are as follows:

- Probability of choosing direct crowdshipping: 0.4
- Probability of choosing joint crowdshipping on leg 1: 0.3
- Probability of choosing joint crowdshipping on leg 2: 0.2
- Probability of declining the task: 0.1

To model this behavior, you generate a random number between 0 and 1. Depending on the value of this random number, the carrier makes their choice as follows:

- If the random number is less than 0.4, the carrier chooses direct crowdshipping.
- If the random number is greater than or equal to 0.4 but less than 0.7, the carrier chooses joint crowdshipping on leg 1.
- If the random number is greater than or equal to 0.7 but less than 0.9, the carrier chooses joint crowdshipping on leg 2.
- If the random number is greater than or equal to 0.9, the carrier declines the task.

This approach simulates the probabilistic nature of the carrier's decision-making process within the crowdshipping network.

3.4.4. Key Performance Indicator

In the model, TT represents the travel time for a carrier when they do not accept a task, which is the time spent on the randomly generated route. On the other hand, TDT represents the travel time for a carrier when they accept a task. It includes the time it takes to travel from the randomly generated route's starting point to the package pickup point, then to the package delivery point, and finally back to the original route's endpoint. These values for TT and TDT are automatically calculated by the model based on the carrier's choice determined by the utility function. Detour is then computed as the difference between TDT and TT. There is an example shown in Figure 3.5.

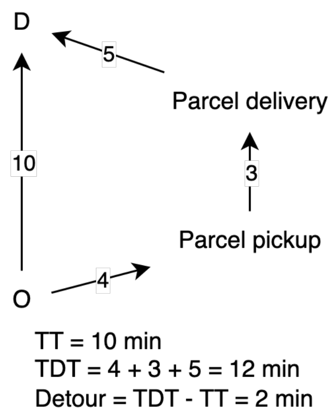


Figure 3.5: Example of detour

To compare the impact of parcel lockers on crowdshipping, the model is divided into two parts, and five Key Performance Indicators (KPIs) are presented as the output results of the model. The first part does not incorporate parcel lockers within the network. Carriers directly deliver the parcels to their destinations, which is called direct crowdshipping. There is an example shown in Figure 3.6. The KPIs without the use of parcel lockers are shown by Equations 3.7 and 3.8.

$$Acceptance\_Rate\_without\_Locker = \frac{Num\_pup\_without\_locker}{Num\_total} \times 100\% \tag{3.7}$$

$$Average\_Detour\_without\_Locker = \frac{Detour\_total\_without\_locker}{Num\_total} [min] \tag{3.8}$$

Which is valid where $Num\_pup\_without\_locker$ is the number of individuals accepting crowdshipping tasks, $Detour\_total\_without\_locker$ is all the detours generated by completing tasks and Num_total is the total number of carriers selected.

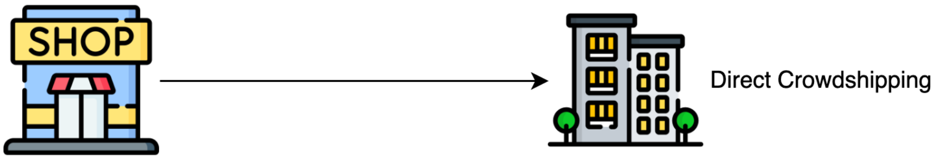


Figure 3.6: Example of direct crowdshipping

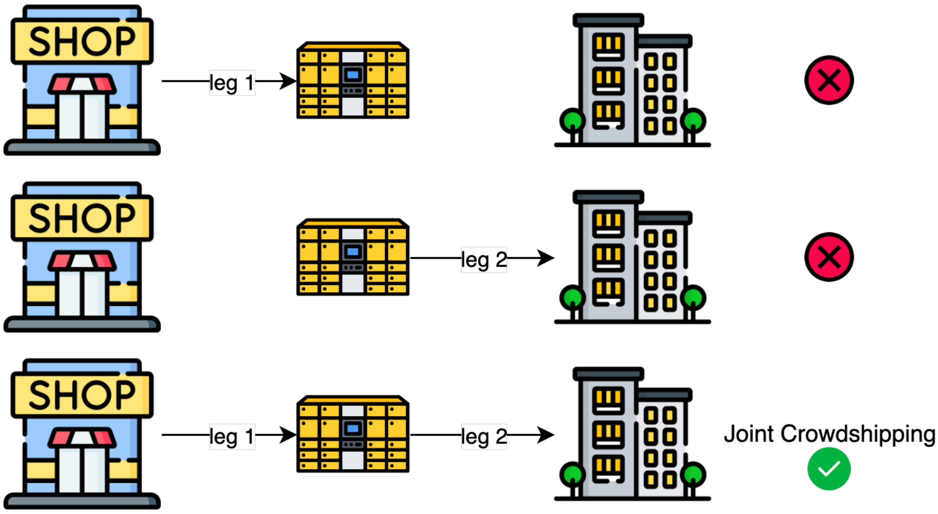


Figure 3.7: Example of joint crowdshipping

The second part involves the incorporation of a certain number of parcel lockers within the network. When two carriers are randomly selected to complete leg 1 and leg 2 with the same parcel locker as a transit point, it represents the completion of one joint crowdshipping. There is an example shown in Figure 3.7. The KPIs with the use of parcel lockers are shown by Equations 3.9, 3.10 and 3.11.

$$Acceptance\_Rate\_with\_Locker = \frac{Num\_pickup\_with\_locker}{Num\_total} \times 100\% \tag{3.9}$$

$$Average\_Detour\_with\_Locker = \frac{Detour\_total\_with\_locker}{Num\_total}[min] \tag{3.10}$$

$$Percentage\_of\_Joint\_Crowdshipping = \frac{Num\_joint}{Num\_joint + Num\_direct} \times 100\% \tag{3.11}$$

Which is valid where Num_joint is the number of joint crowdshipping, Num_direct is the number of direct crowdshipping, $Detour\_total\_with\_locker$ is all the detours generated by completing tasks and Num_total is the total number of carriers.

To gain insights into the utilization of parcel lockers within the network and assist companies offering parcel locker services in long-term planning and layout, the usage frequency of each parcel locker within the network will be recorded as part of the KPIs. The average detour will be of particular interest to both the parcel locker provider and the crowdshipping platform. This metric can provide insights into the impact of parcel lockers on detours within the crowdshipping network. The parcel locker provider aims to optimize the parcel locker network to minimize detours and increase locker utilization, thereby earning fees. The crowdshipping platform seeks effective means to reduce detours, enhance the user experience, and generate higher profits. The acceptance rate and percentage of joint crowdshipping directly reflect the impact of parcel lockers on crowdshipping and can aid both the crowdshipping platform and parcel locker provider in making relevant planning and adjustments. In addition, these KPIs serve as analysis tools for the subsequent case study.

3.5. Conclusion

The conceptual model has introduced the project framework, providing a detailed explanation for each component. Firstly, five factors were selected as research variables to serve as inputs for the choice model. Model estimation results were obtained through RP and SP data to determine the roles played by each factor in carriers' choices. P-values were used to assess whether each factor had an impact, and coefficient estimates were used to understand the direction and magnitude of significant factors' influence. Through the analysis of the choice model, we ultimately gain insights into whether the implementation of parcel lockers adds extra appeal for carriers to select crowdshipping tasks. Subsequently, the choice model serves as input for the simulation model, which determines carriers' selection behaviors within the crowdshipping network. A comparison is made between scenarios with and without parcel lockers to understand the impact of implementing parcel lockers on the crowdshipping system. By integrating the results of the choice model and simulation model, we provide a comprehensive answer to the research question of this project. This section includes the design of the RP experiment, the methods for collecting, processing, and analyzing RP data, the use of SP data for supplementation, as well as a detailed explanation of the choice model and simulation model. These elements collectively lay the theoretical foundation for the subsequent case study.

4 Case Study

In this chapter, the case study focuses on the last-mile delivery within a city. It utilizes the simulation model mentioned in Section 3.4 to analyze the impact of parcel lockers as transfer points on crowdshipping from a macro perspective. First, the case is presented, followed by the introduction of simulation scenarios. Because the results of the choice model are required as inputs for the simulation model, the analysis of choice data will be presented as the third part. At the end of this chapter, the results of the case study are discussed.

4.1. Background

According to TUD (2022), in October 2022, the total number of students at TU Delft was 27,824, which was roughly the same as the previous year's figure of 27,933. Additionally, there were 8,651 students who registered at TU Delft for the first time during that period. A large number of new students come to Delft to reside here and commence their academic life. Living in a new city often requires new household items, especially for students residing in student apartments. On the outskirts of Delft, there is an IKEA store that offers cost-effective household products for consumers. Therefore, students may be willing to visit IKEA for some of their household purchases. However, IKEA is located on the city's outskirts, and it takes a considerable amount of time to reach it by cycling or using public transportation. Alternatively, if consumers choose to shop on the IKEA e-commerce platform, they would incur a delivery fee of either 5 euros or 7 euros, and it would take at least two days to receive the ordered items. In this situation, consumers prefer a delivery method that is cheap and quick to receive their ordered goods. As the focus of this project, crowdshipping can effectively meet the consumers' needs. If there is a group of people traveling from IKEA to destinations within Delft, they can serve as carriers to deliver the goods ordered by consumers from IKEA, offering a fast and cheap way to complete the tasks.

As there is currently no large-scale operational crowdshipping platform in the Netherlands, the cooperation model between IKEA and the crowdshipping platform in this case study is based on assumptions. When consumers place an order on the IKEA website, they choose the crowdshipping option. IKEA then shares the order details with the crowdshipping platform to match it with an appropriate carrier. If the match is unsuccessful, IKEA informs the consumer via email that the order cannot be successfully delivered and suggests alternative purchase methods. If the match is successful, IKEA prepares the items in advance for pickup by the carrier. After successfully delivering the package to its destination, the carrier can receive the corresponding compensation from the crowdshipping platform. For each task, there are three options: delivering the package from IKEA to the destination, delivering it from IKEA to a specific parcel locker, and delivering it from a specific parcel locker to the destination.

For the latter two options, the task will only be initiated when both of them are accepted. In contrast, for direct delivery to the destination, the task can be initiated as soon as someone accepts it.

In this case study, the parcel delivery starting point is selected as IKEA in Delft, the delivery endpoints are five student apartment buildings scattered across different locations, and the transfer points are three parcel lockers set up by MyPup in Delft. Since this study primarily focuses on bicycle delivery mode, it utilizes the bicycle network within Delft as the main mode of transportation. The transportation network and specific locations of all these points are indicated in Figure 4.1.

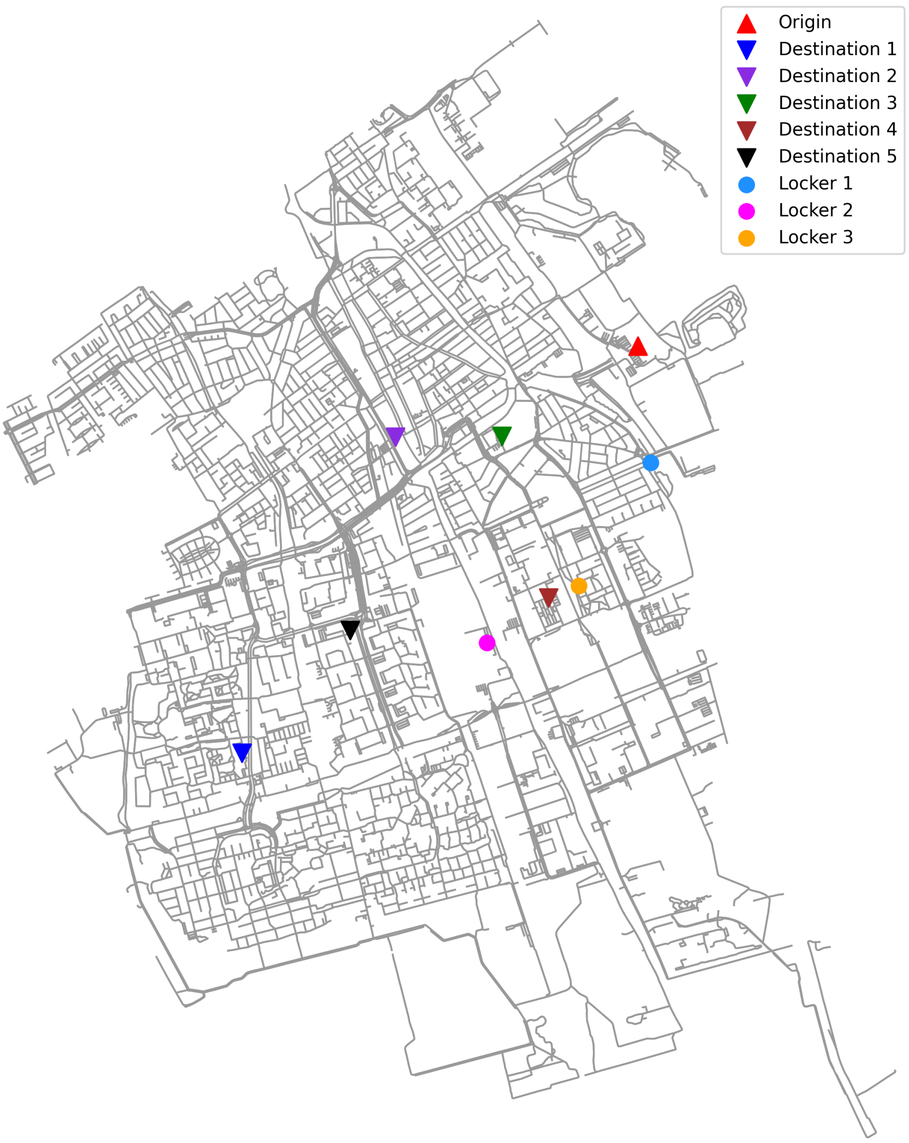


Figure 4.1: Map

It's worth noting that this project primarily focuses on the supply-side research of crowd-shipping, and variables related to the demand side are not within the scope of this study. Therefore, all subsequent analyses are approached from the perspective of carriers, and this aspect should be kept in mind.

4.2. Assumptions

Due to limitations in the model, certain assumptions were made for the simulation to simplify the complexity of real-world situations:

1. **Research Focus:** The study focuses on the supply side of crowdshipping and does not consider factors related to consumer demand. As mentioned in Section 4.1, the preconditions involve consumers choosing crowdshipping as their parcel delivery method, with a crowdshipping platform collaborating with IKEA to match carriers.
2. **Carrier Mode of Transportation:** All carriers are assumed to use bicycles as their mode of transportation for simplicity.
3. **Generation of Routes:** The carriers' original routes are randomly generated within the research area's network.
4. **Task Completion:** Carriers commence parcel delivery promptly upon task acceptance and invariably achieve successful completion. In addition, consider only single-package delivery to the same destination, excluding scenarios involving multiple packages transported to different destinations.
5. **Route Selection:** Between two points, carriers choose the shortest path.
6. **Bidding:** For some existing crowdshipping platforms, such as Nimber, there is a bidding process. However, in the simulation, there is no bidding process. Once the remuneration is set, carriers can only choose to accept or decline the task, and there is no provision for making new bids.

These assumptions were necessary to simplify the model and make it feasible for the case study. However, it's important to acknowledge that they may not fully represent real-world conditions. Therefore, further research should be conducted in the future to investigate these unconsidered aspects.

4.3. Alternatives

This utility function in the simulation model determines the behavior choices of carriers. For each carrier, there are three choices when it comes to parcel delivery:

1. Directly delivering the parcel from the starting point to the destination without using a parcel locker (Direct crowdshipping).
2. Using a parcel locker to deliver the parcel from the starting point to the locker (leg1) or from the locker to the destination (leg2). When both leg1 and leg2 are completed, it is referred to as a "joint crowdshipping".
3. Rejecting the task and not accepting it.

In this case, there are three parcel lockers, and carriers can freely choose from these three lockers. Therefore, for each carrier, it is necessary to calculate the utility associated with leg1 and leg2 for each of the three parcel lockers, in addition to considering direct delivery and rejecting the task. This results in a total of eight possible choices, which is shown in Figure 4.2. Then, the total utility is computed for each of these choices, followed by calculating their respective probabilities. A higher probability indicates a greater likelihood that the carrier will opt for a specific choice, and Section 3.4.3 provides a detailed demonstration of how the simulation model obtains the final choice outcome for each carrier.

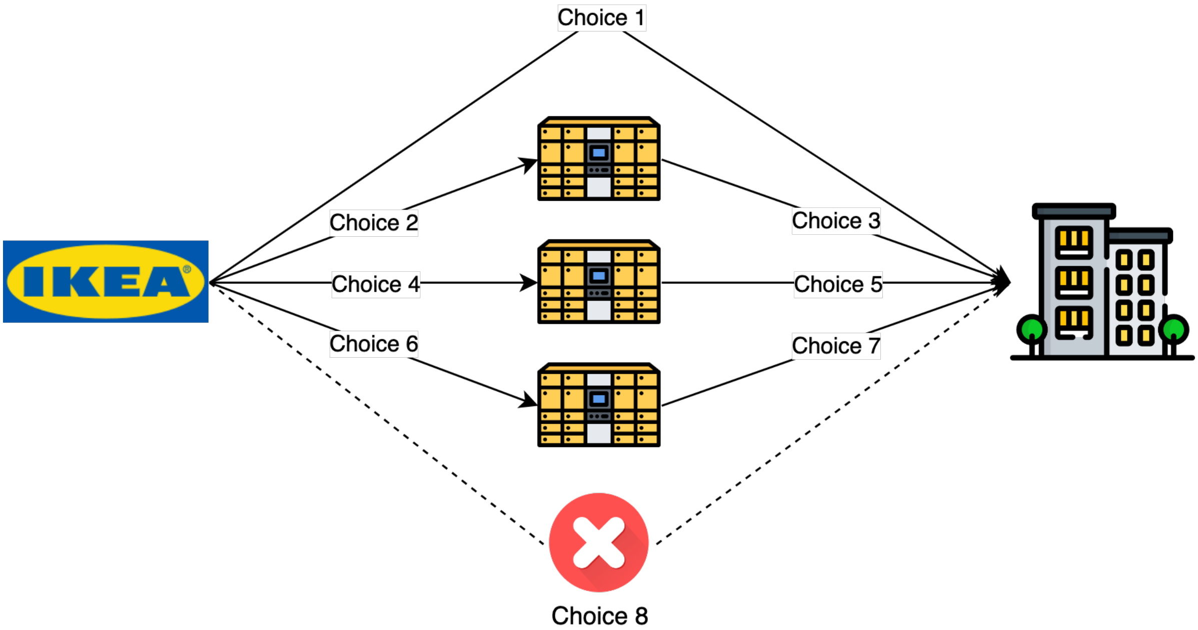


Figure 4.2: Alternatives

4.4. Operational Procedures

The script for the simulation model is shown in Appendix D. Before commencing scenario setup, it is essential to make adjustments and confirm certain parameters within the model. The specific utility function, represented by Equations 4.1 and 4.2, should be incorporated into the model. Subsequently, the value for 'remuneration' needs to be specified, with its determination explained in the subsequent scenario analysis. According to Satrio Wicaksono (2018), the number of commuting trips within Delft was estimated at 22,723 in 2017. Due to the presence of an error term in the choice model, carriers' choices for each alternative are probabilistic. To make the simulation results more representative, 23 carriers were set on each randomly generated route, and a total of 1000 routes were randomly generated within the actual Delft transportation network. This approach ensures that 23,000 commuting trips are met in the simulation. Eventually, the output KPI data was used for a detailed analysis of the case. It is noteworthy that the output of KPIs for crowdshipping without lockers and crowdshipping with lockers is based on the same set of carriers. The calculation methods of the KPIs are mentioned in Section 3.4.4.

4.5. Results

In this section, the results of the choice model and simulation model were given as well as the results analysis. For the simulation, two scenarios were configured, including a testing of destination location and remuneration. The content of the following sections gave specific explanations.

4.5.1. Choice Model Estimation

Before commencing the collection of simulation data, it is essential to validate the carrier's choice model. This involves fitting the obtained choice data from experiments to the proposed utility mathematical model to identify significant factors affecting carriers' task selection and their corresponding parameter values. This quantifies the influence of each factor on the choice and serves as input for the simulation model, enabling the research to proceed with simulations.

According to Hess & Palma (2023), the combination of SP data and RP data was finished. The script for model estimation is shown in Appendix C, and the result is shown in Table 4.1.

Table 4.1: Model estimation

Model Estimation		
Coefficients	Est.	p-value
β_{tt_trip}	-0.17631	0.0002*
β_{rem}	0.96582	0.0004*
β_{num_p}	-0.42040	0.3551
β_{pup}	1.43706	0.1684
ASC_NP	4.72156	0.0902
Data Source		
Indicators	Value	
Number of choice sets	2477	
RP Observations	77	
SP Observations	2400	

*Significance level on 95% confidence interval
"ASC" stands for Alternative Specific Constant

Based on the results of model estimation, it is evident that travel time, total delivery time, and remuneration are significant factors that influence carriers' choices. On the other hand, parcel quantity, whether to use parcel lockers and ASC_{NP} (Alternative Specific Constant for Not Picking up) are insignificant factors, indicating that carriers do not take these factors into consideration when making task selections. The estimated coefficient values reveal that remuneration has a positive effect on carriers' acceptance of tasks, while travel time and total delivery time have a negative impact on their decision to accept tasks. Finally, the utility function can be expressed as follows:

$$V_{Pickup} = -0.17631 * TDT + 0.96582 * Rem \tag{4.1}$$

$$V_{Notpickup} = -0.17631 * TT \tag{4.2}$$

Where TDT, TT and Rem stand for the total delivery time, travel time and Remuneration. In this scenario, it is assumed that all carriers use bicycles as their mode of transportation. Therefore, the time can be calculated by dividing the distance between two locations by the average bicycle speed of 4.2 m/s.

The VoT values provide insights into the trade-off between time and money for individuals participating in crowdshipping. It helps to understand the economic incentives and motivations for users to engage in these activities. The VoT represents the monetary value that individuals place on their time. The VoT value is calculated by Equation 4.3. The calculated result is 11 €/h, which means that the carrier should be compensated with 11 euros to offset the additional one hour of time spent on delivering the parcel.

$$\frac{-\beta_{tt_{trip}}[1/min]}{\beta_{rem}[1/euro]} * 60[h/min] \tag{4.3}$$

4.5.2. Scenario 1: Destination Location

In Scenario 1, we keep the value of remuneration fixed and conduct experiments by selecting different destination locations. In 2021, the average price of parcel delivery in the business-to-consumer market was €3,66 in the Netherlands (Markt, 2021). Upon querying IKEA's online store, it was found that there are two delivery services available for the shipment of small items to Delft, both managed by PostNL. One is the standard express delivery service, incurring an additional cost of €5, with delivery scheduled for the third day following the order placement. The other option is the evening express delivery service, requiring an extra expenditure of €7, and with delivery set for the evening of the second day after the order is placed. Combining these two pieces of information, in Scenario 1, remuneration is set at €4. The remuneration of 4 euros is awarded for completing the delivery from IKEA to the student apartment building. The remuneration related to deliveries from IKEA to the parcel locker and from the parcel locker to IKEA is divided proportionally based on the respective distances, calculated according to Equation 4.4 and 4.5.

$$Rem\_leg1 = \frac{Distance\_leg1}{Distance\_leg1 + Distance\_leg2} Rem\_total[euro] \tag{4.4}$$

$$Rem\_leg2 = \frac{Distance\_leg2}{Distance\_leg1 + Distance\_leg2} Rem\_total[euro] \tag{4.5}$$

Which is valid where Rem_leg1 is the remuneration for the first leg of joint crowdshipping, Rem_leg2 is the remuneration for the second leg of joint crowdshipping, $Distance\_leg1$ is the distance from IKEA to the parcel locker, $Distance\_leg2$ is the distance from the parcel locker to the student apartment building and Rem_total is the total remuneration from IKEA to the student apartment building, which is €4. The remuneration for leg1 and leg2 is calculated automatically by the model.

For the convenience of subsequent analysis, the distances between IKEA, the five student apartment buildings, and the three parcel lockers have all been computed. The distances are presented in Table 4.2, and the location numbers are shown in Figure 4.1.

Table 4.2: Distances

[meter]	**IKEA**	**Locker 1**	**Locker 2**	**Locker 3**
IKEA		1151	2898	2163
Destination 1	4487	4064	2675	3503
Destination 2	2451	2348	1628	2167
Destination 3	1536	1119	1667	1224
Destination 4	2419	1501	1718	481
Destination 5	3208	2696	1692	2231

The output results for the crowdshipping network without parcel lockers as transfer points are displayed in Table E.1. Meanwhile, Figure E.1 provides a more visual representation of the results. From the figure, it is evident that there are five destinations, each of which can be considered as a scenario. The same 23,000 carriers have to make choices in each scenario, and the choice results have been labeled in the figure. Based on the choice results, the acceptance rate of the crowdshipping task for each destination can be calculated using Equation 3.7. The acceptance rate reflects the proportion of the 23,000 carriers who choose to accept tasks. The initial challenge for the successful operation of a crowdshipping service is ensuring an adequate supply, and the acceptance rate precisely reflects carrier participation willingness, providing valuable reference data for IKEA and the crowdshipping platform.

According to Assumption 4, if a carrier accepts a task, the task will definitely be completed. Therefore, the number of fulfilled tasks is equal to the number of carriers who accepted the tasks. In addition, the average detour calculated using Equation 3.8 represents the average extra time spent by the 23,000 carriers when they choose to accept tasks.

The output results for the crowdshipping network with parcel lockers as transfer points are displayed in Table E.2, and Figure E.3 provides a visual description of the results. From the graph, it is evident that each destination can be considered as a scenario, and the same set of 23,000 carriers has to make choices within each of these scenarios. Compared to direct crowdshipping, joint crowdshipping offers three parcel lockers, providing carriers with more options to participate in crowdshipping. Similar to the analysis of the crowdshipping network without parcel lockers, acceptance rate and average detour were also used in the analysis of the crowdshipping network with parcel lockers as transfer points. Equations 3.9 and 3.10 show the calculation method. Due to the requirement of two carriers to complete two corresponding sub-tasks in joint crowdshipping, for the crowdshipping network with parcel lockers, the number of fulfilled tasks is no longer equal to the number of carriers who accepted the tasks. Instead, it can be represented by Equation 4.6. In addition, to understand the proportion of joint delivery among all completed tasks, the percentage of joint crowdshipping is calculated based on Equation 3.9.

$$Fulfilled\_tasks\_with\_lockers = Num\_direct + \sum_{i}^{3} min(Num_{lockeri}leg1 + Num_{lockeri}leg2) \quad (4.6)$$

Which is valid where Num_direct is the number of carriers who accepted direct crowdshipping tasks, $Num_{lockeri}leg1$ is the number of carriers who accepted the leg 1 task for locker i and $Num_{lockeri}leg1$ is the number of carriers who accepted the leg 2 task for locker i.

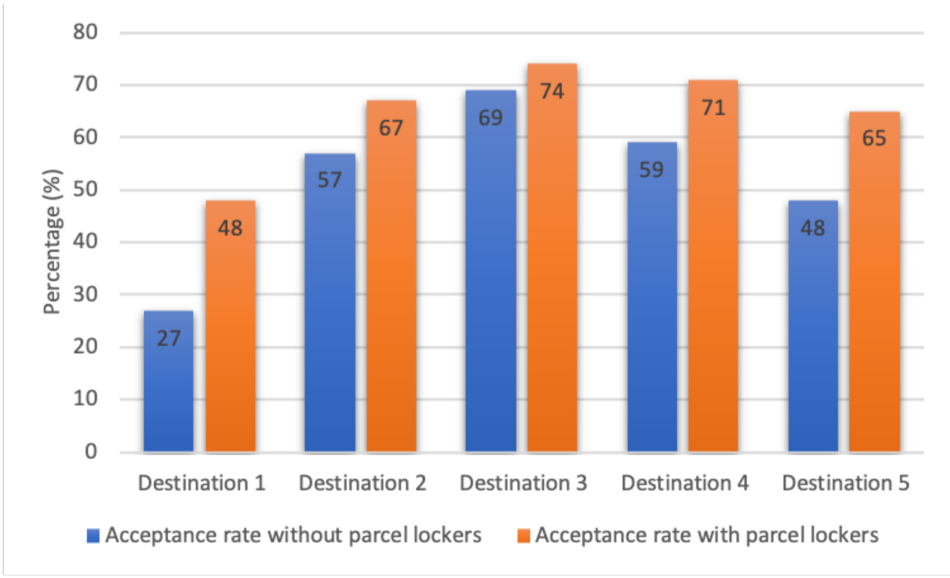


Figure 4.3: Acceptance rate with and without lockers

Firstly, the 'acceptance rate with lockers' and 'acceptance rate without lockers' are displayed in Figure 4.3. Based on the figure, it can be observed that the acceptance rate with parcel lockers for each location is consistently higher than the acceptance rate without parcel lockers. This suggests that the utilization of parcel lockers has indeed increased the number of carriers who accept the crowdshipping tasks, with the most significant improvement seen for Destination 1 and the smallest for Destination 3. Additionally, according to Table 4.2, the distance from IKEA to Destination 3 is the longest, while the distance to Destination 1 is the shortest. For destinations farther away, it is more likely that the use of parcel lockers as transfer points can enhance the system's acceptance rate.

Secondly, Tables 4.3 and 4.4 respectively display the task completion status for crowdshipping with and without the presence of parcel lockers. It is evident that joint crowdshipping attracts more participants to engage in parcel transportation while it also leads to some carriers who originally chose direct crowdshipping to switch to joint crowdshipping. However, except for Destination 1, the number of fulfilled tasks in the crowdshipping network without parcel lockers for all other destinations is higher than that in the crowdshipping network with parcel lockers. There are primarily two reasons for this phenomenon. First, carriers who were initially willing to accept direct crowdshipping tasks may switch to joint crowdshipping after its adoption, leading to a decrease in overall efficiency as joint crowdshipping requires two carriers to complete a task. Second, this study's compensation principle for joint crowdshipping is based on the length of the two legs' routes to allocate the total remuneration for the task. This approach may not achieve the best balance in task completion between the two legs, thus affecting the completion of joint crowdshipping tasks.

Table 4.3: Task fulfillment status in the crowdshipping network without parcel lockers

Destination	Fulfilled	Non-acceptance
1	6165	16835
2	13178	9822
3	15757	7243
4	13593	9407
5	11017	11983

Table 4.4: Task fulfillment status in the crowdshipping network with parcel lockers

Destination	Fulfilled direct crowdshipping	Fulfilled joint crowdshipping				Fulfilled in total	Non-acceptance
		Locker 1	Locker 2	Locker 3	Total		
1	3979	1104	1104	1081	3289	7268	11845
2	8878	621	1104	782	2507	11385	7590
3	11500	690	782	460	1932	13432	5934
4	8441	322	0	368	690	9131	6670
5	6992	1104	851	943	2898	9890	8073

The percentage of joint crowdshipping for the five destinations is depicted in Figure 4.4. For Destinations 1, 2, and 5, the percentage of joint crowdshipping is all above 20%, with Destination 1 having the highest value at 45%. Following that is Destination 5, with a percentage of 29%. Considering Table 4.2, the three destinations with longer transport distances correspond to Destinations 1, 2, and 5. From this, we can conclude that for crowdshipping tasks with longer transport distances, the proportion of joint crowdshipping is more likely to be higher. In addition, the average detour by carriers, which reflects the performance of the crowdshipping network, is presented in Figure 4.5. Based on the results from the graph, it is evident that after the application of parcel lockers, the average detour to all destinations has decreased, with a reduction in travel time ranging from 1 to 5 minutes. Since the detour is calculated based on individual carriers, the reduction in detours pertains to a single transportation task for a carrier. For joint crowdshipping, which requires two transportation tasks to connect, the total detour is indeed increased compared to direct crowdshipping. Consequently, consumers theoretically have to wait longer to receive their packages. Overall, while the application of parcel lockers has brought about a reduction in the additional time spent by carriers to some extent, the decrease in travel time for individual journeys has not reduced the overall time it takes to transport parcels from IKEA to the student apartments. Therefore, in this scenario, consumers do not seem to benefit from the application of parcel lockers in terms of time costs.

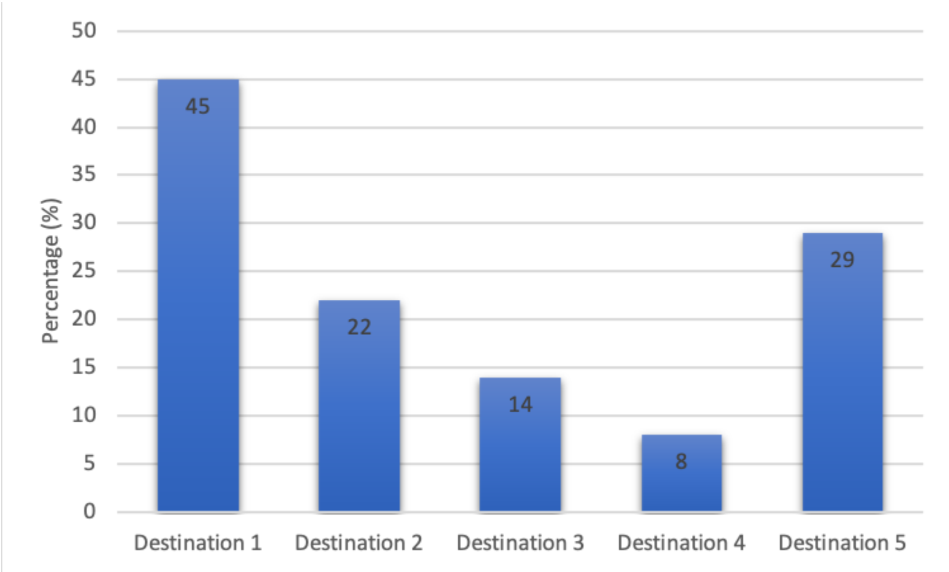


Figure 4.4: Percentage of joint delivery

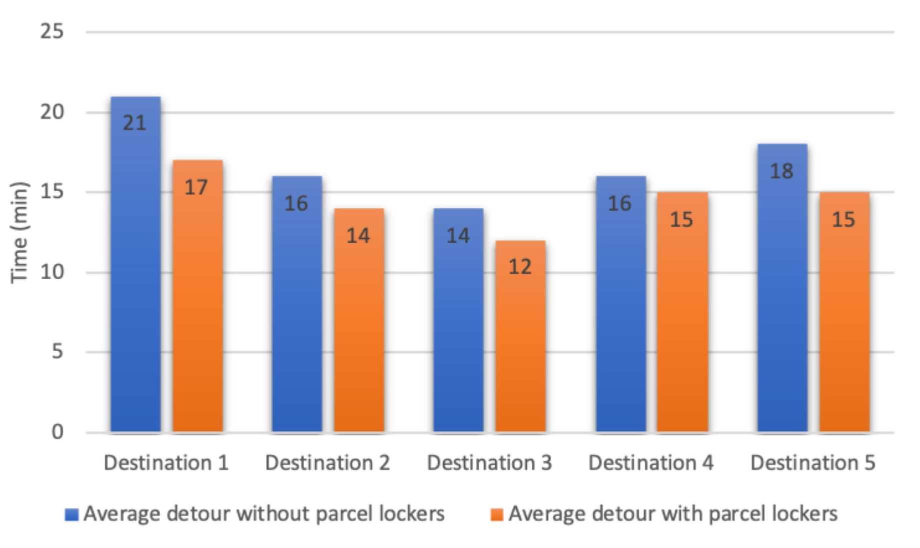


Figure 4.5: Average detour with and without parcel lockers

Finally, Table 4.5 displays the successful utilization of the three parcel lockers in this scenario. Based on the total usage counts of the parcel lockers, the three parcel lockers are used roughly equally in terms of frequency, which means that each parcel locker in this case study has provided a similar level of service for the five destinations. According to Table E.2, the number of completed joint crowdshipping tasks also reflects the usage of parcel lockers in crowdshipping. It can be observed that parcel lockers provide significant support in crowdshipping.

Table 4.5: Utilization of the parcel lockers

	Destination 1	Destination 2	Destination 3	Destination 4	Destination 5	Total
Locker 1	1104	621	690	322	1104	3841
Locker 2	1104	1104	782	0	851	3841
Locker 3	1081	782	460	368	943	3634

4.5.3. Scenario 2: Remuneration

In this scenario, the primary focus is to investigate how remuneration, as a variable, influences the role of parcel lockers in crowdshipping. Hence, the values of remuneration are set to 0, 2, 4 and 6, and data processing and analysis were conducted for each destination to obtain more representative conclusions. The remunerations for leg 1 and leg 2 of the joint crowdshipping have been already mentioned by Equations 4.4 and 4.5.

Firstly, the changes in the number of fulfilled tasks in the network with and without parcel lockers as remuneration varies for each destination are presented. As shown in Table 4.6 and 4.7, for most destinations, at a remuneration of €0 and €2, the number of fulfilled tasks with parcel lockers is higher than that without parcel lockers. With the increase in remuneration, both the number of fulfilled tasks with parcel lockers and the fulfilled tasks without parcel lockers are growing. However, the number of fulfilled tasks without parcel lockers surpasses the one with parcel lockers when the remuneration is €4. This result is entirely reasonable. The increase in remuneration stimulates carriers to accept parcel delivery tasks, whether with or without parcel lockers. However, in the case of parcel lockers, the growth in task completion is constrained to some extent due to the characteristic of joint crowdshipping requiring two carriers to complete, ultimately resulting in a lower number of fulfilled tasks compared to the scenario without parcel lockers.

Table 4.6: Number of fulfilled tasks in the network without parcel lockers

Destination	Fulfilled (€0)	Fulfilled (€2)	Fulfilled (€4)	Fulfilled (€6)
1	458	2530	6165	13340
2	1127	5521	13178	19778
3	1748	7820	15757	20705
4	1382	5752	13593	19783
5	921	4372	11017	18625

Table 4.7: Number of fulfilled tasks in the network with parcel lockers

Remuneration = €0			
Destination	Fulfilled direct crowdshipping	Fulfilled joint crowdshipping	Fulfilled in total
1	299	575	874
2	1127	966	2093
3	1403	1633	3036
4	736	529	1265
5	690	943	1633

Remuneration = €2			
Destination	Fulfilled direct crowdshipping	Fulfilled joint crowdshipping	Fulfilled in total
1	1012	2024	3036
2	3887	2415	6302
3	4715	2415	7130
4	3519	2990	6509
5	2484	2208	4692

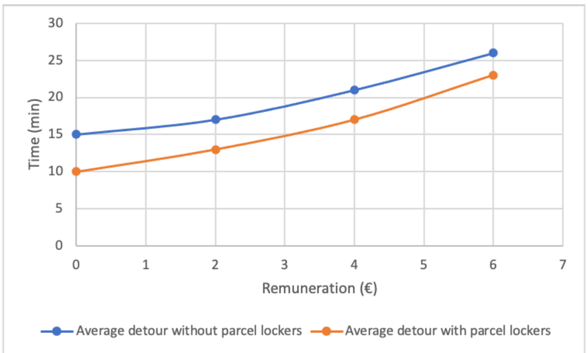
Remuneration = €4			
Destination	Fulfilled direct crowdshipping	Fulfilled joint crowdshipping	Fulfilled in total
1	3979	3289	7268
2	8878	2507	11385
3	11500	1932	13432
4	8441	690	9131
5	6992	2898	9890

Remuneration = €6			
Destination	Fulfilled direct crowdshipping	Fulfilled joint crowdshipping	Fulfilled in total
1	8556	3289	11845
2	14927	1265	16192
3	17894	1127	19021
4	12627	0	12627
5	12834	1610	14444

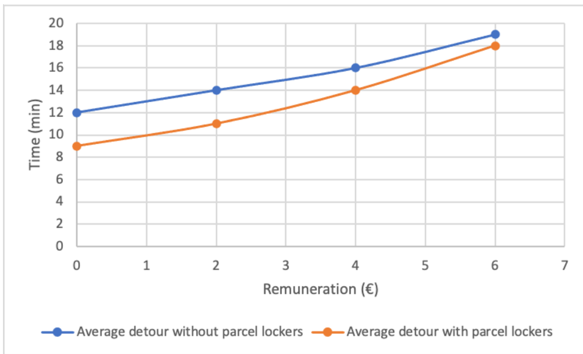
Next, the curves depicting the changes in average detour with parcel lockers and average detour without parcel lockers for the five destinations as remuneration varies are presented. As shown in Figure 4.6, when remuneration increases, the average detour for carriers also increases, regardless of the presence of parcel lockers. This indicates that when carriers receive higher compensation, they are willing to spend more additional time on parcel delivery. When comparing the average detour without parcel lockers to the average detour with parcel lockers, it can be observed that the detour generated in the crowdshipping system with parcel lockers is lower than that without parcel lockers. When remuneration is low, carriers are not inclined to spend excessive additional time to complete delivery tasks. The application of parcel lockers allows tasks to no longer be limited to a single starting point and a single destination, making it more likely for carriers to complete tasks with lower detours, thus effectively reducing the detour compared to the scenario without parcel lockers. However, As remuneration increases, the effectiveness of parcel lockers in reducing detours gradually diminishes. When remuneration is high, carriers are willing to accept higher detours. Even in a system with parcel lockers, many carriers are willing to invest more additional time to complete tasks, thereby diminishing the advantage of parcel lockers in reducing detours. Eventually, the performance of the system with parcel lockers in terms of average detour becomes close to that of the system without parcel lockers.

Lastly, based on Figure 4.7, we can observe the trend of the percentage of joint delivery as remuneration increases. As remuneration increases, apart from a slight increase occurring on Destinations 1 and 4, the percentage of joint crowdshipping for the other destinations gradually decreases, indicating a growing proportion of direct crowdshipping. Furthermore, combining the information from Figure 4.8 allows us to summarize the changes in carriers' flow. When remuneration is low, the acceptance rate with parcel lockers is higher than that without parcel lockers, indicating that the application of parcel lockers attracts more carriers.

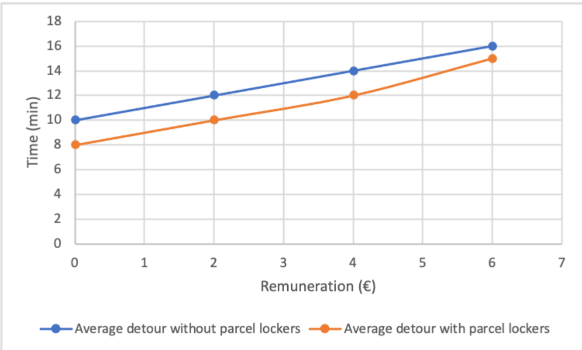
At the same time, the percentage of joint crowdshipping is high, ranging from 30% to 70% when the remuneration is €2. This suggests that in the absence of a parcel locker, some carriers who accept tasks are willing to use parcel lockers after the introduction of parcel lockers. However, from Figure 4.8, it can be observed that the acceptance rate without parcel lockers gradually catches up to that with parcel lockers. This suggests that carriers are gradually shifting towards direct crowdshipping.



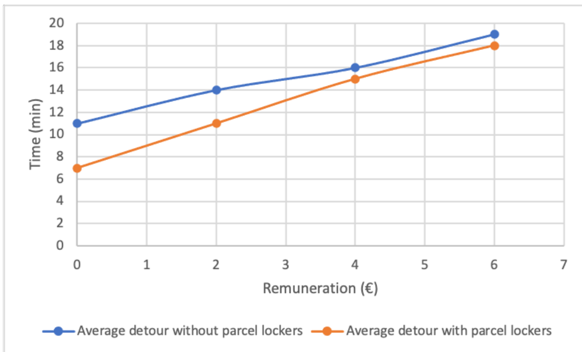
(a) Destination 1



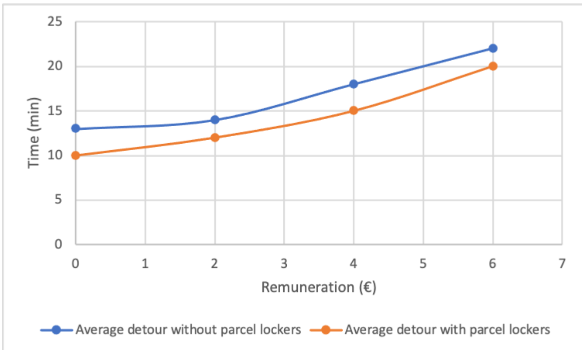
(b) Destination 2



(c) Destination 3

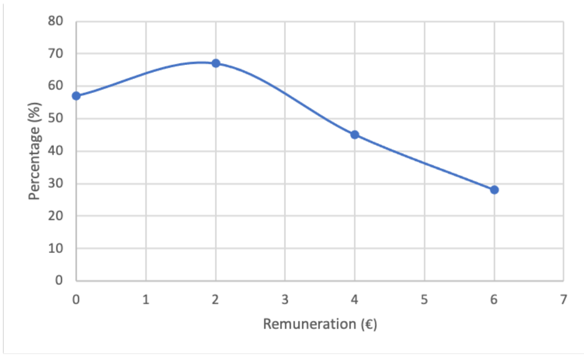


(d) Destination 4

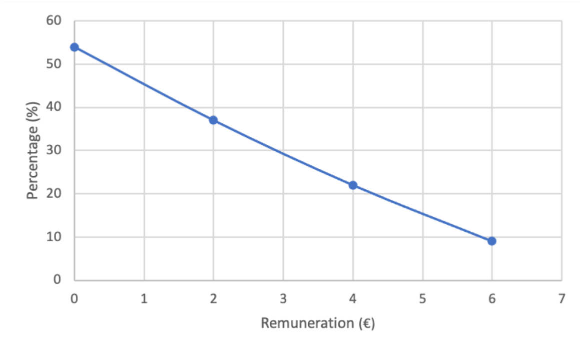


(e) Destination 5

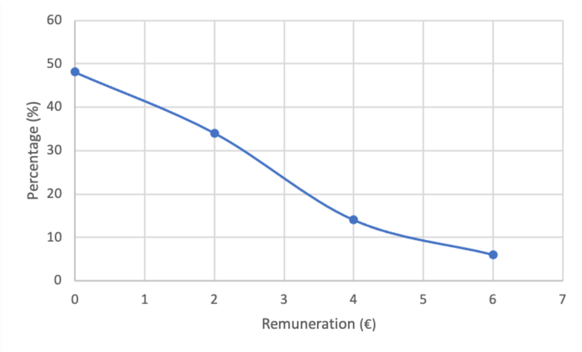
Figure 4.6: Average detour with and without parcel lockers



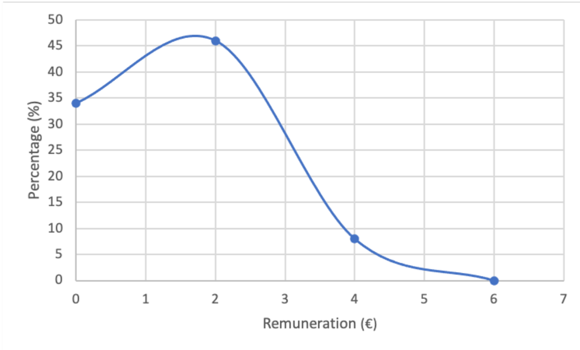
(a) Destination 1



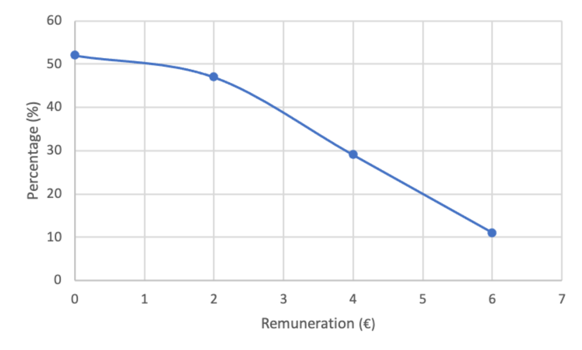
(b) Destination 2



(c) Destination 3

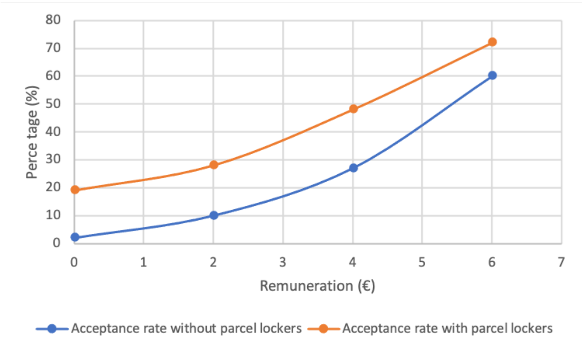


(d) Destination 4

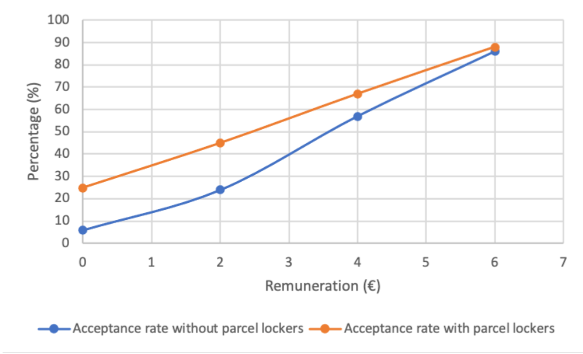


(e) Destination 5

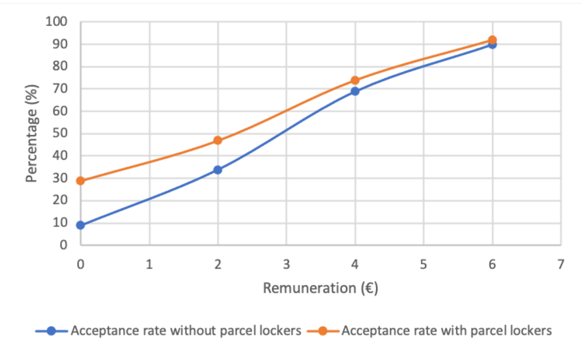
Figure 4.7: Percentage of joint crowdshipping



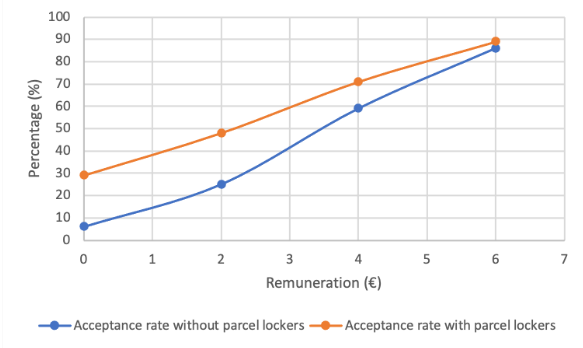
(a) Destination 1



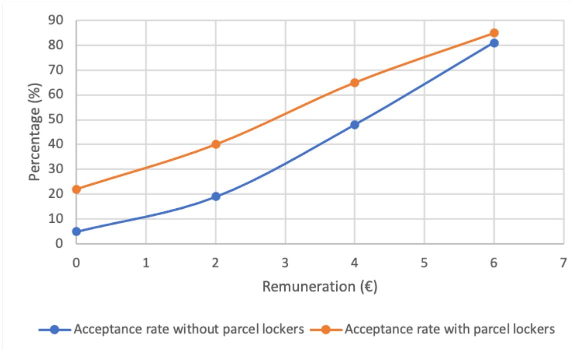
(b) Destination 2



(c) Destination 3



(d) Destination 4



(e) Destination 5

Figure 4.8: Acceptance rate with and without parcel lockers

4.6. Conclusion

This chapter primarily introduced the background of the case analysis, presented the results of the choice model, as inputs for simulation, and established two scenario analyses, utilizing destination location and remuneration as variables. Through an analysis of the output by the model, the impact of parcel lockers on crowdshipping systems was elucidated, along with corresponding explanations. Finally, this chapter solves research sub-questions 2 and 3.

Firstly, the estimation results of the choice model indicate that only travel time, total delivery time, and remuneration are the significant factors influencing carriers' choice behavior. Therefore, at the individual level, carriers are primarily concerned with the amount of compensation they receive and the extra time they need to spend on parcel transportation. The parcel lockers themselves do not provide any additional appeal to carriers. In addition, the computed VoT is €11 per hour, meaning that carriers are willing to spend an additional hour on parcel delivery for compensation of 11 euros. Since crowdshipping has no precedent in the Netherlands, and this study serves as a pilot study for crowdshipping with a small number of participants who lack experience, the reliability of this VoT needs further validation. If crowdshipping can encompass a sufficiently broad pool of carriers, it would be possible to find carriers with lower detours for each parcel transportation task, for example, keeping the detour within twenty minutes. In this case, if we exclude the platform service fee, the price would be slightly lower than the average price of traditional courier services, which is €3.66. It would be competitively priced, especially for intracity parcel transportation needs. Crowdshipping would be a good choice for meeting local delivery demands while ensuring both speed and reasonable pricing.

Then, for the scenario analysis, two scenarios were established. The first one tested different destination locations, with remuneration set at 4 euros. The second scenario varied remuneration, with values of 0, 2, 4 and 6, and the results for each location were observed to derive more general patterns. For the first scenario, acceptance rates for tasks to all destinations, except Destination 1, exceeded 50%, and the application of parcel lockers attracted more carriers. However, except for Destination 1, the number of fulfilled tasks in the crowdshipping network without parcel lockers for all other destinations is higher than that in the crowdshipping network with parcel lockers. This is primarily due to the requirement that both legs of the joint crowdshipping, pertaining to the same parcel locker, must be completed. Any imbalance between leg1 and leg2 results in a lower number of fulfilled tasks. In terms of the average detour, the application of parcel lockers slightly reduced the additional time spent by carriers on parcel transportation. Looking at the percentage of joint crowdshipping, the values varied for different destinations, but parcel lockers indeed influence the flow of carriers. Finally, examining the usage of the three parcel lockers, each parcel locker in this case study has provided a similar level of service for the five destinations. It can be observed that parcel lockers provide significant support in crowdshipping.

For the second scenario, as remuneration increases, both systems, with and without parcel lockers, experience growth in acceptance rates, the number of fulfilled tasks, an increase in average detour, and a general decrease in the percentage of joint crowdshipping. The increase in remuneration gradually shifts carriers towards direct crowdshipping, diminishing the advantage of using parcel lockers as transfer points in crowdshipping in terms of detour and the number of fulfilled tasks. Hence, parcel lockers play a more significant role in a crowdshipping system when offering lower remuneration.

5 Conclusion and Recommendation

5.1. Conclusion

This chapter summarizes all the conclusions drawn in this study and addresses the research questions posed in Section 1.4. The main issue addressed in this study is the impact of parcel lockers on crowdshipping. First, the research sub-questions are discussed, and finally, the main question is answered.

RQ1: What are the attributes affecting willingness to become carriers?

Based on the literature review, it can be concluded that the factors influencing carrier choices mainly include remuneration, total travel time, parcel characteristics, whether to use a parcel locker or not, and some platform-related factors such as delivery booking and bank credit mode. Additionally, carriers may have preferences for not accepting tasks. Among these factors, remuneration and total travel time are the two factors that were most frequently studied. Remuneration has a positive impact on carriers' task selection behavior, while an increase in total travel time leads to a decrease in carriers' willingness to transport parcels. Additionally, parcel characteristics such as weight, size, and quantity also influence carriers' behavior. The choice of transportation mode can be affected by these factors, leading to varying degrees of impact.

Due to the limited functionality of the crowdshipping platform used in the experiment, it was not possible to test platform-related factors. Regarding the parcel-related factors, in order to make crowdshipping tasks more convenient to complete and attract more participants to the experiment, limitations were imposed on parcel size and weight. The parcel size was set to mailbox size, and the content of the parcels was limited to a book. Therefore, this experiment did not include the impact of parcel weight and size on carriers as part of the investigation. Based on these considerations, the final selection of research variables includes remuneration, parcel quantity, total delivery time and travel time. Data was collected through a combination of a pilot study and a questionnaire to analyze the extent to which each of these factors influences carriers' willingness to deliver packages.

RQ2: How do parcel lockers as a transfer point influence willingness to become carriers?

By collecting, merging, processing, and analyzing the data, we have determined that remuneration, travel time, and total delivery time are significant factors, while ASC for not picking up, parcel quantity, and whether to use a parcel locker or not do not influence carriers' choice behavior. From this result, it appears that the application of parcel lockers does not provide additional utility for carriers to accept tasks. This means that from an individual choice perspective, parcel lockers do not influence crowdshipping. Carriers are more concerned with the earnings they can gain from completing tasks and the extra time they need to spend. If the application of parcel lockers can help carriers reduce detours while earning the same fees, it can have an impact on the crowdshipping system. This aspect will be explained in more detail in the next research question. Based on the estimated coefficients, the utility functions can be obtained as follows:

$$V_{Pickup} = -0.17631 * TDT + 0.96582 * Rem \quad (5.1)$$

$$V_{Notpickup} = -0.17631 * TT \quad (5.2)$$

Where TDT, TT and Rem stand for the total delivery time, travel time and Remuneration.

Based on the estimated coefficient values for time and cost, the VoT is calculated to be 11 €/hour. This indicates that carriers are willing to accept compensation of €11 for each additional hour they spend on parcel delivery. Currently, the average price of traditional courier services is €3.66 (Markt, 2021). To make crowdshipping competitive, it would be desirable to keep the carriers' detours to around 20 minutes or less. This could be more achievable for urban parcel deliveries where the distances are shorter, and crowdshipping can offer a cost-effective and timely alternative to customers.

RQ3: What is the potential impact of parcel lockers on crowdshipping from the supply side in an urban area?

To further investigate the impact of parcel lockers on the crowdshipping system, a detailed case study of Delft was conducted using a simulation method. This study primarily focuses on the supply side of crowdshipping. In the simulation, utility functions generated by the choice model were used to model carriers' behavior. According to Satrio Wicaksono (2018), the number of commuting trips within Delft was estimated at 22,723 in 2017. To simulate 23,000 carriers, 1,000 routes were randomly generated within the Delft network, and 23 carriers were placed on each route. Different scenarios were established to compare the impact of parcel lockers on crowdshipping. This study includes a total of five KPIs, and these KPIs are used for the analysis of the results. In the case analysis, IKEA serves as the origin point for tasks, and there are five student apartments as the destination points. Three parcel lockers established by MyPup in Delft act as intermediate points for tasks, and two scenarios are established. In each scenario, each simulation only includes one type of task, specifically for a particular destination, and the results are subsequently analyzed.

Firstly, with a fixed remuneration of €4, the study explores how different task destinations affect the crowdshipping system with and without parcel lockers. Based on the results obtained, the application of parcel lockers has increased the acceptance rate of tasks, indicating that it has attracted more people to participate in parcel delivery. Among these tasks, the number of fulfilled tasks of joint crowdshipping is lower than that of direct crowdshipping, but the system's average detour is lower when parcel lockers are applied compared to the system without parcel lockers. Furthermore, joint crowdshipping accounts for a certain percentage but is lower than direct crowdshipping. In terms of parcel locker usage, each parcel locker in this case study has provided a similar level of service for the five destinations. In summary, the application of parcel lockers has brought some positive impacts to the supply side of crowdshipping, such as increasing the acceptance rate and reducing detours. However, from the perspective of the number of fulfilled tasks, the matching issues between leg1 and leg2 after applying parcel lockers deserve the attention and further research of crowdshipping platforms. Nevertheless, parcel lockers can provide some support in crowdshipping. For parcel locker providers, setting up parcel lockers should take into account the location and demand volume of crowdshipping services to maximize the utilization of parcel lockers in crowdshipping.

Secondly, incorporating remuneration as a testing variable, results were generated separately for the five destinations. The results indicate that the KPIs for all five destinations exhibit a similar trend with increasing remuneration. With the increase in remuneration, the acceptance rate for the system without parcel lockers initially lags behind the system with parcel lockers but eventually converges to a similar level. Similarly, the average detour also exhibits a similar trend. In the system without parcel lockers, the number of fulfilled tasks is slightly lower than the system with parcel lockers when remuneration is €0 and €2, but it eventually surpasses the system with parcel lockers. Additionally, the percentage of joint crowdshipping generally decreases. These results indicate that the application of parcel lockers has a more positive impact on the crowdshipping system when remuneration is lower. From this perspective, if it is required to improve the performance of the crowdshipping system when remuneration is low, the use of parcel lockers could be a viable option.

MRQ: How does the presence of parcel lockers shape carriers' participation?

From the perspective of carriers' choice behavior, the application of parcel lockers does not have a significant impact on whether carriers accept tasks or not. Carriers primarily consider factors such as time and compensation, and when the positive impact of compensation outweighs the negative impact of additional time spent, carriers are more likely to accept tasks.

From a group perspective, the application of parcel lockers does indeed help attract more carriers to accept tasks because the distribution of parcel lockers throughout the system aids in covering a wider range of carriers. However, joint crowdshipping still faces challenges with low fulfilled tasks. This is primarily due to the characteristic of joint crowdshipping that it requires two carriers to complete one task and the complexity of matching two separate sub-tasks. If there isn't a well-implemented matching mechanism in place, simply increasing the usage of parcel lockers may not be enough to encourage more carriers to successfully participate in parcel delivery. Furthermore, in scenarios where the compensation is low, the application of parcel lockers appears to have a more positive impact on crowdshipping. These are important considerations for crowdshipping platforms when developing and expanding their business.

In conclusion, based on the literature review, crowdshipping has the potential to bring about a range of positive impacts. While the application of parcel lockers may have limitations, it still offers carriers additional options, benefiting various stakeholders. Therefore, overall, research on the application of parcel lockers in crowdshipping is meaningful and worthy of further exploration and discovery.

5.2. Recommendation

This section discusses the contribution of this research, followed by the limitations and potential improvements of the choice model and simulation. Furthermore, recommendations for future research and practice are presented.

5.2.1. Scientific Contribution

First, to the best of the authors' knowledge, this is the first study to collect carriers' choice data using a revealed preference experiment, whereas previous research primarily relied on stated preference experiments, which involve distributing surveys to gather data on consumer or carrier choices related to crowdshipping. While the RP experiment did not yield a sufficient amount of data, this study still offers valuable insights into the design of an RP experiment. Furthermore, the combination of SP and RP data resulted in findings that are more aligned with the real-world context compared to using SP data alone. The second contribution of this research is associated with the exploration of the impact of applying parcel lockers to the crowdshipping system in an urban environment using a simulation method. Importantly, all settings in this study were derived from reality, which lends a significant degree of practical relevance to the results. Finally, the third contribution is related to the completeness of the research content. This study investigates the impact of parcel lockers on the supply side of crowdshipping from both individual choice behavior and group choice behavior, i.e., micro and macro perspectives. This structure is less common in previous research, making the study more comprehensive and persuasive.

5.2.2. Limitation

While this study provides reasonable conclusions regarding the impact of parcel lockers on crowdshipping, there are some simplifications made to ensure the feasibility of the experiments, which could be further improved. The limitations of this research are discussed in both the choice model and simulation model aspects.

In the context of the choice model, it is important to note that this study did not comprehensively validate all influencing factors. Instead, it focused on a selected set of attributes, namely remuneration, travel time, total delivery time, parcel quantity and the decision to use a parcel locker or not. Given the complexity of the experiments, certain constraints were imposed on the experimental scenarios. These constraints included the mode of transportation being limited to cycling and parcels being of mailbox size with consistent content (i.e., a single book). Consequently, several other characteristics of parcels, such as weight and size, were not considered. Additionally, no categorical analysis was conducted for various modes of transportation and carrier travel types. Furthermore, with regard to data collection, the study faced limitations due to a restricted number of participants. As a result, an insufficient amount of RP data was gathered. To mitigate this issue, the study resorted to combining RP data with SP data during the model estimation process. This hybrid approach may have led to results that do not entirely reflect the choice behavior of carriers in real-life situations.

In the context of the simulation model, several assumptions were made in Section 4.2, some of which highlight certain limitations inherent to simulations. Firstly, the modes of transportation were restricted to cycling, with walking and public transit not considered (private cars were excluded from the scope of the study), which imposes certain limitations on the realism of the model. Secondly, in the model, the routes taken by carriers were randomly generated, while in reality, people's travel routes follow certain patterns, and travel demands within each area are constrained within specific ranges. In addition, in this study, carriers' trips did not cover all types of distances, which may lead to certain biases in the results. Lastly, the model assumed that carriers, once they accept a task, are guaranteed to complete it, without considering the probability of delivery failure. In addition, the part of the simulation model concerning carriers' choice behavior relied on the estimation results from the choice model. It is important to acknowledge that this approach may introduce limitations in terms of the comprehensiveness of factors considered in the choice model.

5.2.3. Recommendation for Future Research

For this study, only six factors were included in the analysis of the choice model. In future research, it would be advisable to consider a broader range of attributes, such as parcel size and weight, and to conduct analyses for different modes of transportation and travel purposes. These enhancements would contribute to the credibility and comprehensiveness of the results. In terms of data collection, it is essential to conduct further RP experiments to acquire authentic choice data from carriers. This will be instrumental in establishing a more persuasive and robust choice model. In addition, this study primarily focused on exploring the impact of parcel lockers on the supply side of crowdshipping. In future research, it would be valuable to also examine the demand side to validate whether the use of parcel lockers can make it easier for consumers to adopt crowdshipping services. This holistic approach would provide a more comprehensive understanding of the broader implications of parcel locker applications in the context of crowdshipping.

In the case study, several critical issues were identified that require particular attention when implementing parcel lockers. Firstly, the challenge of carrier matching emerged as a key concern. Joint delivery relies on two carriers each completing a segment of the delivery task. Finding effective methods to identify suitable carriers for task completion is a topic that requires further investigation in future research. Secondly, pricing strategies are of utmost importance. Determining the pricing structure for leg1 and leg2 to ensure that it remains competitive with direct delivery for the same journey while also effectively boosting the fulfillment rate of joint delivery is a complex issue that requires further examination. Lastly, the selection of parcel locker locations presents another avenue for future research. Exploring optimal parcel locker placement within the crowdshipping system to maximize their utilization and reduce the additional time carriers spend on task execution is a valuable direction for further study.

5.2.4. Recommendation for Practice

Currently, there is no well-established crowdshipping platform in the Netherlands. However, from a stakeholder analysis perspective, crowdshipping has the potential to generate certain benefits for various stakeholders. Therefore, from an impact standpoint, crowdshipping is a worthwhile novel logistics transportation method to develop. However, when viewed from a business development perspective, carriers' lack of economies of scale presents challenges. Without the application of additional technologies, it is difficult to generate substantial revenue through sheer quantity, making commercial success relatively challenging.

For crowdshipping platforms, the primary challenge is to attract a sufficient number of carriers to provide services. This can be addressed through extensive promotional efforts and the development of new technologies. The use of parcel lockers represents a potential avenue for development, although further validation is required. Additionally, gaining an understanding of consumer demands and identifying the pain points associated with traditional logistics transportation is essential to provide improved services that can attract a larger user base.

For parcel locker providers, expanding their business into crowdshipping may still be early, and the role of parcel lockers in crowdshipping requires further validation. However, based on this research, it is evident that the application of parcel lockers does yield some positive effects, such as reducing detours and increasing acceptance rates. Therefore, locker providers should still monitor the development of crowdshipping and seize the opportunity to potentially expand their business in the crowdshipping direction in the future.

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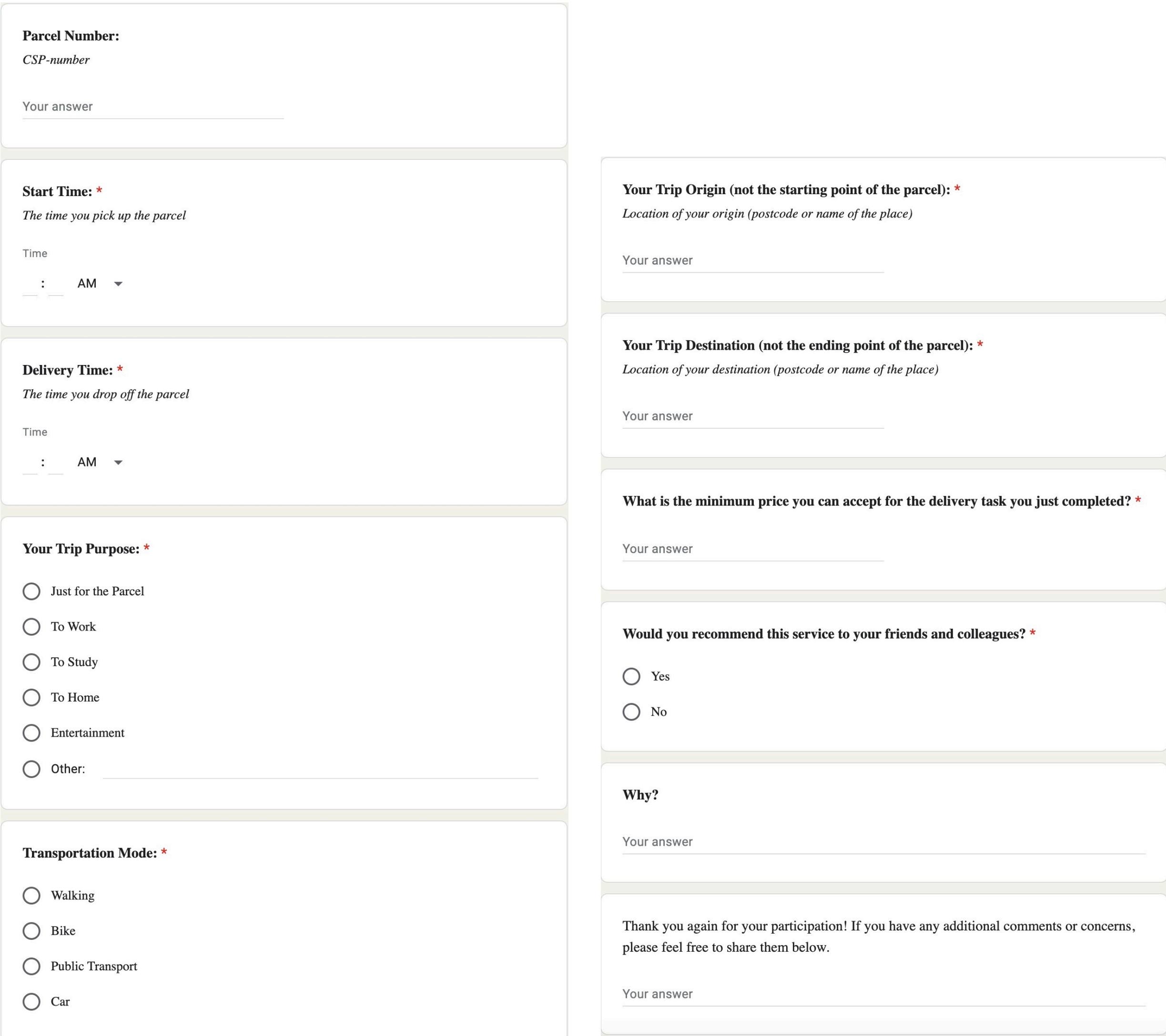
A
Flyer

Figure A.1: Flyer

B
Post-survey



Parcel Number:
CSP-number
Your answer

Start Time: *
The time you pick up the parcel
Time
: AM

Delivery Time: *
The time you drop off the parcel
Time
: AM

Your Trip Purpose: *
- Just for the Parcel
- To Work
- To Study
- To Home
- Entertainment
- Other:

Transportation Mode: *
- Walking
- Bike
- Public Transport
- Car

Your Trip Origin (not the starting point of the parcel): *
Location of your origin (postcode or name of the place)
Your answer

Your Trip Destination (not the ending point of the parcel): *
Location of your destination (postcode or name of the place)
Your answer

What is the minimum price you can accept for the delivery task you just completed? *
Your answer

Would you recommend this service to your friends and colleagues? *
- Yes
- No

Why?
Your answer

Thank you again for your participation! If you have any additional comments or concerns, please feel free to share them below.
Your answer

Figure B.1: Questionnaire

C

Script for Choice Model

```
# ################################################################# #
#### LOAD LIBRARY AND DEFINE CORE SETTINGS                       ####
# ################################################################# #

### Clear memory
# rm(list = ls())

### Load Apollo library
library(apollo)

### Initialise code
apollo_initialise()

### Set core controls
apollo_control = list(
  modelName       = "7_FINAL_MNLs_with one model",
  modelDescr      = "Simple MNL model on mode choice SP-RP data",
  indivID         = "ID",
  outputDirectory = "output"
)

# ################################################################# #
#### LOAD DATA AND APPLY ANY TRANSFORMATIONS                     ####
# ################################################################# #
#database = FINAL_last_version

database <- read.csv("/Users/jerrysu/Desktop/TUD Y2/Thesis project/material/MNL model/Final_SP_RP.csv")
#print(database)
#print(database[2476, ])

# ################################################################# #
#### DEFINE MODEL PARAMETERS                                     ####
# ################################################################# #

### Vector of parameters, including any that are kept fixed in estimation
################################################################# #
#### DEFINE MODEL PARAMETERS                                     ####
# ################################################################# #

### Vector of parameters, including any that are kept fixed in estimation
apollo_beta=c(b_pup_Homebased             = 0,
              asc_before                  = 0,
              asc_after                   = 0,
```

```
              asc_Bike                    = 0,
              asc_Car                     = 0,
              ASC_NP                      = 0,
              lambda_CS                   = 1,
              b_tt                        = 0,
              b_tt_home                   = 0,
              b_tt_trip                   = 0,
              b_rem                       = 0,
              b_cost                      = 0,
              b_pup                       = 0,
              pup_before                  = 0,
              b_pup_General1              = 0,
              b_num                       = 0,

              #b_R_Rem                     = 0,
              #b_R_PL                      = 0,
              b_R_num                     = 0,
              mu_SP                       = 1,
              mu_RP                       = 1,
              scale                       = 1,

              numparceltrip               = 0,
              numparcelhome               = 0
)

### Vector with names (in quotes) of parameters to be kept fixed at their starting
     value in apollo_beta, use apollo_beta_fixed = c() if none
apollo_fixed = c("mu_RP" , "numparceltrip", "numparcelhome")
apollo_fixed = append(apollo_fixed,c('b_pup_Homebased'))
apollo_fixed = append(apollo_fixed,c('lambda_CS'))
apollo_fixed = append(apollo_fixed,c('b_tt'))
apollo_fixed = append(apollo_fixed,c('b_cost'))
apollo_fixed = append(apollo_fixed,c('pup_before'))
apollo_fixed = append(apollo_fixed,c('b_pup'))

# ################################################################# #
#### GROUP AND VALIDATE INPUTS                                    ####
# ################################################################# #

apollo_inputs = apollo_validateInputs()

# ################################################################# #
#### DEFINE MODEL AND LIKELIHOOD FUNCTION                         ####
# ################################################################# #

apollo_probabilities=function(apollo_beta, apollo_inputs, functionality="estimate
    "){

  ### Attach inputs and detach after function exit
  apollo_attach(apollo_beta, apollo_inputs)
  on.exit(apollo_detach(apollo_beta, apollo_inputs))

  ### Create list of probabilities P
  P = list()

  ### List of utilities: these must use the same names as in mnl_settings, order
     is irrelevant
  V = list()

  V[["Normal"]]  = ( b_tt  * Base_TT  + b_tt_trip  *  (Base_TT)) + -b_rem *
     Base_Cost_Car * (Car == "Car")
```

```
V[["Before"]]  = asc_before  + ( b_tt  * Alt1_TT  + b_tt_trip  *  (Alt1_TT)) + b_rem  * Alt1_Rem   + -b_rem * Alt1_Cost_Car * (Car == "Car") + b_pup_General1 *  (Alt1_PUP == "Yes") +    b_pup * (Alt1_PUP == "Yes") + ( pup_before * (Alt1_PUP == "Yes")) + b_num * (Alt1_parcels- 1)
V[["After"]]   = asc_after   + ( b_tt  * Alt2_TT  + b_tt_trip  *  (Alt2_TT)) + b_rem  * Alt2_Rem   + -b_rem * Alt2_Cost_Car * (Car == "Car") + b_pup_General1 *  (Alt2_PUP == "Yes") +    b_pup * (Alt2_PUP == "Yes")
                                     + b_num * (Alt2_parcels- 1)

V[["Home"]]    = scale * (0 - b_rem * Rem - b_pup_General1 * (Alt1_PUP == "Yes"))
V[["PickUp"]]  = scale * (asc_Bike +( b_tt * Bike_TT + b_tt_home * Bike_TT)) + numparcelhome * (Numberparcels - 1)
V[["Car"]]     = scale * (asc_Car  +( b_tt * Car_TT  + b_tt_home * Car_TT )) + numparcelhome * (Numberparcels - 1)
V[["Bike"]]    = scale * (asc_Bike +( b_tt * Bike_TT + b_tt_home * Bike_TT)) + numparcelhome * (Numberparcels - 1)

V[["Pickup"]] =  b_tt_trip * TDT + b_rem * REMUNERATION  + b_pup_General1 * LOCKER_or_NOT  + b_R_num * (NUMBER_of_PARCEL-1)
V[["Notpickup"]] = ASC_NP + b_tt_trip * TT


### Compute probabilities for the RP part of the data using MNL model
mnl_settings_RP = list(
  alternatives = c(Pickup=1, Notpickup=0),
  avail = list(Pickup=1, Notpickup=1),
  choiceVar = CHOICE,
  utilities = list(Pickup = mu_RP*V[["Pickup"]],
                   Notpickup = mu_RP*V[["Notpickup"]]),
  rows = (RP==1)
)

P[['RP']] = apollo_mnl(mnl_settings_RP, functionality)


## Compute probabilities for the SP part of the data using MNL model
mnl_settings_SP = list(
  alternatives  = c(Normal="Do not pick up any parcels" ,
                    Before="Pick Up and delivery the parcels before the activity",
                    After= "Pick Up and delivery the parcels after the activity",
                    Home = "Stay home and do not pick up any parcels",
                    Car = "Pick Up and delivery the parcels by car",
                    Bike = "Pick Up and delivery the parcels by bike",
                    PickUp = "Pick Up and delivery the parcels"),
  avail         = list(Normal=AV_Trips, Before=AV_Trips, After=AV_Trips, Home=AV_Home, Car=AV_Car, Bike=AV_Bike,PickUp = AV_PickUp),
  choiceVar     = value,
  utilities     = list(Normal = mu_SP*V[["Normal"]],
                       Before = mu_SP*V[["Before"]],
                       After = mu_SP*V[["After"]],
                       Home = mu_SP*V[["Home"]],
                       Car = mu_SP*V[["Car"]],
                       Bike = mu_SP*V[["Bike"]],
                       PickUp = mu_SP*V[["PickUp"]]),
  rows = (SP==1)
)

P[["SP"]] = apollo_mnl(mnl_settings_SP, functionality)
```

```
  #



  ### Combined model
  P = apollo_combineModels(P, apollo_inputs, functionality)

  ### Take product across observation for same individual
  P = apollo_panelProd(P, apollo_inputs, functionality)

  ### Prepare and return outputs of function
  P = apollo_prepareProb(P, apollo_inputs, functionality)
  return(P)
}


# ################################################################# #
#### MODEL ESTIMATION                                            ####
# ################################################################# #

model = apollo_estimate(apollo_beta, apollo_fixed, apollo_probabilities,
    apollo_inputs)

# ################################################################# #
#### MODEL OUTPUTS                                               ####
# ################################################################# #

# ----------------------------------------------------------------- #
#---- FORMATTED OUTPUT (TO SCREEN)                               ----
# ----------------------------------------------------------------- #

apollo_modelOutput(model,modelOutput_settings=list(printPVal=TRUE))

# ----------------------------------------------------------------- #
#---- FORMATTED OUTPUT (TO FILE, using model name)               ----
# ----------------------------------------------------------------- #

apollo_saveOutput(model)
```

D Script for Simulation Model

```python
import random
import math
import osmnx as ox
import networkx as nx
import shapely.geometry as sg
import pickle

ox.config(use_cache=True, cache_folder='C:/Users/18642/Desktop/map')

# Define the city or place name
place_name = "Delft, Netherlands"

graph = ox.graph_from_place(place_name, network_type="bike")

# Get the street network graph for the specified place
features = ox.features.features_from_place(place_name, tags={'boundary': 'administrative'}, which_result=1)

# Get the boundary polygon of the place
city_boundary = ox.geocode_to_gdf(place_name, which_result=1)

# Extract the boundary polygon coordinates
boundary_polygon = city_boundary['geometry'].iloc[0]

parcel_delivery = (4.34374, 51.98907) # Van Hasseltlaan
# parcel_delivery = (4.3683009, 52.0075059) # Professor Schermerhornstraat
# parcel_delivery = (4.3539617, 51.9962129) # Roland Holstlaan
# parcel_delivery = (4.3726961, 51.9981023) # Korvezeestraat
# parcel_delivery = (4.3582409, 52.0074543) # Barbarasteeg
parcel_pickup = (4.3811469, 52.0127665)

# Set locations of parcel lockers
parcel_lockers = [(4.3823406, 52.0059629), (4.3668743, 51.9954971), (4.3755745, 51.9988087)]

def calculate_distance(point1, point2):
    nearest_node_1 = ox.distance.nearest_nodes(graph, point1[0], point1[1], return_dist=False)
    nearest_node_2 = ox.distance.nearest_nodes(graph, point2[0], point2[1], return_dist=False)

    try:
        distance = nx.shortest_path_length(graph, nearest_node_1, nearest_node_2, weight='length')
```

```
        return distance
    except (nx.NetworkXNoPath, nx.NodeNotFound):
        return -1

# Generate random points within the boundary polygon
def generate_random_location():
    num_random_points = 1  # Number of random points to generate
    random_points = []

    for _ in range(num_random_points):
        while True:
            random_longitude = random.uniform(boundary_polygon.bounds[0],
                boundary_polygon.bounds[2])
            random_latitude = random.uniform(boundary_polygon.bounds[1],
                boundary_polygon.bounds[3])
            random_point = sg.Point(random_longitude, random_latitude)

            if boundary_polygon.contains(random_point):
                random_points.append(random_point)
                break
    random_points_coords = [(point.x, point.y) for point in random_points]

    for i in random_points_coords:
        if calculate_distance(i, parcel_pickup) != -1 and calculate_distance(i,
            parcel_delivery) != -1 and calculate_distance(i, parcel_lockers[0]) !=
            -1 and calculate_distance(i, parcel_lockers[1]) != -1 and
            calculate_distance(i, parcel_lockers[2]) != -1:
            break
    return i

# Define the file path to store position information
position_file = 'crowdshipper_positions.pkl'

# Try to load position information from the file if it exists
try:
    with open(position_file, 'rb') as file:
        crowdshippers = pickle.load(file)
except FileNotFoundError:
    # If the file doesn't exist or it's the first run of the program, initialize
        an empty crowdshippers list
    crowdshippers = []

num_routes = 1000
crowdshippers_per_route = 23
num_crowdshippers = num_routes * crowdshippers_per_route

# Check if new crowdshipper positions need to be generated
if len(crowdshippers) < num_crowdshippers:
    for _ in range(num_routes):
        while True:
            start_point = generate_random_location()
            end_point = generate_random_location()
            if calculate_distance(start_point, end_point) != -1:
                for _ in range(crowdshippers_per_route):
                    crowdshippers.append({'start': start_point, 'end': end_point})
                break

# Save the generated crowdshipper positions to the file
with open(position_file, 'wb') as file:
    pickle.dump(crowdshippers, file)
```

```python
# Utility function parameters
beta_detour = -0.17631
beta_remuneration = 0.96582
beta_num_parcel = 0
beta_locker = 0
noAccept = 0
split_discount = 0

def calculate_detour(crowdshipper, parcel_pickup, parcel_delivery):
    distance_before = calculate_distance(crowdshipper['start'], crowdshipper['end'])
    distance_after = calculate_distance(crowdshipper['start'], parcel_pickup) + calculate_distance(parcel_pickup, parcel_delivery) + calculate_distance(parcel_delivery, crowdshipper['end'])
    total_distance = distance_after - distance_before
    detour = total_distance / 4.2 / 60 # Dividing by bike speed 4.2 m/s
    return detour

def utility_function(detour, remuneration, num_parcel, locker_or_not):
    return beta_detour * detour + beta_remuneration * remuneration + beta_num_parcel * num_parcel + beta_locker * locker_or_not

# Initialize counters
accepted_count = 0
accepted_count_direct = 0
Not_accepted_count = 0

# Simulate the scenario 1
remuneration = 4
num_parcel = 1

# Record the detours
dt_with_pl = []
dt_without_pl = []

for crowdshipper in crowdshippers:
    detour = calculate_detour(crowdshipper, parcel_pickup, parcel_delivery)
    utility_accept = utility_function(detour, remuneration, num_parcel, 0)
    utility_not_accept = noAccept

    Prob_accept = math.exp(utility_accept)/(math.exp(utility_accept) + math.exp(utility_not_accept))
    if Prob_accept > random.uniform(0, 1):
        accepted_count += 1
        dt_without_pl.append(detour)

# Calculate acceptance probability
acceptance_probability = accepted_count / num_crowdshippers * 100

# Initialize a dictionary to store locker choice counts
locker_choice_counts = {i: 0 for i in range(len(parcel_lockers))}
locker_choice_leg1_counts = {i: 0 for i in range(len(parcel_lockers))}
locker_choice_leg2_counts = {i: 0 for i in range(len(parcel_lockers))}
leg = {m: {} for m in range(len(crowdshippers))}
crowdshipper_pick = []
crowdshipper_locker = {m: {} for m in range(len(crowdshippers))}
locker_utilities = {i: {'leg1': [], 'leg2': []} for i in range(len(parcel_lockers))}
locker_utilities_crowdshipper = {m: {'leg1': [], 'leg2': []} for m in range(len(crowdshippers))}

```

```
# Define the choice probability
def calculate_prob(utility_target, utility_direct, utility_leg1, utility_leg2, noAccept):
    return math.exp(utility_target)/(math.exp(utility_direct) + math.exp(utility_leg1) + math.exp(utility_leg2) + math.exp(noAccept))

# Simulate the scenario 2
for m, crowdshipper in enumerate(crowdshippers):
    detour_direct = calculate_detour(crowdshipper, parcel_pickup, parcel_delivery)
    utility_accept_direct = utility_function(detour_direct, remuneration, num_parcel, 0)

    for i, locker in enumerate(parcel_lockers):
        distance_leg1 = calculate_distance(parcel_pickup, locker)
        distance_leg2 = calculate_distance(locker, parcel_delivery)
        ratio_leg1 = distance_leg1/(distance_leg1 + distance_leg2)
        ratio_leg2 = 1 - ratio_leg1
        detour_leg1 = calculate_detour(crowdshipper, parcel_pickup, locker)
        detour_leg2 = calculate_detour(crowdshipper, locker, parcel_delivery)
        utility_accept_leg1 = utility_function(detour_leg1, remuneration * ratio_leg1, num_parcel, 1)
        utility_accept_leg2 = utility_function(detour_leg2, remuneration * ratio_leg2, num_parcel, 1)

        locker_utilities[i]['leg1'].append(utility_accept_leg1)
        locker_utilities[i]['leg2'].append(utility_accept_leg2)
        locker_utilities_crowdshipper[m]['leg1'].append(utility_accept_leg1)
        locker_utilities_crowdshipper[m]['leg2'].append(utility_accept_leg2)

    # Find the locker with the maximum utility for each leg
    max_utility_locker_leg1 = max(locker_utilities.items(), key=lambda x: max(x[1]['leg1']))
    max_utility_locker_leg2 = max(locker_utilities.items(), key=lambda x: max(x[1]['leg2']))

    # Record the utility values
    max_utility_leg1 = max_utility_locker_leg1[1]['leg1'][0]
    max_utility_leg2 = max_utility_locker_leg2[1]['leg2'][0]

    prob_direct = calculate_prob(utility_accept_direct, utility_accept_direct, max_utility_leg1, max_utility_leg2, noAccept)
    prob_leg1 = calculate_prob(max_utility_leg1, utility_accept_direct, max_utility_leg1, max_utility_leg2, noAccept)
    prob_leg2 = calculate_prob(max_utility_leg2, utility_accept_direct, max_utility_leg1, max_utility_leg2, noAccept)
    # print(prob_leg1, prob_leg2, prob_direct)

    L = random.uniform(0, 1)
    color = ['green', 'brown', 'magenta', 'pink', 'red']
    if L < prob_direct:
        accepted_count_direct += 1
        crowdshipper_pick.append(m+1)
        crowdshipper_locker[m]['color'] = 'green'
        dt_with_pl.append(detour_direct)
        print(f"Crowdshipper {m+1} is willing to do direct crowdshipping")

    elif L < (prob_direct + prob_leg1):
        locker_choice_counts[max_utility_locker_leg1[0]] += 1
        locker_choice_leg1_counts[max_utility_locker_leg1[0]] += 1
        crowdshipper_pick.append(m+1)
        crowdshipper_locker[m]['color'] = 'blue'
```

```
        dt_with_pl.append(calculate_detour(crowdshipper, parcel_pickup, parcel_lockers[max_utility_locker_leg1[0]]))
        print(f"Crowdshipper {m+1} is willing to do crowdshipping leg1 by locker {max_utility_locker_leg1[0] + 1}")

    elif L < (prob_direct + prob_leg1 + prob_leg2):
        locker_choice_counts[max_utility_locker_leg2[0]] += 1
        locker_choice_leg2_counts[max_utility_locker_leg2[0]] += 1
        crowdshipper_pick.append(m+1)
        crowdshipper_locker[m]['color'] = 'purple'
        dt_with_pl.append(calculate_detour(crowdshipper, parcel_lockers[max_utility_locker_leg2[0]], parcel_delivery))
        print(f"Crowdshipper {m+1} is willing to do crowdshipping leg2 by locker {max_utility_locker_leg2[0] + 1}")

    else:
        Not_accepted_count += 1
        crowdshipper_locker[m]['color'] = 'orange'
        print(f"Crowdshipper {m+1} is not willing to pick up a parcel")

    # Empty locker_utilities after each loop
    for locker_utility in locker_utilities.values():
        locker_utility['leg1'] = []
        locker_utility['leg2'] = []

# Print locker choice counts
for i, count in locker_choice_counts.items():
    print(f"Locker {i + 1} chosen {count} times")

leg1_counts_list = []
leg2_counts_list = []
num_success = 0
for i, count in locker_choice_leg1_counts.items():
    leg1_counts_list.append(count)

for i, count in locker_choice_leg2_counts.items():
    leg2_counts_list.append(count)

for m, n in zip(leg1_counts_list, leg2_counts_list):
    num_success += min(m,n)

print(f"Direct crowdshipping chosen {accepted_count_direct} times")
print(f"Joint crowdshipping has been successful {num_success} times")
print(f"Locker 1 has been successful used {min(leg1_counts_list[0], leg2_counts_list[0])} times")
print(f"Locker 1 leg1: {leg1_counts_list[0]} times")
print(f"Locker 1 leg2: {leg2_counts_list[0]} times")
print(f"Locker 2 has been successful used {min(leg1_counts_list[1], leg2_counts_list[1])} times")
print(f"Locker 2 leg1: {leg1_counts_list[1]} times")
print(f"Locker 2 leg2: {leg2_counts_list[1]} times")
print(f"Locker 3 has been successful used {min(leg1_counts_list[2], leg2_counts_list[2])} times")
print(f"Locker 3 leg1: {leg1_counts_list[2]} times")
print(f"Locker 3 leg2: {leg2_counts_list[2]} times")
print(f"Not picking up chosen {Not_accepted_count} times")
print("------------------------------KPI----------------------------------")
print("Fulfillment rate without parcel lockers: {:.0f}%".format(acceptance_probability))
print("Fulfillment rate of DC with parcel lockers: {:.0f}%".format(accepted_count_direct/num_crowdshippers * 100))
```

```
print("Fulfillment rate of JC parcel lockers: {:.0f}%".format(num_success/num_crowdshippers * 100))
print("Fulfillment rate with parcel lockers: {:.0f}%".format((accepted_count_direct + num_success)/num_crowdshippers * 100))
print("Acceptance rate with parcel lockers: {:.0f}%".format((num_crowdshippers - Not_accepted_count)/num_crowdshippers * 100))
if accepted_count == 0:
    print("Average detour without parcel lockers: Invalid")
else:
    print("Average detour without parcel lockers: {:.0f} min".format(sum(dt_without_pl)/accepted_count))

if num_crowdshippers - Not_accepted_count ==0:
    print("Average detour with parcel lockers: Invalid")
else:
    print("Average detour with parcel lockers: {:.0f} min".format(sum(dt_with_pl)/(num_crowdshippers - Not_accepted_count)))

if accepted_count_direct + num_success == 0:
    print("Invalid")
else:
    print("Percentage of joint delivery: {:.0f}%".format(num_success/(accepted_count_direct + num_success) * 100))

with open("output_Kor6.txt", "w") as file:
    file.write(f"Direct crowdshipping chosen {accepted_count_direct} times\n")
    file.write(f"Joint crowdshipping has been successful {num_success} times\n")
    file.write(f"Locker 1 has been successful used {min(leg1_counts_list[0], leg2_counts_list[0])} times\n")
    file.write(f"Locker 1 leg1: {leg1_counts_list[0]} times\n")
    file.write(f"Locker 1 leg2: {leg2_counts_list[0]} times\n")
    file.write(f"Locker 2 has been successful used {min(leg1_counts_list[1], leg2_counts_list[1])} times\n")
    file.write(f"Locker 2 leg1: {leg1_counts_list[1]} times\n")
    file.write(f"Locker 2 leg2: {leg2_counts_list[1]} times\n")
    file.write(f"Locker 3 has been successful used {min(leg1_counts_list[2], leg2_counts_list[2])} times\n")
    file.write(f"Locker 3 leg1: {leg1_counts_list[2]} times\n")
    file.write(f"Locker 3 leg2: {leg2_counts_list[2]} times\n")
    file.write(f"Not picking up chosen {Not_accepted_count} times\n")
    file.write("----------------------------KPI---------------------------------\
n")
    file.write("Fulfillment rate without parcel lockers: {:.0f}%\n".format(acceptance_probability))
    file.write("Fulfillment rate of DC with parcel lockers: {:.0f}%\n".format(accepted_count_direct/num_crowdshippers * 100))
    file.write("Fulfillment rate of JC parcel lockers: {:.0f}%\n".format(num_success/num_crowdshippers * 100))
    file.write("Fulfillment rate with parcel lockers: {:.0f}%\n".format((accepted_count_direct + num_success)/num_crowdshippers * 100))
    file.write("Acceptance rate with parcel lockers: {:.0f}%\n".format((num_crowdshippers - Not_accepted_count)/num_crowdshippers * 100))
    file.write("Average detour without parcel lockers: {:.0f} min\n".format(sum(dt_without_pl)/accepted_count))
    file.write("Average detour with parcel lockers: {:.0f} min\n".format(sum(dt_with_pl)/(num_crowdshippers - Not_accepted_count)))
    file.write("Percentage of joint delivery: {:.0f}%".format(num_success/(accepted_count_direct + num_success) * 100))
```

E

Simulation Results for Scenario 1

This section records all the results from the simulation model output in Scenario 1.

Table E.1: Simulation Result without parcel lockers

Destination	Crowdshipping	Non-acceptance
1	6165	16835
2	13178	9822
3	15757	7243
4	13593	9407
5	11017	11983

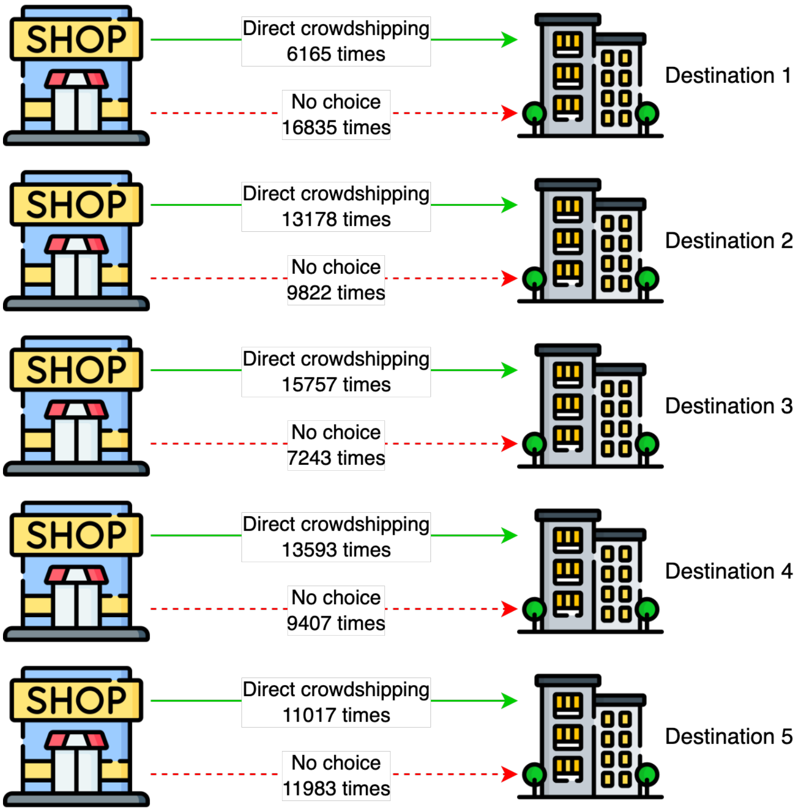
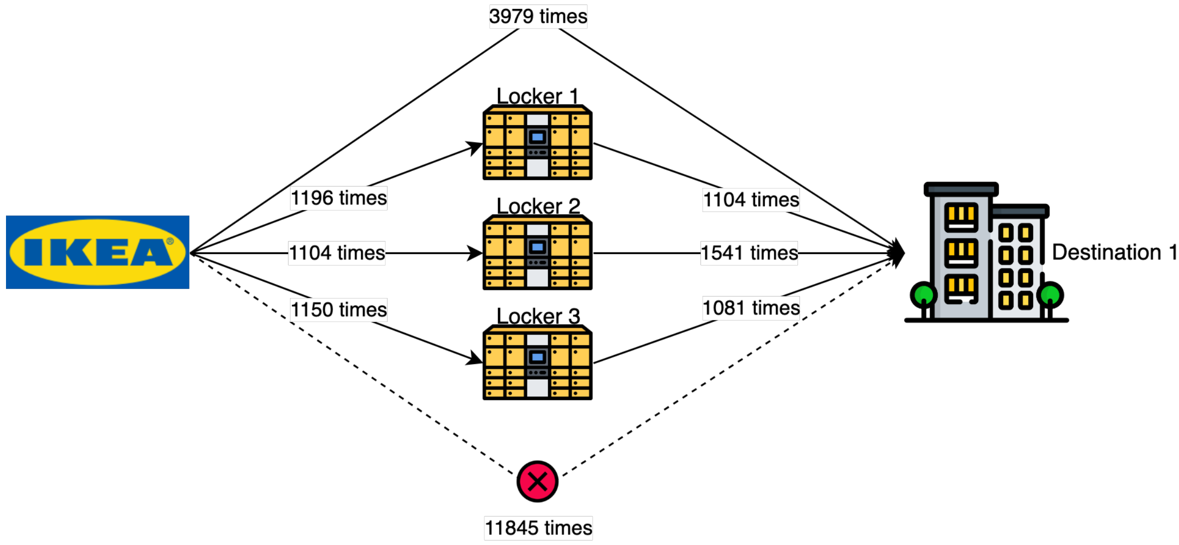
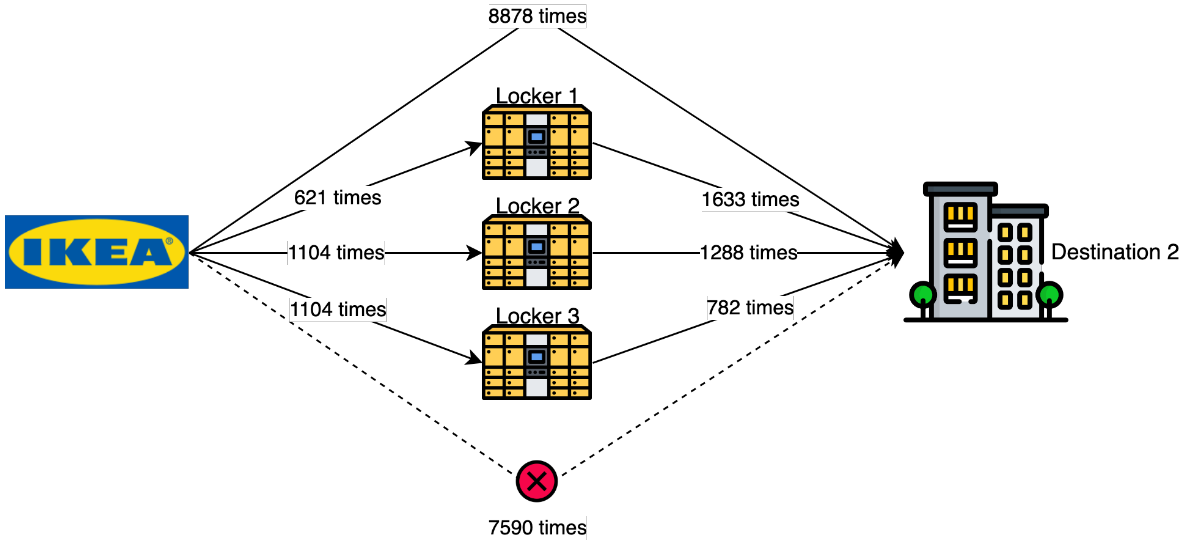


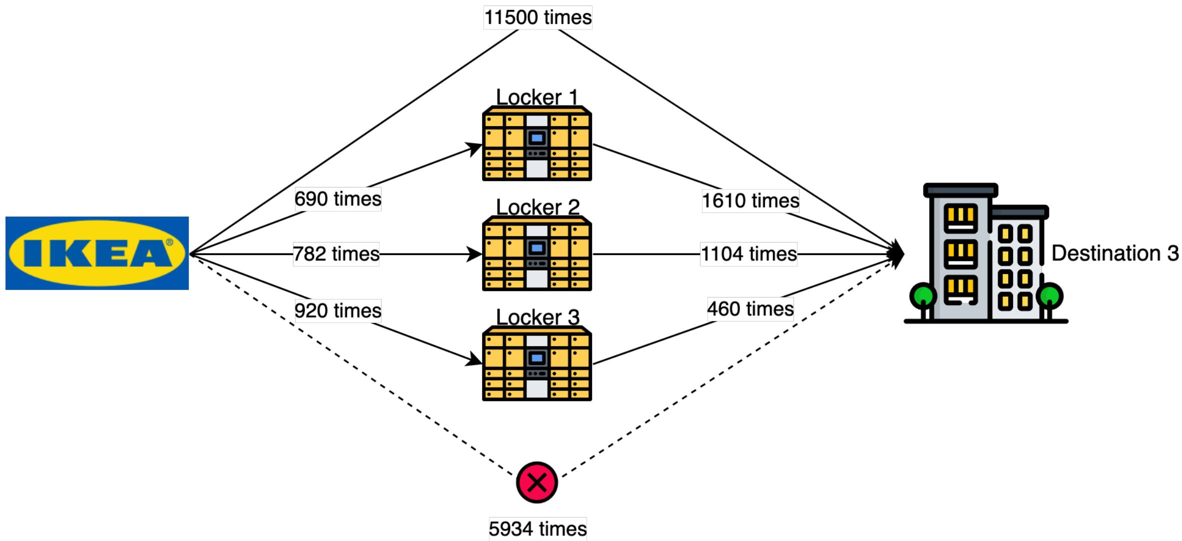
Figure E.1: Results for crowdshipping without parcel lockers

Table E.2: Simulation Result with parcel lockers

Destination	Direct crowdshipping	Joint crowdshipping							Non-acceptance
		Locker 1 leg 1	Locker 1 leg 2	Locker 2 Leg 1	Locker 2 leg 2	Locker 3 leg 1	Locker 3 leg 2	Fulfilled	
1	3979	1196	1104	1104	1541	1150	1081	3289	11845
2	8878	621	1633	1104	1288	1104	782	2507	7590
3	11500	690	1610	782	1104	920	460	1932	5934
4	8441	322	2024	0	1173	4002	368	690	6670
5	6992	1104	2047	851	1978	943	1012	2898	8073


3979 times
Locker 1
Locker 2
Locker 3
1196 times
1104 times
1150 times
1104 times
1541 times
1081 times
Destination 1
11845 times


8878 times
Locker 1
Locker 2
Locker 3
621 times
1104 times
1104 times
1633 times
1288 times
782 times
Destination 2
7590 times


11500 times
Locker 1
Locker 2
Locker 3
690 times
782 times
920 times
1610 times
1104 times
460 times
Destination 3
5934 times

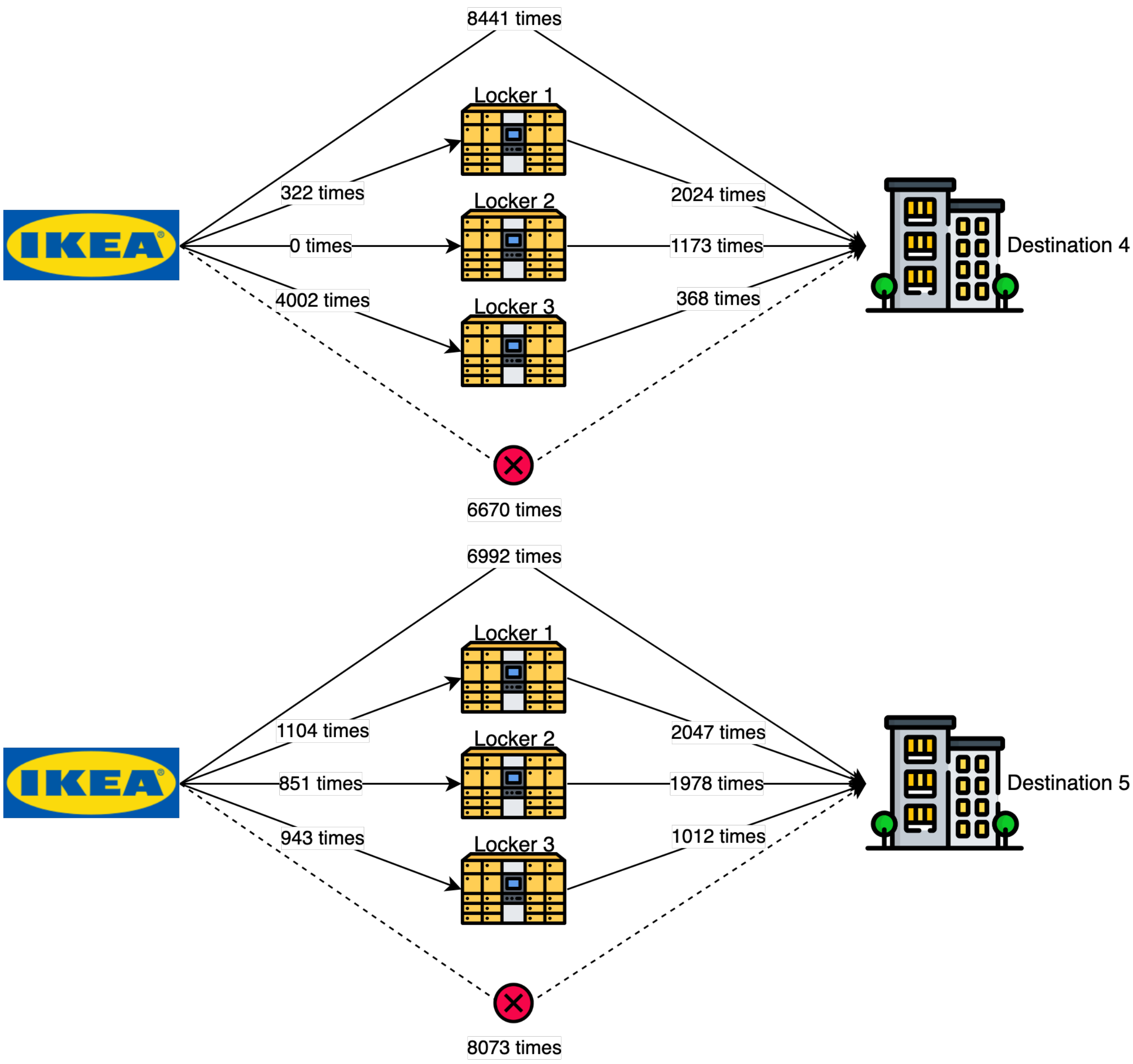


Figure E.3: Results for crowdshipping without parcel lockers

F Simulation Results for Scenario 2

This section records all the results from the simulation model output in Scenario 2, especially the number of fulfilled tasks with parcel lockers.

Table F.1: Simulation Result with parcel lockers

Remuneration = €0							
Destination	Fulfilled direct crowdshipping	Fulfilled joint crowdshipping				Fulfilled in total	Non-acceptance
		Locker 1	Locker 2	Locker 3	Total		
1	299	92	437	46	575	874	19228
2	1127	437	345	184	966	2093	17641
3	1403	1127	391	115	1633	3036	16836
4	736	391	0	138	1634	1265	16008
5	690	368	345	230	1635	1633	18262

Remuneration = €2							
Destination	Fulfilled direct crowdshipping	Fulfilled joint crowdshipping				Fulfilled in total	Non-acceptance
		Locker 1	Locker 2	Locker 3	Total		
1	1012	460	989	575	2024	3036	16514
2	3887	874	966	575	2415	6302	12650
3	4715	1265	391	759	2415	7130	12190
4	3519	1150	0	1840	2990	6509	12052
5	2484	805	713	690	2208	4692	13846

Remuneration = €4							
Destination	Fulfilled direct crowdshipping	Fulfilled joint crowdshipping				Fulfilled in total	Non-acceptance
		Locker 1	Locker 2	Locker 3	Total		
1	3979	1104	1104	1081	3289	7268	11845
2	8878	621	1104	782	2507	11385	7590
3	11500	690	782	460	1932	13432	5934
4	8441	322	0	368	690	9131	6670
5	6992	1104	851	943	2898	9890	8073

Remuneration = €6							
Destination	Fulfilled direct crowdshipping	Fulfilled joint crowdshipping				Fulfilled in total	Non-acceptance
		Locker 1	Locker 2	Locker 3	Total		
1	8556	920	1472	897	3289	11845	6417
2	14927	276	989	0	1265	16192	2783
3	17894	391	529	207	1127	19021	1794
4	12627	0	0	0	0	12627	2438
5	12834	368	851	391	1610	14444	3496

G
Scientific Paper

The scientific paper can be found on the following pages.

Impact of Parcel Lockers as Transfer Points on Crowdshipping Services: Carriers' Perspective

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Abstract

In the context of striving for zero emissions in cities in the future, finding new logistics methods is of paramount importance. Inspired by the concept of the Physical Internet, a parcel transportation method called "crowdshipping" has begun to gain attention. In this study, a new form of crowdshipping is investigated, where parcel lockers are introduced as transfer points within crowdshipping. The research examines the impact of parcel lockers on crowdshipping services from the supply side in two aspects: carrier's choice behavior and the status of crowdshipping task completion in the simulation of Delft network with and without parcel lockers. The results suggest that the application of parcel lockers has a positive impact on crowdshipping services, and this new form of crowdshipping has the potential for further development.

Keywords: Crowdshipping, Parcel Locker, Revealed Preference, Stated Preference

1. Introduction

With the increase in e-commerce, there has been rapid growth in home deliveries. This means that there is a significant volume of packages being transported between and within cities on a daily basis. However, with the increasing demand for last-mile delivery, traditional courier companies such as DHL, PostNL and FedEx face immense pressure and challenges. The courier companies deliver the parcels to the doors so consumers can easily collect the parcels. However, there are several issues regarding this way of delivery, such as failed deliveries (Song et al., 2009; Morganti et al., 2014; Wang et al., 2016), complex transportation routes and more emissions (Nogueira et al., 2022). To ensure a sustainable future for urban areas, it is essential to plan for environmentally friendly transportation and mobility both within cities and beyond, with the aim of reducing energy consumption, air pollution, noise, and greenhouse gas (GHG) emissions.

To build more efficient last-mile delivery systems, the vision of the Physical Internet (PI) was proposed as an innovative solution. It emphasizes several key concepts, including standardized containerization, shared resources, intelligent systems and sustainability. One of the applications proposed in PI is crowdshipping in which passenger mobility and last-mile delivery operations can be combined (Crainic and Montreuil, 2016). The main idea is that users can become carriers when their destinations are not far from those of the parcels. The large-scale implementation of such a service can help reduce the infrastructure and operational costs, as well as courier-generated traffic (Rougès and Montreuil, 2014; Ghaderi et al., 2022). Thanks to the bicycle-friendly environment and convenient public transportation in the Netherlands, carriers can utilize environmentally friendly modes of transportation to facilitate the delivery of parcels. In this way, crowdshipping can make better use of the current transportation capacity, achieving faster, cheaper and more sustainable deliveries (Miller et al., 2017; Pourrahmani and Jaller, 2021; Arditi and Toch, 2022). However, crowdshipping services are also facing several challenges in practice. According to Wang et al. (2016), in crowdshipping each task is independent and the task is performed on a one-to-one communication basis. As a result, there are few consolidation effects. Rougès and Montreuil (2014) state that the feasibility and efficiency of large-scale crowdshipping depend on carriers' proximity to the origins and destinations of parcels. If the flow between the parcel origin and destination is low, then the efficiency of crowdshipping services can be influenced. Therefore, one of the most significant challenges in the establishment of crowdshipping is to guarantee reliable and scalable delivery procedures (Boysen et al., 2022).

In recent years, the use of parcel lockers has been popular (Iwan et al., 2016). Parcel lockers are groups of strategically situated lockers, located in urban areas, that can be emptied and filled 24/7, so people are able to collect or return their parcels at a moment that fits their agenda best. Various business models are in existence when employing parcel lockers. Vertically integrated courier companies invest in developing their own network of lockers, while certain specialized operators provide on-demand locker services catering to both individuals and businesses. Of particular note is that the use of parcel lockers provides a flexible solution to transfer goods between different modes and actors for collaborative delivery (Ghaderi et al., 2022; Pan et al., 2021). The utilization of parcel lockers in a crowdshipping network can improve the performance of crowdshipping services by reducing the trip detour and achieving better coverage (Ghaderi et al., 2022). Therefore, it is possible to explore the integration of parcel lockers in crowdshipping, enabling multiple occasional carriers to complete one task. However, the studies on crowdshipping are mostly optimization-based, and there is still insufficient theoretical support regarding the impact of parcel lockers on crowdshipping services, particularly due to the lack of analysis based on empirical data. Hence, behavioral studies are still lacking. The aim of this research is twofold. First, it is important to identify the factors that influence carriers' choices, especially when incorporating this service with parcel lockers. Second, it is necessary to comprehend the impact of parcel lockers on crowdshipping which is the main aim of this study since the role that parcel lockers can play in crowdshipping services remains unknown, especially from the supply side.

2. Literature review

2.1. State of the art

There has been an increasing number of studies on crowdshipping recently, and the studies can be divided into four types, including the optimization of crowdshipping systems (Ghaderi et al., 2022; Barbosa et al., 2023; Boysen et al., 2022), the evaluation of crowdshipping services in terms of economic, environmental and societal benefits (Tapia et al., 2023; Ballare and Lin, 2020; Arditi and Toch, 2022; Farizky WIjanarko, 2022), the acceptance of crowdshipping from demand and supply sides (Gatta et al., 2018; Serafini et al., 2018; Fessler et al., 2023; Le and Ukkusuri, 2019b; Miller et al., 2017; Wicaksono et al., 2022; Cebeci et al., 2023a) and the integration of crowdshipping with other technologies (Ghaderi et al., 2022; Le Pira et al., 2021; Zhu et al., 2023). In this section, these perspectives of crowdshipping are specified.

Regarding the optimization of crowdshipping systems, there are several papers discussing the network of parcel lockers, job-to-crowdshipper assignment strategy and pricing strategy. Ghaderi et al. (2022) proposed a novel model for determining the locations of parcel lockers and allocating delivery tasks. By conducting numerical analyses on large instances, it has been demonstrated that joint delivery can enhance the success rate of deliveries by up to 5%. Barbosa et al. (2023) developed a dynamic compensation scheme through the integration of logistic regression and optimization methods. It will determine the optimal reward to be provided to occasional carriers, which maximizes the acceptance of being an occasional carrier. In order to simultaneously maximize the number of matched shipments and take into account the employees' minimum expected earnings, Boysen et al. (2022) offered an effective solution procedure based on Benders decomposition. In summary, research on optimization problems involves almost every step of crowdshipping services. In addition, the optimization of the parcel locker network is a new trend since the use of parcel lockers has the potential to improve the performance of crowdshipping services.

Concerning the performance of crowdshipping, it is evaluated by many studies in terms of economic, environmental and societal benefits. According to Tapia et al. (2023), introducing crowdshipping with the use of cars and bicycles for L2L deliveries results in an increase in both vehicle kilometers and CO_2 emissions. However, it suggests that crowdshipping services can be efficient in less dense areas. According to Ballare and Lin (2020), the delivery paradigm of Microhubs with crowdshipping was proved to significantly reduce the number of trucks, truck VMT, total daily operating costs and total fuel consumption compared with the traditional hub-and-spoke paradigm for the same demand. But trucks are still involved in this type of crowdshipping to transport goods among hubs, and occasional carriers are only responsible for the trips between hub and consumer. Farizky WIjanarko (2022) concluded that car-based crowdshipping services would not have benefits on vehicle mileage and carbon dioxide emission, while public transport-based crowdshipping can lead to a reduction in particulates and carbon dioxide (Gatta et al., 2018). To summarize, the impacts of crowdshipping services vary depending on the type of service and city characteristics.

The acceptance of crowdshipping has been analyzed by many studies in terms of the demand and supply sides. According to Marcucci et al. (2017), a majority of students, 87%, expressed their readiness to participate in crowdshipping, although this figure declines with larger delivery boxes and lower pay rates. Conversely, 93% of respondents would be open to receiving goods through a crowdshipping platform, but this number would significantly drop if there was no way for customers to communicate with the crowdshipping company. Meanwhile, about half of the sample expresses a positive attitude toward the success of crowdshipping services by public transport (Gatta et al., 2018; Serafini et al., 2018). According to Miller et al. (2017), crowdshipping could be an attractive alternative for particular urban commuters and, if properly handled, may offer a more eco-friendly and efficient shipping choice for individuals, private firms, and government entities. And high-income group is not likely to perform the delivery. As to the consumers of crowdshipping services, trust plays an important role (Cebeci et al., 2023a; Pourrahmani and Jaller, 2021). Consumers are likely to trust and use crowdshipping services with a strong reputation and low damage risk, and direct communication between couriers and consumers is necessary during the delivery process. From the above overview, it can be seen that research on the acceptance of crowdshipping is quite complete. The use of parcel lockers is mentioned in some of the studies. However, there is no explanation of the potential impacts of parcel lockers, which can be a topic for further research.

Regarding the integration of crowdshipping with other technologies, related research is limited. Le Pira et al. (2021) proposed a concept integrating freight transport into a Mobility as a Service (MaaS) environment. Crowdshipping can be involved in this process to improve the system's efficiency. According to Ghaderi et al. (2022), parcel lockers can be used as exchange points in crowdshipping to reduce detours and achieve better geographical coverage, improving the performance of crowdshipping.

2.2. Definition of attributes

In order to determine the attributes to be tested in the experiment, conducting a literature review is necessary to summarize potential factors that may influence carriers' acceptance of

Table 1: Significant variables for occasional carrier

Variables	Source
Remuneration	Gatta et al. (2019); Fessler et al. (2022); Cebeci et al. (2023b); Tapia et al. (2023); Wicaksono et al. (2022); Miller et al. (2017); Le and Ukkusuri (2019a); Galkin et al. (2021); Marcucci et al. (2017); Le and Ukkusuri (2018)
Detour/total travel time	Fessler et al. (2022); Cebeci et al. (2023b); Tapia et al. (2023); Wicaksono et al. (2022); Miller et al. (2017); Le and Ukkusuri (2018)
Parcel characteristics (weight, size and quantity)	Fessler et al. (2022); Wicaksono et al. (2022); Marcucci et al. (2017); Le and Ukkusuri (2018)
Whether to use parcel locker or not	Gatta et al. (2019); Cebeci et al. (2023b)
Other (delivery booking and bank credit mode)	Gatta et al. (2019)

tasks. Based on the conclusions drawn from the literature review and considering their practical applicability in the experiment, relevant attributes will be selected for the analysis of experimental data. Table 1 summarizes all the factors found in the literature that may influence carriers' task selection. Based on the table, it can be observed that remuneration and travel time are the most significant factors considered by carriers in their task selection. Additionally, parcel characteristics and the use of parcel lockers also have some influence on carriers' choices. According to Gatta et al. (2019), when controlling all variables to zero, carriers tend to lean towards not accepting any tasks, suggesting the possible presence of an alternative special constant (ASC) in the utility function for "non-acceptance". Furthermore, some other factors such as delivery booking and bank credit mode can also impact carriers' selection. Considering the feasibility of the experiment, only the quantity of parcels will be selected for validation concerning parcel characteristics. Since Delivery booking and bank credit modes require specific platform technologies, they will not be tested in this experiment. Therefore, this study ultimately selects remuneration, detour, parcel quantity and the use of parcel locker as the primary factors influencing carriers' acceptance of tasks and incorporates them into the utility function. Further validation of these attributes will be conducted in the model estimation derived from experimental data. Based on the results of the literature review, five factors have been selected as the validation objects for this study, including remuneration, parcel quantity, whether to use a parcel locker or not, total delivery time and travel time. The explanations for each factor are shown in Table 2. These factors will be examined and validated in the context of the study.

Table 2: Factors to be tested in this study

Factor	Explanation
Remuneration	The amount of compensation offered for completing tasks.
Parcel Quantity	The number of parcels to be delivered in a single task.
Whether to Use Parcel Locker or Not	The decision to use a parcel locker as part of the delivery process or not.
Total Delivery Time	The total time required to complete the delivery task.
Travel Time	The time spent traveling from the starting point to the destination.

3. Methodology

This chapter first introduces the conceptual framework adopted in this study, followed by an explanation of the data collection and data processing methods employed in establishing the choice model to address the second research subquestion. Lastly, the simulation model is explained for the subsequent case study.

3.1. Conceptual model

It is worth noting that there is currently a lack of research investigating the impact of parcel lockers on crowdshipping from the perspective of individual choice behavior. Additionally, there is a lack of further understanding of how crowdshipping services may vary based on individual choice behavior in the presence or absence of parcel lockers. The conceptual model for this research is given in Figure 1. The focus of the conceptual model is to understand the key elements of this research and the interactions between these elements.

Based on the literature review, five factors have been identified as influencing carriers' choice behavior, including remuneration, detour, travel time, total delivery time, parcel quantity and the use of parcel locker. In this study, the use of parcel lockers is one of the leading research objectives. Therefore, the experiment involves the practical use of parcel lockers. Ultimately, through the analysis of carriers' choice behavior and the application of the simulation model in a case study, theoretical support is provided for understanding the impact of parcel lockers on crowdshipping from a supply-side perspective.

The experiment collected carriers' choice data and fitted it to a choice model that incorporates the research factors. This allows for an assessment of the impact of each factor on choice behavior. The data obtained from the revealed preference experiment can reflect carriers' behavior in the real world, enhancing the persuasiveness of the model estimation. Due to the time constraints as well as technical problems in the crowdshipping platform used in the experiment, insufficient data were obtained. To ensure reliable results, an available SP survey from another research was used to collect SP data, but most SP data

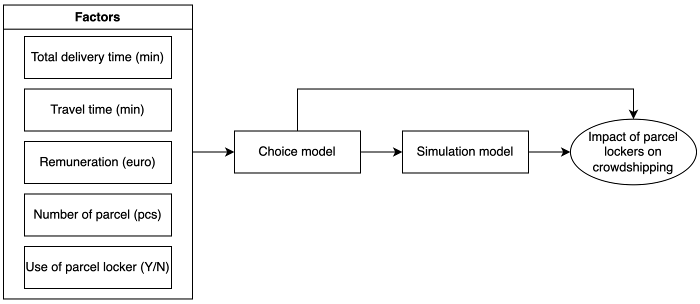


Figure 1: Conceptual model

was retrieved from the same research. This data was then combined with the RP data to obtain the final results. Eventually, the utility function representing carriers' choice behavior was used as input to establish a supply-side simulation model, providing insights into the impact of parcel lockers on crowdshipping.

3.2. Revealed preference experiment

Revealed preference methods are a set of techniques used in economics and consumer behavior research to infer an individual's preferences and choices based on their observed behavior (Richter, 1966; Houthakker, 1950; Sen, 1971). Revealed preference methods offer non-intrusive, real-world insights into consumer choices, based on observed behavior, with broad applications and policy relevance. Crowdshipping, as a logistics model with potential applications in the future, requires further validation through real-world observational data to genuinely understand the principles underlying carriers' choice behavior. This will lay the foundation for the development of a business model.

3.2.1. Experiment objectives and scope

There is currently no crowdshipping service in operation in the Netherlands. Therefore, the factors influencing individuals' decisions to become carriers, as identified, are predominantly derived from the stated preference experiments conducted at the research level. Furthermore, given the novelty of applying parcel lockers in crowdshipping services, it is essential to gain insights into the impacts of parcel lockers on crowdshipping services. Therefore, the experiment focuses on the collection of revealed preference data, where participants actively engage in crowdshipping tasks and provide feedback based on their real-world experiences.

To reduce the complexity of the experiment, the experiment involves only three regions: Delft, Den Haag, and Rotterdam. Although it is not possible to conduct the experiment throughout the entire Netherlands, these cities are representative and suitable for the purpose since these cities are highly populated (**?**). These cities provide a significant commuting population, which can provide sufficient support for crowdshipping services with an adequate number of carriers. Moreover, in terms of distance, the trips among these cities represent a variety of distance categories ranging from 3 km to 35 km, offering the possibility of diverse delivery distances. According to **?**, universities can be considered as a favorable community for the development of crowdshipping services. University students and staff members are generally more receptive to new developments and innovative solutions, which may make it easier to collect a larger amount of data from this group. Therefore, the parcel lockers used in this experiment are located at the TU Delft Faculty of Civil Engineering and Geosciences, which results in the target audience mainly consisting of students and faculty members.

3.2.2. Experiment design

After deciding to use Delft, Rotterdam, and Den Haag as the research area, it is necessary to select specific addresses within the study area as starting and ending points for parcel delivery. Subsequently, we reached out to our network residing in these cities and individuals who showed interest in participating in the experiment to make use of their addresses. Ultimately, we acquired five addresses in Den Haag, nine addresses in Delft, and three addresses in Rotterdam. The compensations offered to carriers are calculated based on the distance between the origin and destination. Therefore, it is necessary to know the distance between the addresses. According to Tapia et al. (2023), crowdshipping is likely to increase congestion and GHG emissions. However, there are no constraints on the mode of transportation in his research. In the case of car-based crowdshipping, it is expected that the current situation is not improved in terms of GHG and emissions. Thus, this experiment encourages people to use active modes as a means of reducing the negative impacts associated with parcel delivery. Google Maps is utilized to determine average travel times and distances between the specified origins and destinations.

The main research attributes of this experiment include detour, total travel time, remuneration, number of parcels, and whether to use parcel lockers. Due to the different modes of transportation used by carriers, there may be significant variations in estimating travel time and consequently the detour between origin and destinations. Therefore, distance is used as a criterion to decide the remunerations instead of time. Detour is measured in time because the post-task questionnaires provide insights into the travel mode of occasional carriers, enabling a relatively accurate estimation of the time spent completing a delivery task. In the experiment, three levels of remuneration were established for completing a delivery task, which includes 0.5€/km, 1€/km, and 1.5€/km. Then, it is possible to see people's choice behavior toward different pricing. To establish various parcel delivery distances, different addresses were selected as the starting and ending points for parcel delivery. As for the number of parcels, two parcels were made to two destinations from the same origin. The corresponding compensation was set at or above the level of compensation for single-package tasks within the same distance range. Finally, the consideration of parcel locker factors was incorporated by introducing parcel lockers as either the starting or ending point for parcel delivery in some of the tasks.

The crowdshipping platform called Nimber was used in this project. The tasks were created and posted on this platform, and people can download an app called "Nimber for Bringers" to search for tasks based on their preferences. After the tasks are posted on Nimber, users can get notifications if they save the preferred locations. The parcel locker utilized in the experiment, located at TU Delft, is provided by MyPup. Codes for opening lockers can be generated by issuing a new item in the system. The entire process of the experiment can be summarized as follows:

1. Prior to the experiment, the parcels are handed over to the starting points of the parcel delivery tasks.
2. According to the plan, crowdshipping tasks are gradually posted on the platform, with approximately ten tasks scheduled per week.
3. Carrier accepts a task if agrees with the offered remuneration. Additionally, bringers have the possibility to bid for a parcel.
4. Carrier picks up the parcels at the designated points. If the origin is at the parcel lockers in TU Delft, the code for opening the locker will be sent to the carrier in the chat box on the Nimber platform. To generate the code MyPup platform is used, as explained above.
5. Carrier delivers the parcel to the destination. If the destination is the parcel lockers located at TU Delft, the carrier will receive the code generated by MyPuP platform to open the locker through the chat box on the Nimber platform.

The experiment utilized parcels of mailbox size, each containing a single book. It is motivated by three main reasons. Firstly, this study focuses primarily on the transportation of small parcels. With the rapid growth of the e-commerce industry, an increasing number of people opt for online shopping. E-commerce platforms typically sell small-sized items such as clothing, shoes, electronics, and food, which are commonly shipped in the form of small parcels. Therefore, the transportation of small parcels is an integral and essential component that cannot be overlooked. Secondly, it simplifies the operational complexity of the experiment, as occasional carriers can simply drop the parcels into the corresponding mailboxes in apartment buildings without the need for practical coordination with the receivers. Reducing task complexity may potentially attract a greater number of experimental participants. Thirdly, it enables occasional carriers to conveniently carry the parcels while cycling or using public transportation, thereby minimizing potential additional emissions by using private cars. This aligns with the values advocated by crowdshipping.

3.2.3. Data collection

In order to calculate the total delivery time and travel time, it is necessary to know the transportation modes used by carriers and carriers' trip origins and destinations. To facilitate the gathering of this information, an electronic questionnaire has been created and distributed to individuals who have completed parcel delivery tasks. Based on the transportation mode and travel distance, the total delivery time and travel time were obtained through Google Maps. Total delivery time refers to the overall time it takes for the carrier to travel from the starting point of the journey to the parcel pickup location, then to the parcel delivery location, and finally to the destination point of the journey. Travel time refers to the duration it takes for a person to travel from the starting point to the destination point of a journey, without considering any additional time spent on delivering packages. It represents the time spent solely on the personal transportation aspect of the journey. After collecting this data, it comes to the data preprocessing step. Based on the results of the survey, we can obtain information about the origin and destination of the participants' trips in crowdshipping. In order to obtain data in a format where one person's choices for multiple tasks can be matched with the requirements of data processing, several assumptions were made:

- Carriers' trips occur regularly since the experiment targets individuals who frequently commute to universities.
- Carriers would frequently check for published tasks since the participants demonstrated a high level of acceptance in the post-survey.
- If an individual submits an application for a specific task, it is assumed that the individual has chosen to accept that task, even if each task can only be completed by one carrier.

Based on these assumptions, all tasks posted on the platform can be considered potential choices for each carrier. In the end, the experiment involved the participation of 7 individuals who successfully completed 11 tasks. Therefore, each carrier had 11 choices, resulting in a total of 77 choice sets.

3.3. Choice data combination

Due to the involvement of only 7 participants, a total of 77 observations were ultimately obtained. In order to ensure the credibility of the choice model, a stated preference (SP) experiment method was employed to continue data collection. Then, the combination of RP and SP data can be finished to perform choice model estimation. Eventually, the significant factors can be obtained from the interpretation of the model estimation result.

3.3.1. Stated preference data

The challenge in conducting RP experiments for crowdshipping lies in the fact that this service is a completely new concept for the public. People are often reluctant to participate in such experiments when they have little or no prior knowledge of the service. On the other hand, SP experiments can assist in collecting data more efficiently and rapidly, as they allow participants to express their preferences and choices without the need for prior real-world experience with the new concept. According to Lavasani et al. (2017), SP experiments are generally useful if there is a need to understand people's responses to new alternatives that have not yet been implemented. In the SP experiment, respondents are requested to make choices within a series of hypothetical scenarios. The data obtained from the SP experiment originated from a study conducted by Cebeci et al. (2023b). Table **??** displays the attributes and their corresponding levels for the SP experiment.

With this information, relevant surveys were designed, and respondents were asked to indicate their acceptance of crowdshipping tasks based on the hypothetical scenarios and provided attribute levels in the questionnaire. A total of 2400 choice sets were ultimately obtained from the SP experiment.

3.3.2. Mathematical formulation

According to Bierlaire (1998), discrete choice models (DCMs) were deployed to analyze the decision-making of the respondents. Here, econometric modeling techniques are employed to identify the behavioral preferences of the respondents. The random utility Maximization (RUM) is adopted by DCMs (McFadden, 1974). It assumes that individuals choose the alternative i which has the highest utility (U_i) in the choice set M as shown in the equation below.

$$U_i > U_j \qquad \forall i \neq j \in M \tag{1}$$

The utility of alternative i evaluated by individual n can be shown as:

$$U_{in} = V_i + \varepsilon_{in} \tag{2}$$

Where V_i is the systematic utility of alternative i and ε_{in} is the error term that captures uncertainty in choice making. The total utility is defined as a linear additive function combined with an error term, which can be shown as:

$$U_{in} = \sum_m \beta_m x_{im} + \varepsilon_{in} \tag{3}$$

Where β_m stands for the coefficient of an attribute m and x_{im} is the attribute value. The factors that are explored in this project are total delivery time, travel time, remuneration, the number of parcels and whether to use a parcel locker. For each task, the potential occasional carriers have two choices: to pick up the package or not to pick up the package. Then, the utility function for picking up and not picking up was created respectively:

$$\begin{aligned} V_{Pickup} =& \beta_{tt\_trip} * TDT + \beta_{rem} * Rem + \beta_{pup} * Locker\_or\_Not \\ &+ \beta_{num\_p} * (Num\_P - 1) \end{aligned} \tag{4}$$

$$V_{Notpickup} = \beta_{tt\_trip} * TT + ASC\_NP \tag{5}$$

Where TDT, TT, Rem, Num_P, $Locker\_or\_Not$ and ASC_NP stand for the total delivery time, travel time, remuneration, number of parcels, whether to use a parcel locker or not and alternative specific constant for not picking up, respectively.

The Multinomial Logit (MNL) model is a widely used and straightforward approach for modeling discrete choices under the Random Utility Maximization (RUM) assumption. It assumes that the error terms are independent and identically distributed according to the Gumbel distribution. In this type of model, the probability of an individual n choosing alternative i is estimated by the following equation:

$$P_i = \frac{e^{V_i}}{\sum_{i=1}^{I} V_i} \tag{6}$$

In this study, each alternative is independent and identically distributed. Therefore, the probability of each alternative can be calculated by Equation 6.

3.3.3. Combination of RP and SP

RP and SP data sources have their own strengths and weaknesses, and by using both of them, we can better understand how people make choices and express their preferences (Hensher et al., 1998). In the MNL model, there is typically a single scale parameter, often denoted as λ. It is a positive real number used to adjust the scale parameter of the Gumbel distribution. The MNL model assumes that the error terms for all choices have the same scale parameter λ, meaning that the variances of error terms are equal across all choices. The scale parameter is useful in the process of merging RP and SP data. Here is a detailed description of the data merging process:

1. **Data Preparation:** Organize and prepare RP and SP data for modeling. Ensure that both datasets have a similar structure, including the same choices, attributes, and identification information.
2. **Model Estimation:** For both RP and SP datasets, estimate choice models. These models capture the relationships between attributes, choices, and preferences. The scale parameter is an essential part of these models, helping to scale the utility values.
3. **Scale Adjustment:** Adjust the scale parameter for the SP dataset, to align it with the scale of the RP dataset. This adjustment is necessary because the scale parameters may differ between the two datasets due to differences in data collection methods and response behaviors. The scale parameter is estimated using Maximum Likelihood Estimation. According to Hess and Palma (2023), the scale adjustment was performed through R (Apollo).

3.3.4. Data analysis and interpretation

There are multiple choices regarding the estimation of MNL models, such as R (Apollo), Python (statsmodels), Stata and MATLAB. In this study, R (Apollo) is used to estimate the MNL model. According to Hess and Palma (2023), the combination of RP and SP data was implemented. After inputting the data into the estimation tool, the model calculates the coefficients and their corresponding standard errors, t-values and p-values, which provide information about the statistical significance of each variable in the model. These coefficients represent the estimated effects of the independent variables on the choice probabilities. By analyzing these coefficients, we can understand the influence of each variable on the decision-making process and the relative importance of different factors in determining the choices made by individuals.

The interpretation of the results starts by examining the signs (+/-) of the estimated coefficients. A positive coefficient indicates a positive effect on the probability of choosing a particular alternative, while a negative coefficient indicates a negative effect. The magnitude of the coefficient represents the size of the effect. Then, it is necessary to assess the statistical significance of the estimated coefficients. The p-value associated with each coefficient indicates the probability of observing the estimated coefficient if there is no true effect in the population. Generally, coefficients with p-values less than a predefined significance level (e.g., 0.05) are considered statistically significant, indicating high confidence in the estimated effect. In order to identify the most influential factors in the choice model, compare the magnitude and statistical significance of the coefficients. Coefficients with larger magnitudes and smaller p-values generally have a stronger impact on the choice probabilities. The results of the data analysis will reveal whether the inclusion of parcel lockers has an impact on carriers' individual choice behavior.

3.4. Simulation model

To gain a deeper understanding of the potential impact of parcel lockers on crowdshipping, this section explains how, based on the individual choice model, a simulation model was developed to simulate the choices of carriers regarding crowdshipping tasks. This enhances the comprehensiveness of the research.

3.4.1. Generation of carriers

Based on the context of this study, carriers make their parcel delivery choices based on their existing travel plans. Therefore, it is necessary to generate starting and ending points for carriers' trips in the model. The travel routes of people are set to be random in the model. In each path, several carriers are set, and the model will output their choice behaviors. The model is run multiple times to compare the output data to ensure the reliability of the results.

3.5. Crowdshipping task

To generate crowdshipping tasks, the first step is to define the starting and ending points of the tasks within the network. Then, the locations of parcel lockers need to be determined within the network. The locations of the starting point, ending point, and parcel lockers will affect the travel time for carriers, and travel time is one of the factors influencing carriers' decisions. Afterward, it's necessary to consider attribute levels that influence carriers' choice behavior, such as the level of remuneration, the number of parcels, etc. However, in this context, only the significant factors obtained from the model estimation need to be considered. The values of these attributes can directly influence the task choices made by carriers.

3.6. Choice behavior of carriers

The choice behavior of each carrier depends on the utility functions mentioned by Equations 4 and 5. By setting the values of significant factors derived from the choice model estimation, the utilities for each leg in joint crowdshipping, direct crowdshipping and declining a task within a parcel delivery task can be derived. Then, it is possible to determine the corresponding probabilities for carriers to choose each alternative by Equation 6. The larger the probability associated with an alternative, the more likely a carrier is to select that alternative, and conversely, the smaller the probability, the less likely they are to choose that alternative. For instance, in a crowdshipping network with only one parcel locker, let's assume a carrier's probabilities for different choices are as follows:

- Probability of choosing direct crowdshipping: 0.4

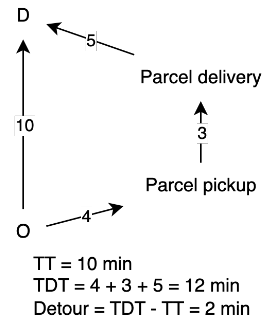


Figure 2: Example of detour

- Probability of choosing joint crowdshipping on leg 1: 0.3
- Probability of choosing joint crowdshipping on leg 2: 0.2
- Probability of declining the task: 0.1

To model this behavior, you generate a random number between 0 and 1. Depending on the value of this random number, the carrier makes their choice as follows:

- If the random number is less than 0.4, the carrier chooses direct crowdshipping.
- If the random number is greater than or equal to 0.4 but less than 0.7, the carrier chooses joint crowdshipping on leg 1.
- If the random number is greater than or equal to 0.7 but less than 0.9, the carrier chooses joint crowdshipping on leg 2.
- If the random number is greater than or equal to 0.9, the carrier declines the task.

This approach simulates the probabilistic nature of the carrier's decision-making process within the crowdshipping network.

3.6.1. Key performance indicator

In the model, TT represents the travel time for a carrier when they do not accept a task, which is the time spent on the randomly generated route. On the other hand, TDT represents the travel time for a carrier when they accept a task. It includes the time it takes to travel from the randomly generated route's starting point to the package pickup point, then to the package delivery point, and finally back to the original route's endpoint. These values for TT and TDT are automatically calculated by the model based on the carrier's choice determined by the utility function. Detour is then computed as the difference between TDT and TT. There is an example shown in Figure 2.

To compare the impact of parcel lockers on crowdshipping, the model is divided into two parts, and five Key Performance Indicators (KPIs) are presented as the output results of the model. The first part does not incorporate parcel lockers within the network. Carriers directly deliver the parcels to their destinations, which is called direct crowdshipping. There is an example shown in Figure 3. The KPIs without the use of parcel

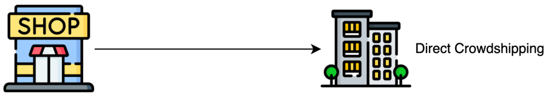


Figure 3: Example of direct crowdshipping

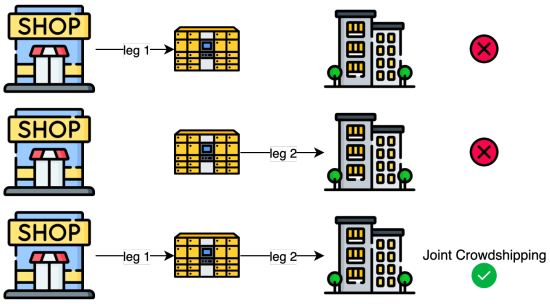


Figure 4: Example of joint crowdshipping

lockers are shown by Equations 7 and 8.

$$Acceptance\_Rate\_without\_Locker = \frac{Num\_pup\_without\_locker}{Num\_total} \times 100\% \quad (7)$$

$$Average\_Detour\_without\_Locker = \frac{Detour\_total\_without\_locker}{Num\_total} [min] \quad (8)$$

Which is valid where $Num\_pup\_without\_locker$ is the number of individuals accepting crowdshipping tasks, $Detour\_total\_without\_locker$ is all the detours generated by completing tasks and Num_total is the total number of carriers selected.

The second part involves the incorporation of a certain number of parcel lockers within the network. When two carriers are randomly selected to complete leg 1 and leg 2 with the same parcel locker as a transit point, it represents the completion of one joint crowdshipping. There is an example shown in Figure 4. The KPIs with the use of parcel lockers are shown by Equations 9, 10 and 11.

$$Acceptance\_Rate\_with\_Locker = \frac{Num\_pickup\_with\_locker}{Num\_total} \times 100\% \quad (9)$$

$$Average\_Detour\_with\_Locker = \frac{Detour\_total\_with\_locker}{Num\_total} [min] \quad (10)$$

$$Percentage\_of\_JC = \frac{Num\_joint}{Num\_joint + Num\_direct} \times 100\% \quad (11)$$

Which is valid where Num_joint is the number of joint crowdshipping, Num_direct is the number of direct crowdshipping, $Detour\_total\_with\_locker$ is all the detours generated by completing tasks and Num_total is the total number of carriers.

To gain insights into the utilization of parcel lockers within the network and assist companies offering parcel locker services in long-term planning and layout, the usage frequency of each parcel locker within the network will be recorded as part of the KPIs. The average detour will be of particular interest to both the parcel locker provider and the crowdshipping platform. This metric can provide insights into the impact of parcel lockers on detours within the crowdshipping network. The parcel locker provider aims to optimize the parcel locker network to minimize detours and increase locker utilization, thereby earning fees. The crowdshipping platform seeks effective means to reduce detours, enhance the user experience, and generate higher profits. The acceptance rate and percentage of joint crowdshipping directly reflect the impact of parcel lockers on crowdshipping and can aid both the crowdshipping platform and parcel locker provider in making relevant planning and adjustments. In addition, these KPIs serve as analysis tools for the subsequent case study.

4. Case study

In this section, the case study focuses on the last-mile delivery within a city. It utilizes the simulation model mentioned in Section 3.4 to analyze the impact of parcel lockers as transfer points on crowdshipping from a macro perspective. First, the case is presented, followed by the introduction of simulation scenarios. Because the results of the choice model are required as inputs for the simulation model, the analysis of choice data will be presented as the third part. At the end of this chapter, the results of the case study are discussed.

4.1. Background

According to TUD (2022), in October 2022, the total number of students at TU Delft was 27,824, which was roughly the same as the previous year's figure of 27,933. Additionally, there were 8,651 students who registered at TU Delft for the first time during that period. A large number of new students come to Delft to reside here and commence their academic life. Living in a new city often requires new household items, especially for students residing in student apartments. On the outskirts of Delft, there is an IKEA store that offers cost-effective household products for consumers. Therefore, students may be willing to visit IKEA for some of their household purchases. However, IKEA is located on the city's outskirts, and it takes a considerable amount of time to reach it by cycling or using public transportation. Alternatively, if consumers choose to shop on the IKEA e-commerce platform, they would incur a delivery fee of either 5 euros or 7 euros, and it would take at least two days to receive the ordered items. In this situation, consumers prefer a delivery method that is cheap and quick to receive their ordered goods. As the focus of this project, crowdshipping can effectively meet the consumers' needs. If there is a group of people traveling from IKEA to destinations within Delft, they can serve as carriers to deliver the goods ordered by consumers from IKEA, offering a fast and cheap way to complete the tasks. As there is currently no large-scale operational crowdshipping platform in the Netherlands, the cooperation model between IKEA and the crowdshipping platform in this case study is based on assumptions. When consumers place an order on the IKEA website, they choose the crowdshipping option. IKEA then shares the order details with the crowdshipping platform to match it with an appropriate carrier. If the match is unsuccessful, IKEA informs the consumer via email that the order cannot be successfully delivered and suggests alternative purchase methods. If the match is successful,

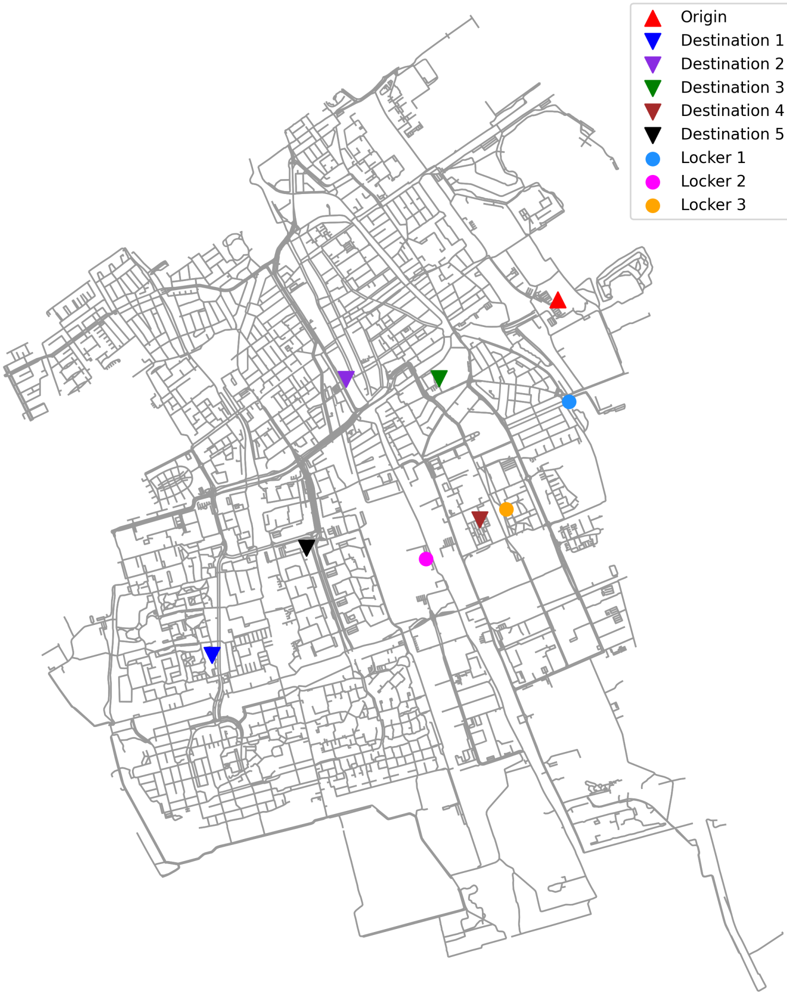


Figure 5: Map

IKEA prepares the items in advance for pickup by the carrier. After successfully delivering the package to its destination, the carrier can receive the corresponding compensation from the crowdshipping platform. For each task, there are three options: delivering the package from IKEA to the destination, delivering it from IKEA to a specific parcel locker, and delivering it from a specific parcel locker to the destination. For the latter two options, the task will only be initiated when both of them are accepted. In contrast, for direct delivery to the destination, the task can be initiated as soon as someone accepts it.

In this case study, the parcel delivery starting point is selected as IKEA in Delft, the delivery endpoints are five student apartment buildings scattered across different locations, and the transfer points are three parcel lockers set up by MyPup in Delft. Since this study primarily focuses on bicycle delivery mode, it utilizes the bicycle network within Delft as the main mode of transportation. The transportation network and specific locations of all these points are indicated in Figure 5.

It's worth noting that this project primarily focuses on the supply-side research of crowdshipping, and variables related to the demand side are not within the scope of this study. Therefore, all subsequent analyses are approached from the perspective of carriers, and this aspect should be kept in mind.

4.2. Assumptions

Due to limitations in the model, certain assumptions were made for the simulation to simplify the complexity of real-world situations:

1. **Research Focus:** The study focuses on the supply side of crowdshipping and does not consider factors related to consumer demand. As mentioned in Section 4.1, the preconditions involve consumers choosing crowdshipping as their parcel delivery method, with a crowdshipping platform collaborating with IKEA to match carriers.
2. **Carrier Mode of Transportation:** All carriers are assumed to use bicycles as their mode of transportation for simplicity.
3. **Generation of Routes:** The carriers' original routes are randomly generated within the research area's network.
4. **Task Completion:** Carriers commence parcel delivery promptly upon task acceptance and invariably achieve suc-

cessful completion. In addition, consider only single-package delivery to the same destination, excluding scenarios involving multiple packages transported to different destinations.
5. **Route Selection:** Between two points, carriers choose the shortest path.
6. **Bidding:** For some existing crowdshipping platforms, such as Nimber, there is a bidding process. However, in the simulation, there is no bidding process. Once the remuneration is set, carriers can only choose to accept or decline the task, and there is no provision for making new bids.

These assumptions were necessary to simplify the model and make it feasible for the case study. However, it's important to acknowledge that they may not fully represent real-world conditions. Therefore, further research should be conducted in the future to investigate these unconsidered aspects.

4.3. Alternatives

This utility function in the simulation model determines the behavior choices of carriers. For each carrier, there are three choices when it comes to parcel delivery:

1. Directly delivering the parcel from the starting point to the destination without using a parcel locker (Direct crowdshipping).
2. Using a parcel locker to deliver the parcel from the starting point to the locker (leg1) or from the locker to the destination (leg2). When both leg1 and leg2 are completed, it is referred to as a "joint crowdshipping".
3. Rejecting the task and not accepting it.

In this case, there are three parcel lockers, and carriers can freely choose from these three lockers. Therefore, for each carrier, it is necessary to calculate the utility associated with leg1 and leg2 for each of the three parcel lockers, in addition to considering direct delivery and rejecting the task. This results in a total of eight possible choices, which is shown in Figure 6. Then, the total utility is computed for each of these choices, followed by calculating their respective probabilities. A higher probability indicates a greater likelihood that the carrier will opt for a specific choice, and Section 3.6 provides a detailed demonstration of how the simulation model obtains the final choice outcome for each carrier.

5. Operational procedures

Before commencing scenario setup, it is essential to make adjustments and confirm certain parameters within the model. The specific utility function, represented by Equations 4 and 5, should be incorporated into the model. Subsequently, the value for 'remuneration' needs to be specified, with its determination explained in the subsequent scenario analysis. According to Satrio Wicaksono (2018), the number of commuting trips within Delft was estimated at 22,723 in 2017. Due to the presence of an error term in the choice model, carriers'

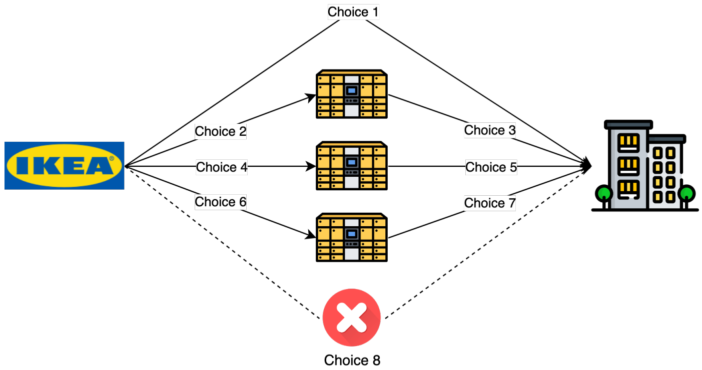


Figure 6: Alternatives

choices for each alternative are probabilistic. To make the simulation results more representative, 23 carriers were set on each randomly generated route, and a total of 1000 routes were randomly generated within the actual Delft transportation network. This approach ensures that 23,000 commuting trips are met in the simulation. Eventually, the output KPI data was used for a detailed analysis of the case. It is noteworthy that the output of KPIs for crowdshipping without lockers and crowdshipping with lockers is based on the same set of carriers. The calculation methods of the KPIs are mentioned in Section 3.6.1.

5.1. Results

In this section, the results of the choice model and simulation model were given as well as the results analysis. For the simulation, two scenarios were configured, including a testing of destination location and remuneration. The content of the following sections gave specific explanations.

5.1.1. Choice model estimation

Before commencing the collection of simulation data, it is essential to validate the carrier's choice model. This involves fitting the obtained choice data from experiments to the proposed utility mathematical model to identify significant factors affecting carriers' task selection and their corresponding parameter values. This quantifies the influence of each factor on the choice and serves as input for the simulation model, enabling the research to proceed with simulations.

According to Hess and Palma (2023), the combination of SP data and RP data was finished. The result is shown in Table 3.

Based on the results of model estimation, it is evident that travel time, total delivery time, and remuneration are significant factors that influence carriers' choices. On the other hand, parcel quantity, whether to use parcel lockers and ASC_{NP} (Alternative Specific Constant for Not Picking up) are insignificant factors, indicating that carriers do not take these factors into consideration when making task selections. The estimated coefficient values reveal that remuneration has a positive effect on carriers' acceptance of tasks, while travel time and total delivery time have a negative impact on their decision to accept tasks. Finally, the utility function can be expressed as follows:

$$V_{Pickup} = -0.17631 * TDT + 0.96582 * Rem \tag{12}$$

Table 3: Model estimation

Model Estimation		
Coefficients	Est.	p-value
β_{tt_trip}	-0.17631	0.0002*
β_{rem}	0.96582	0.0004*
β_{num_p}	-0.42040	0.3551
β_{pup}	1.43706	0.1684
ASC_NP	4.72156	0.0902
Data Source		
Indicators	Value	
Number of choice sets	2477	
RP Observations	77	
SP Observations	2400	

*Significance level on 95% confidence interval
"ASC" stands for Alternative Specific Constant

$$V_{Notpickup} = -0.17631 * TT \quad (13)$$

Where TDT, TT and *Rem* stand for the total delivery time, travel time and Remuneration. In this scenario, it is assumed that all carriers use bicycles as their mode of transportation. Therefore, the time can be calculated by dividing the distance between two locations by the average bicycle speed of 4.2 m/s.

The VoT values provide insights into the trade-off between time and money for individuals participating in crowdshipping. It helps to understand the economic incentives and motivations for users to engage in these activities. The VoT represents the monetary value that individuals place on their time. The VoT value is calculated by Equation 14. The calculated result is 11 €/h, which means that the carrier should be compensated with 11 euros to offset the additional one hour of time spent on delivering the parcel.

$$\frac{-\beta_{tt_{trip}}[1/min]}{\beta_{rem}[1/euro]} * 60[h/min] \quad (14)$$

5.1.2. Scenario 1: Destination location

In Scenario 1, we keep the value of remuneration fixed and conduct experiments by selecting different destination locations. In 2021, the average price of parcel delivery in the business-to-consumer market was €3,66 in the Netherlands (Markt, 2021). Upon querying IKEA's online store, it was found that there are two delivery services available for the shipment of small items to Delft, both managed by PostNL. One is the standard express delivery service, incurring an additional cost of €5, with delivery scheduled for the third day following the order placement. The other option is the evening express delivery service, requiring an extra expenditure of €7, and with delivery set for the evening of the second day after the order is placed. Combining these two pieces of information, in Scenario 1, remuneration is set at €4. The remuneration of 4 euros is awarded for completing the delivery from IKEA to the student apartment building. The remuneration related to deliveries from IKEA to the parcel locker and from the parcel locker to IKEA is divided proportionally based on the respective distances, calculated according to Equation 15 and 16.

Table 4: Distances

[meter]	**IKEA**	**Locker 1**	**Locker 2**	**Locker 3**
IKEA		1151	2898	2163
Destination 1	4487	4064	2675	3503
Destination 2	2451	2348	1628	2167
Destination 3	1536	1119	1667	1224
Destination 4	2419	1501	1718	481
Destination 5	3208	2696	1692	2231

$$Rem\_leg1 = \frac{Distance\_leg1}{Distance\_leg1 + Distance\_leg2} Rem\_total[euro] \quad (15)$$

$$Rem\_leg2 = \frac{Distance\_leg2}{Distance\_leg1 + Distance\_leg2} Rem\_total[euro] \quad (16)$$

Which is valid where Rem_leg1 is the remuneration for the first leg of joint crowdshipping, Rem_leg2 is the remuneration for the second leg of joint crowdshipping, $Distance\_leg1$ is the distance from IKEA to the parcel locker, $Distance\_leg2$ is the distance from the parcel locker to the student apartment building and Rem_total is the total remuneration from IKEA to the student apartment building, which is €4. The remuneration for leg1 and leg2 is calculated automatically by the model.

Due to the requirement of two carriers to complete two corresponding sub-tasks in joint crowdshipping, for the crowdshipping network with parcel lockers, the number of fulfilled tasks is no longer equal to the number of carriers who accepted the tasks. Instead, it can be represented by Equation 9.

$$Fulfilled\_tasks\_with\_lockers = \sum_{i}^{3} min(Num_{lockeri}leg1 + Num_{lockeri}leg2) + Num\_direct \quad (17)$$

Which is valid where Num_direct is the number of carriers who accepted direct crowdshipping tasks, $Num_{lockeri}leg1$ is the number of carriers who accepted the leg 1 task for locker i and $Num_{lockeri}leg1$ is the number of carriers who accepted the leg 2 task for locker i.

For the convenience of subsequent analysis, the distances between IKEA, the five student apartment buildings, and the three parcel lockers have all been computed. The distances are presented in Table 4, and the location numbers are shown in Figure 5.

Firstly, the 'acceptance rate with lockers' and 'acceptance rate without lockers' are displayed in Figure 7. Based on the figure, it can be observed that the acceptance rate with parcel lockers for each location is consistently higher than the acceptance rate without parcel lockers. This suggests that the utilization of parcel lockers has indeed increased the number of carriers who accept the crowdshipping tasks, with the most significant improvement seen for Destination 1 and the smallest for Destination 3. Additionally, according to Table 4, the distance

Table 5: Task fulfillment status in the crowdshipping network with parcel lockers

Destination	Fulfilled direct crowdshipping	Fulfilled joint crowdshipping				Fulfilled in total	Non-acceptance
		Locker 1	Locker 2	Locker 3	Total		
1	3979	1104	1104	1081	3289	7268	11845
2	8878	621	1104	782	2507	11385	7590
3	11500	690	782	460	1932	13432	5934
4	8441	322	0	368	690	9131	6670
5	6992	1104	851	943	2898	9890	8073

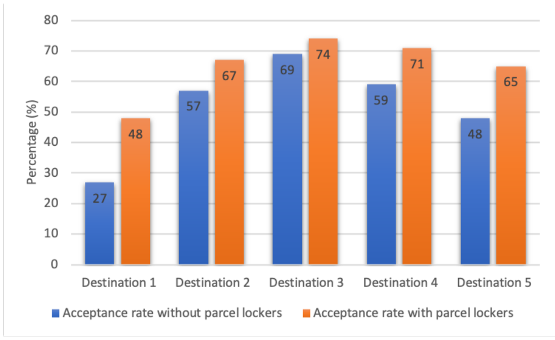


Figure 7: Acceptance rate with and without lockers

from IKEA to Destination 3 is the longest, while the distance to Destination 1 is the shortest. For destinations farther away, it is more likely that the use of parcel lockers as transfer points can enhance the system's acceptance rate.

Secondly, Tables 6 and 5 respectively display the task completion status for crowdshipping with and without the presence of parcel lockers. It is evident that joint crowdshipping attracts more participants to engage in parcel transportation while it also leads to some carriers who originally chose direct crowdshipping to switch to joint crowdshipping. However, except for Destination 1, the number of fulfilled tasks in the crowdshipping network without parcel lockers for all other destinations is higher than that in the crowdshipping network with parcel lockers. There are primarily two reasons for this phenomenon. First, carriers who were initially willing to accept direct crowdshipping tasks may switch to joint crowdshipping after its adoption, leading to a decrease in overall efficiency as joint crowdshipping requires two carriers to complete a task. Second, this study's compensation principle for joint crowdshipping is based on the length of the two legs' routes to allocate the total remuneration for the task. This approach may not achieve the best balance in task completion between the two legs, thus affecting the completion of joint crowdshipping tasks.

The percentage of joint crowdshipping for the five destinations is depicted in Figure 8. For Destinations 1, 2, and 5, the percentage of joint crowdshipping is all above 20%, with Destination 1 having the highest value at 45%. Following that is Destination 5, with a percentage of 29%. Considering Table 4, the three destinations with longer transport distances correspond to Destinations 1, 2, and 5. From this, we can conclude that for crowdshipping tasks with longer transport distances, the proportion of joint crowdshipping is more likely to be higher. In

Table 6: Task fulfillment status in the crowdshipping network without parcel lockers

Destination	Fulfilled	Non-acceptance
1	6165	16835
2	13178	9822
3	15757	7243
4	13593	9407
5	11017	11983

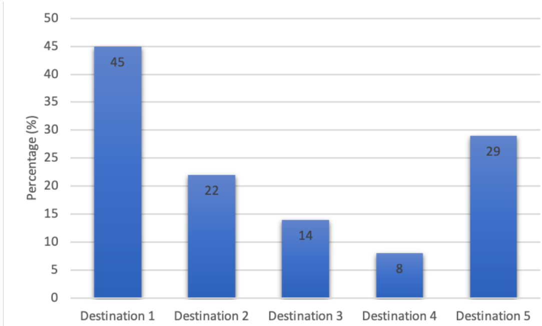


Figure 8: Percentage of joint delivery

addition, the average detour by carriers, which reflects the performance of the crowdshipping network, is presented in Figure 9. Based on the results from the graph, it is evident that after the application of parcel lockers, the average detour to all destinations has decreased, with a reduction in travel time ranging from 1 to 5 minutes. Since the detour is calculated based on individual carriers, the reduction in detours pertains to a single transportation task for a carrier. For joint crowdshipping, which requires two transportation tasks to connect, the total detour is indeed increased compared to direct crowdshipping. Consequently, consumers theoretically have to wait longer to receive their packages. Overall, while the application of parcel lockers has brought about a reduction in the additional time spent by carriers to some extent, the decrease in travel time for individual journeys has not reduced the overall time it takes to transport parcels from IKEA to the student apartments. Therefore, in this scenario, consumers do not seem to benefit from the application of parcel lockers in terms of time costs.

5.1.3. Scenario 2: Remuneration

In this scenario, the primary focus is to investigate how remuneration, as a variable, influences the role of parcel lockers in crowdshipping. Hence, the values of remuneration are set to

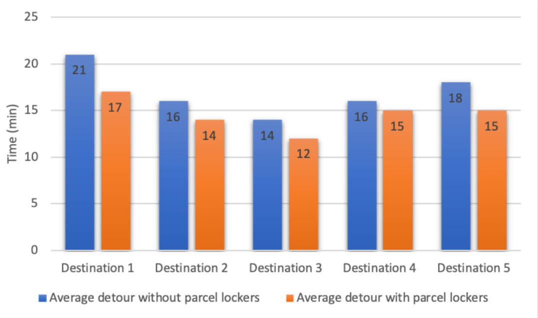


Figure 9: Average detour with and without parcel lockers

0, 2, 4 and 6, and data processing and analysis were conducted for each destination to obtain more representative conclusions. The remunerations for leg 1 and leg 2 of the joint crowdshipping have been already mentioned by Equations 15 and 16.

Firstly, the changes in the number of fulfilled tasks in the network with and without parcel lockers as remuneration varies for each destination are presented. As shown in Table 7 and 8, for most destinations, at a remuneration of €0 and €2, the number of fulfilled tasks with parcel lockers is higher than that without parcel lockers. With the increase in remuneration, both the number of fulfilled tasks with parcel lockers and the fulfilled tasks without parcel lockers are growing. However, the number of fulfilled tasks without parcel lockers surpasses the one with parcel lockers when the remuneration is €4. This result is entirely reasonable. The increase in remuneration stimulates carriers to accept parcel delivery tasks, whether with or without parcel lockers. However, in the case of parcel lockers, the growth in task completion is constrained to some extent due to the characteristic of joint crowdshipping requiring two carriers to complete, ultimately resulting in a lower number of fulfilled tasks compared to the scenario without parcel lockers.

Next, the curves depicting the changes in average detour with parcel lockers and average detour without parcel lockers for the five destinations as remuneration varies are presented. As shown in Figure 10, when remuneration increases, the average detour for carriers also increases, regardless of the presence of parcel lockers. This indicates that when carriers receive higher compensation, they are willing to spend more additional time on parcel delivery. When comparing the average detour without parcel lockers to the average detour with parcel lockers, it can be observed that the detour generated in the crowdshipping system with parcel lockers is lower than that without parcel lockers. When remuneration is low, carriers are not inclined to spend excessive additional time to complete delivery tasks. The application of parcel lockers allows tasks to no longer be limited to a single starting point and a single destination, making it more likely for carriers to complete tasks with lower detours, thus effectively reducing the detour compared to the scenario without parcel lockers. However, As remuneration increases, the effectiveness of parcel lockers in reducing detours gradually diminishes. When remuneration is high, carriers are willing to accept higher detours. Even in a system with parcel lockers, many carriers are willing to invest more additional time to complete tasks, thereby diminishing the advantage of parcel lockers in reducing detours. Eventually, the performance of the system with parcel lockers in terms of average detour becomes close to that of the system without parcel lockers.

Table 7: Number of fulfilled tasks in the network without parcel lockers

Destination	Fulfilled (€0)	Fulfilled (€2)	Fulfilled (€4)	Fulfilled (€6)
1	458	2530	6165	13340
2	1127	5521	13178	19778
3	1748	7820	15757	20705
4	1382	5752	13593	19783
5	921	4372	11017	18625

Table 8: Number of fulfilled tasks in the network with parcel lockers

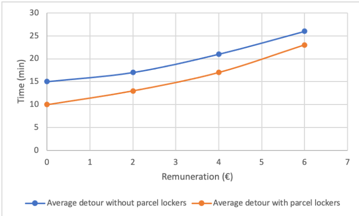
Remuneration = €0			
Destination	Fulfilled direct crowdshipping	Fulfilled joint crowdshipping	Fulfilled in total
1	299	575	874
2	1127	966	2093
3	1403	1633	3036
4	736	529	1265
5	690	943	1633

Remuneration = €2			
Destination	Fulfilled direct crowdshipping	Fulfilled joint crowdshipping	Fulfilled in total
1	1012	2024	3036
2	3887	2415	6302
3	4715	2415	7130
4	3519	2990	6509
5	2484	2208	4692

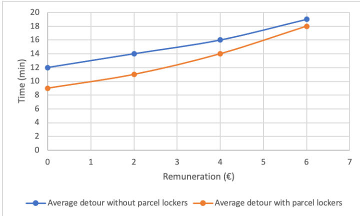
Remuneration = €4			
Destination	Fulfilled direct crowdshipping	Fulfilled joint crowdshipping	Fulfilled in total
1	3979	3289	7268
2	8878	2507	11385
3	11500	1932	13432
4	8441	690	9131
5	6992	2898	9890

Remuneration = €6			
Destination	Fulfilled direct crowdshipping	Fulfilled joint crowdshipping	Fulfilled in total
1	8556	3289	11845
2	14927	1265	16192
3	17894	1127	19021
4	12627	0	12627
5	12834	1610	14444

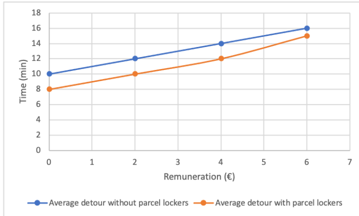
Lastly, based on Figure 11, we can observe the trend of the percentage of joint delivery as remuneration increases. As remuneration increases, apart from a slight increase occurring on Destinations 1 and 4, the percentage of joint crowdshipping for the other destinations gradually decreases, indicating a growing proportion of direct crowdshipping. Furthermore, combining the information from Figure 12 allows us to summarize the changes in carriers' flow. When remuneration is low, the acceptance rate with parcel lockers is higher than that without parcel lockers, indicating that the application of parcel lockers attracts more carriers. At the same time, the percentage of joint crowdshipping is high, ranging from 30% to 70% when the remuneration is €2. This suggests that in the absence of a parcel locker, some carriers who accept tasks are willing to use parcel lockers after the introduction of parcel lockers. However, from Figure 12, it can be observed that the acceptance rate without parcel lockers gradually catches up to that with parcel lockers. This suggests that carriers are gradually shifting towards direct crowdshipping.



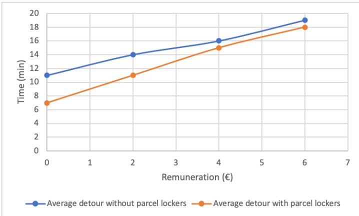
(a) Destination 1



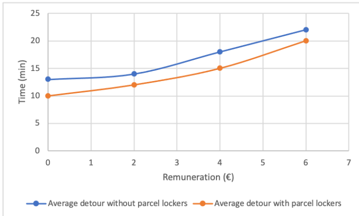
(b) Destination 2



(c) Destination 3

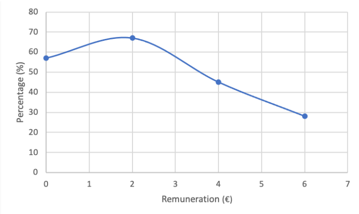


(d) Destination 4

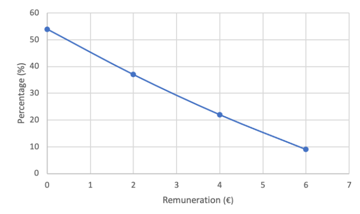


(e) Destination 5

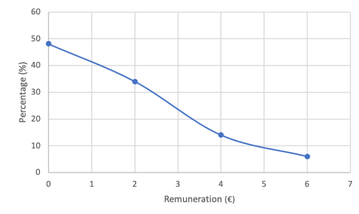
Figure 10: Average detour with and without parcel lockers



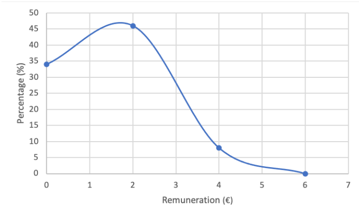
(a) Destination 1



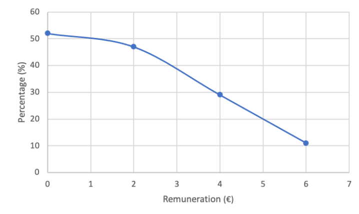
(b) Destination 2



(c) Destination 3

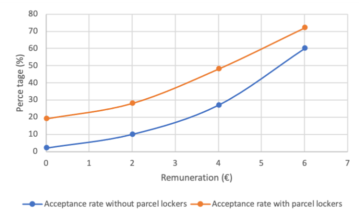


(d) Destination 4

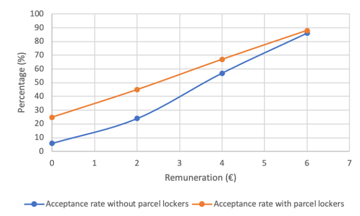


(e) Destination 5

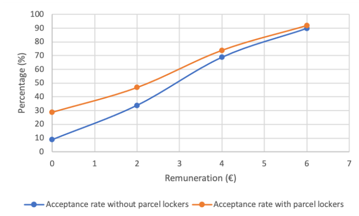
Figure 11: Percentage of joint crowdshipping



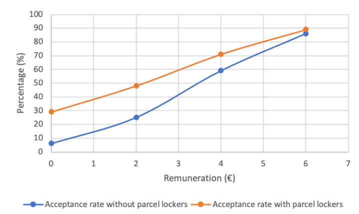
(a) Destination 1



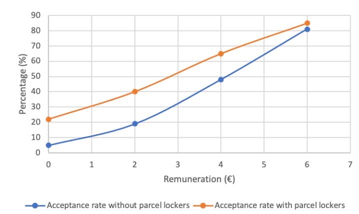
(b) Destination 2



(c) Destination 3



(d) Destination 4



(e) Destination 5

Figure 12: Acceptance rate with and without parcel lockers

6. Conclusions

From the perspective of carriers' choice behavior, the application of parcel lockers does not have a significant impact on whether carriers accept tasks or not. Carriers primarily consider factors such as time and compensation, and when the positive impact of compensation outweighs the negative impact of additional time spent, carriers are more likely to accept tasks.

From a group perspective, the application of parcel lockers does indeed help attract more carriers to accept tasks because the distribution of parcel lockers throughout the system aids in covering a wider range of carriers. However, joint crowdshipping still faces challenges with low fulfilled tasks. This is primarily due to the characteristic of joint crowdshipping that it requires two carriers to complete one task and the complexity of matching two separate sub-tasks. If there isn't a well-implemented matching mechanism in place, simply increasing the usage of parcel lockers may not be enough to encourage more carriers to successfully participate in parcel delivery. Furthermore, in scenarios where the compensation is low, the application of parcel lockers appears to have a more positive impact on crowdshipping. These are important considerations for crowdshipping platforms when developing and expanding their business.

Based on the literature review, crowdshipping has the potential to bring about a range of positive impacts. While the application of parcel lockers may have limitations, it still offers carriers additional options, benefiting various stakeholders. Therefore, overall, research on the application of parcel lockers in crowdshipping is meaningful and worthy of further exploration and discovery.

7. Recommendations

7.1. Recommendation for future research

For this study, only six factors were included in the analysis of the choice model. In future research, it would be advisable to consider a broader range of attributes, such as parcel size and weight, and to conduct analyses for different modes of transportation and travel purposes. These enhancements would contribute to the credibility and comprehensiveness of the results. In terms of data collection, it is essential to conduct further RP experiments to acquire authentic choice data from carriers. This will be instrumental in establishing a more persuasive and robust choice model. In addition, this study primarily focused on exploring the impact of parcel lockers on the supply side of crowdshipping. In future research, it would be valuable to also examine the demand side to validate whether the use of parcel lockers can make it easier for consumers to adopt crowdshipping services. This holistic approach would provide a more comprehensive understanding of the broader implications of parcel locker applications in the context of crowdshipping.

In the case study, several critical issues were identified that require particular attention when implementing parcel lockers. Firstly, the challenge of carrier matching emerged as a key concern. Joint delivery relies on two carriers each completing a segment of the delivery task. Finding effective methods to identify suitable carriers for task completion is a topic that requires further investigation in future research. Secondly, pricing strategies are of utmost importance. Determining the pricing structure for leg1 and leg2 to ensure that it remains competitive with direct delivery for the same journey while also effectively boosting the fulfillment rate of joint delivery is a complex issue that requires further examination. Lastly, the selection of parcel locker locations presents another avenue for future research. Exploring optimal parcel locker placement within the crowdshipping system to maximize their utilization and reduce the additional time carriers spend on task execution is a valuable direction for further study.

7.2. Recommendation for practice

Currently, there is no well-established crowdshipping platform in the Netherlands. However, from a stakeholder analysis perspective, crowdshipping has the potential to generate certain benefits for various stakeholders. Therefore, from an impact standpoint, crowdshipping is a worthwhile novel logistics transportation method to develop. However, when viewed from a business development perspective, carriers' lack of economies of scale presents challenges. Without the application of additional technologies, it is difficult to generate substantial revenue through sheer quantity, making commercial success relatively challenging.

For crowdshipping platforms, the primary challenge is to attract a sufficient number of carriers to provide services. This can be addressed through extensive promotional efforts and the development of new technologies. The use of parcel lockers represents a potential avenue for development, although further validation is required. Additionally, gaining an understanding of consumer demands and identifying the pain points associated with traditional logistics transportation is essential to provide improved services that can attract a larger user base.

For parcel locker providers, expanding their business into crowdshipping may still be early, and the role of parcel lockers in crowdshipping requires further validation. However, based on this research, it is evident that the application of parcel lockers does yield some positive effects, such as reducing detours and increasing acceptance rates. Therefore, locker providers should still monitor the development of crowdshipping and seize the opportunity to potentially expand their business in the crowdshipping direction in the future.

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