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The effects of crowdshipping on transport use

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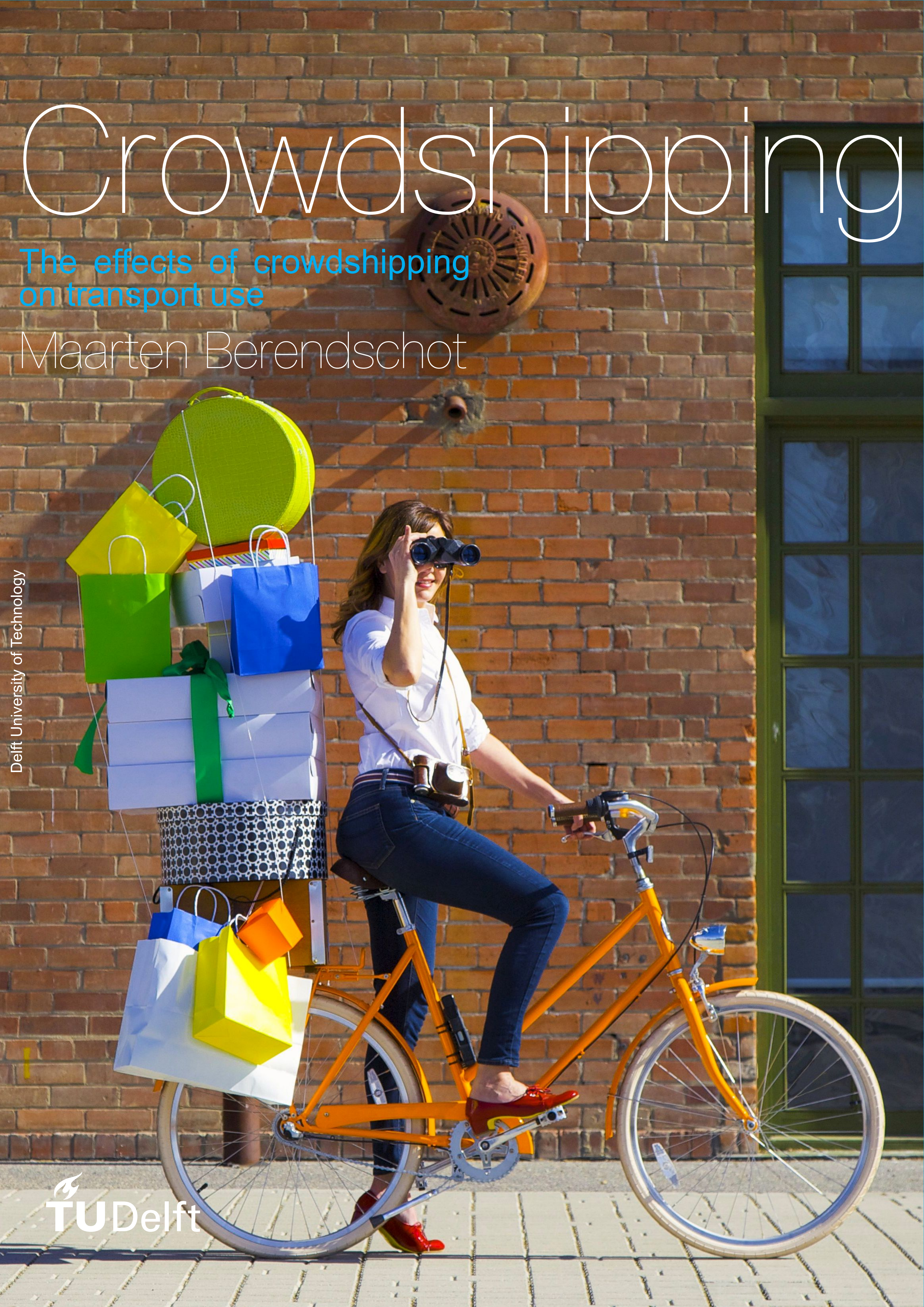

TU Delft

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by

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Preface

For the last six months, I have been working on this master thesis project. This report is the final deliverable in my master program Complex Systems Engineering and Management. It was a long and sometimes tough period where I was faced with many challenges. I would like to thank all people who supported me during this project:

First of all, I would like to thank Significance for providing me with the possibility to work on this subject. Most of all, thanks to Michiel for your support in this process. You gave me insights into crowdshipping and the quantitative transport research area and helped me to bring focus to my research. Our meetings were always helpful and relaxed at the same time. Thanks as well to all other colleagues, for the coffee breaks, lunch meetings and other social events. Even when working from home, I felt welcome in the team and I really appreciate your support.

I would also like to express my gratitude to my other supervisors for this project. Lóri, Ron, Floortje and Pieter, thank you for your clear and constructive feedback. Based on your critical view, I have shaken up my report layout several times. Sometimes not knowing how it would result, but in the end, I am proud of this report; thanks to you!

Furthermore, thanks to my fellow graduate students Leonard and Hugo. We had some good cups of coffee and these meetings always gave new insights into the research. I wish you the best of luck in finishing your graduation projects.

A huge thanks to my girlfriend Evita, who was always there for me during the entire project. You motivated me to keep on pushing, and when it was needed, you helped me to relax as well. Thanks as well to Lukas and Katinka. We've shared our living, working and chilling space for a long time. It was always a pleasure to work at home, thanks to you.

I would like to end by showing appreciation to my parents Marcel and Anita for your continuing support throughout all study years. It has been a long process where you gave me all possible support in developing myself and having fun all the way. And so I did. Thanks!

Maarten Berendschot
The Hague, April 2021

Summary

In recent decades, logistic markets have been changing. E-commerce is growing steadily, and the recent Covid-19 pandemic gave an extra boost to that. Besides, customers are seeking more flexibility in the logistic services. Parcel delivery is changing, yet this leads to various negative externalities including congestion, air-, and noise pollution. These effects let companies seek innovative solutions for their parcel transport. One of these innovations is 'crowdshipping', parcel delivery done by the crowd instead of conventional delivery companies. By making use of existing passenger transport rather than a specially dispatched driver to ship parcels, parcel shipping should be economically and environmentally more sustainable.

Crowdshipping is a service that has shown potential in pilots and small-scale researches. However, strategic analyses of the impact of crowdshipping on all actors in the transport systems are still lacking. The goal of this research is to explore the interactions between travellers and parcel shipments in various strategic crowdshipping contexts and assess their impact on transport use. To achieve that, the following main research question will be answered: '**How could sustainable crowdshipping impact freight and passenger transport use?**'. A simulation model is built using agent-based modelling to explore behaviour and simulate possible effects.

This model consists of interactions between four agents in the system; the customers, crowdshipping platform, travellers and occasional carriers. First, the customers place their orders at the platform. When travellers make their trip, they could consider carrying a parcel along their way. They notice their planned trip to the platform, which will calculate the optimal parcels for them. The travellers could opt for one of the parcels and turn into occasional carriers. The impact of crowdshipping is assessed by calculating the detour the occasional carriers travel to deliver their parcels. Other outcomes are the provided compensation and percentage of matched parcels, to determine the viability of the platform.

The spatial demarcation of the simulation is most of the province of South Holland in the Netherlands. In this study area, 2.3 million people reside who order over 220,000 parcels each day. Furthermore, 4.1 million trips are made daily by car and bicycle. Taking the willingness of both customers and travellers into account, 13,000 parcels and 750,000 traveller trips enter the model.

Four experiments are performed to inspect system behaviour in various contexts. The results show that implementing crowdshipping in this study area could be viable. The average provided compensation is lower than the price consignors currently pay for conventional delivery. Besides, the delivery degree seems acceptable to get a decent level of service. Through crowdshipping, the travelled distance in the passenger transport system will increase because of the detours taken by occasional carriers. This increase subsequently leads to a decrease in freight transport distance through a decreased demand in conventional parcel demand. However, the passenger transport increase exceeds the freight transport decrease. The crowdshipping platform could limit the taken detours by making strategic choices in their implementation. This might be at the expense of their delivery degree. It is advised for the public authority to set boundaries for the platform and stimulate strategic matching choices based on these possible externalities.

When interpreting these results, caution should be taken. The approach has some shortcomings regarding the spatial distribution of detours, costs of platform's viability and first leg distances for parcel transport. Furthermore, limitations could be found in the assumptions made for the simulation model. This includes the abstraction that travellers do not deviate from their planned trips and modalities, and travellers could only carry one parcel. Another simplification is made in the matching strategy by the platform which might have led to sub-optimal drivers for the parcels. Other limitations are caused by flawed data use. Travellers' and customers' willingness could therefore be unreliable. Also, pedestrian and public transport travellers are not considered due to data deficiency.

Further research could be done in three ways within this field of study. First, more data can be gathered to solve the above-mentioned limitations. This includes data on preferential routes for occasional carriers and willingness data for travellers in all modes. Secondly, other conceptual choices can be made to optimise the detours per parcel with forecasted travellers, or to conceptualise the collaboration between conventional and crowdshipping delivery. Finally, research can be done to study intervention methods and corresponding legal possibilities for the public administration to limit travellers' detours.

Contents

1 Introduction

Logistics has been changing in the recent decades; the world is more globally connected, people increasingly live in urban areas and technological innovations cause an exponential rise in e-commerce. In 2014, global e-commerce sales in the B2C market reached $1,9 trillion, rising to $3,5 trillion in 2019 and are expecting to double again towards 2024 (Clement, 2020). Additionally, the recent coronavirus pandemic gave an additional boost to online sales due to the obligatory working-from-home. Figures show that during the pandemic, the growth of e-commerce more than doubled compared to the same period last year (Ali, 2020). These globally increasing e-commerce sales subsequently lead to an increase in parcel transport, which is also noticeable in the Netherlands. The largest Dutch parcel delivery service, PostNL, noted a volume increase of 29.6% in the last quarter of 2020 (PostNL, 2021).

At the same time, consumers prefer more flexibility in delivery channels and times. Logistics service provider DHL classifies a new generation of logistic consumers as ”Logsumer” (DHL, 2013). Consumers expect logistics services to be smoothly integrated into their daily routine activities, deliveries should be right on time, sometimes delivered same-day or even same-hour at any location the consumer wishes. Meanwhile, customers desire fair logistic services which include environmental friendly delivery.

The latter is not without cause, parcel delivery leads to various negative effects. These effects mostly consist of congestion in urban areas, air- and noise pollution (Demir et al., 2015). Allen et al. (2018) assessed goods delivery traffic in the UK and found that this accounts for 7% of all vehicle kilometres travelled on roads. This increases up to 13% in urban areas (Verlinde, 2015). Air pollution mostly consists of carbon dioxide (CO_2) and greenhouse gasses nitrous oxide (N_2O) and methane (CH_4) (van Binsbergen and Visser, 2001). These emissions must all be decreased according to the Paris agreement (COP21, 2015). Research by Wiese et al. (2012) shows that online retailing emits less CO_2 compared to the brick-and-mortar channel on large distances but on deliveries within a 27-kilometre radius, e-commerce scores worse.

These externalities let companies seek innovative solutions for their parcel transport. One of these innovations is ”crowdshipping”, parcel delivery done by the crowd instead of conventional delivery companies. By making use of existing passenger transport rather than a specially dispatched driver to ship parcels, shipping should be economically and environmentally more sustainable (Punel et al., 2018).

1.1. Crowdshipping

Getting the crowd to take care of services is a growing trend since the widely available smartphone with internet connection. This trend is noticed in passenger transport (Uber) and food delivery (Deliveroo). Amazon and Walmart are experimenting with the idea of crowdshipping (Barr and Wohl, 2013) and various pilots have been done all over the world as well.

Crowdshipping could take place in various ways and the definition varies ambiguously over literature (Mehmann et al., 2015, Rai et al., 2017, Punel et al., 2018). Therefore, the following definition is used in this report ”Crowdshipping is the transport of parcels done by an undefined and external crowd which is coordinated using an information platform”. To elaborate further, the parcel transport is done by a crowd rather than conventional delivery companies. The crowd joins voluntarily using their free time and capacity to ship the parcels in return for compensation. The information platform matches the supply of both passenger and parcel transport to fulfil the demand of the parcel shipment. The platform is managed by a third party (a crowdshipping company).

The impact of crowdshipping is hardly examined in literature. Archetti et al. (2016) 'have found that substantial cost savings can be realized when there many people with a generous amount of flexibility available to make deliveries.' Dahle et al. (2019) ratify this statement and claims a 10-15% cost reduction even using sub-optimal compensation schemes. Furthermore, Devari et al. (2017) find a potential truck mileage reduction up to 57% using occasional drivers when crowdshipping is fully adopted. This reduction resulted in an increase in car miles of about 60% of the truck decrease, which means an overall efficiency gain is noted. Macrina et al. (2020) claim a CO_2 reduction due to the truck mileage reduction, yet this reduction is highly dependent on implementation and optimization objective. Paloheimo et al. (2016) analysed a library case in Finland where a CO_2 reduction of only 4% was achieved.

There are diverse ways crowdshipping could be implemented. At first, the routes over which the delivery should be carried out by an occasional driver could be the full trip of the parcel, but it could also be done for parts of the trip using pick-up points (first or last-mile delivery). Next, there could be multiple ways of infrastructure/modality use. Crowdshipping could either be done using private vehicles, or public vehicles like the bus, tram, or train. Followed by variations in compensation schemes; as said, the drivers join voluntarily but are compensated for their effort. This compensation partly determines the willingness for travellers to become a crowdshipper and could be set in various ways. When the reimbursement is set, the matching procedure could take shape in different ways as well. Finally, crowdshipping could be done for parcels with various shipping characteristics, in different socio-economic environments and at different integration levels with conventional delivery services. A full literature review on variations of crowdshipping is given in chapter 2.

1.2. Problem definition

To date, crowdshipping research has been based on case studies (Paloheimo et al., 2016), quantitative data of start-up crowdshipping firms (Ermagun and Stathopoulos, 2018, Rai et al., 2017), small-scale hypothetical data (Macrina et al., 2020) and survey data (Punel et al., 2018). These studies resulted in small-scale analyses which lack integration of the above-mentioned crowdshipping aspects. This is substantiated in a recent review by Le et al. (2019). This integration is necessary to assess the impact of crowdshipping on transport use. Another way to assess the impact could be using transport models, yet a search for the implementation of crowdshipping in existing models leads to no results. Kourounioti et al. (2020) made a theoretical framework for the integration in transport systems, which could be a good starting point for the conceptual model. This results in the following knowledge gaps:

- Current researches present small-scale analyses which lack integration of the pricing, matching and routing problems.
- Strategic analyses of the impact of crowdshipping on all actors in the transport systems are still lacking.
- Crowdshipping has not yet been integrated into transport models.

To address these research gaps, the goal of this research is to explore the interactions between travellers and parcel shipments in various strategic crowdshipping contexts and assess their impact on transport use. To achieve this goal, the following research question is set:

How could sustainable crowdshipping impact freight and passenger transport use?

This question consists of several aspects. First, the term **sustainable** is deliberately chosen ambiguously. Sustainable in this case refers to both (1) being able to continue over a long period of time and (2) causing little or no damage to the environment. Next, the term **crowdshipping** is defined in the introduction, yet various implementation strategies exist. In the first sub-question, these implementations are further explored and a choice is made on which types of crowdshipping are assessed in this research. In the assessment, both the **freight and passenger** systems are taken into account. In transport planning, these are mostly analysed separately from each other yet crowdshipping affects both. In the first place because parcel transport falls into the freight system. And in the second place because the travellers who become an occasional carrier are in the passenger system, performing a freight service. Finally, the main question contains **transport use**, which is conceptualised to the driven distance in certain modes.

To answer this broad question, the question is broken down into sub-questions. The breakdown starts with a theoretical question on crowdshipping implementations using a literature study. Following, the conceptual model is built to explore actors' interactions. This is followed by the model implementation to assess the crowdshipping impacts. Finally, experiments are performed to cover the various crowdshipping strategies and results are drawn from these. The following sub-questions are defined:

1. Which implementation strategies of crowdshipping exist and which will be analysed?
2. What interactions take place between agents in the freight and passenger transport systems through crowdshipping?
3. How could the impacts of crowdshipping be simulated?
4. In what way does crowdshipping impact transport use?

1.3. Research approach

A research approach is set up to answer the research questions and therefore achieve the goal of this research. To start, the general approach is to model the crowdshipping system. This is chosen to explore the interactions and discover what outcomes follow from these. Interactions between actors are modelled using agent-based modelling (ABM). This technique of microsimulation is highly adaptive and could be used to explore emergent behaviour from those interactions. This is applied to transport modelling as well wherein agents usually represent individual travellers, drivers, or institutional entities (Shinya Kikuchi, 2002). The simulation is applied to a study area in the Netherlands.

Within the agent-based approach, various methods are used to answer the sub-questions. An overview of these questions and corresponding methods is given in table 1.1. These methods are elaborated further after the table. Furthermore, the research approach is shown visually using a research flow diagram in figure 1.1. In this diagram, the sub-questions are linked to the practical agent-based modelling steps described by van Dam et al. (2012). Furthermore, the position of these steps and the research questions within this report could be seen.

	Sub-Question	**Method**	**Chapter**
1	Which implementation strategies of crowdshipping exist and which will be analysed?	Literature	2
2	What interactions take place between agents in the freight and passenger transport systems through crowdshipping?	Conceptualising	3
3	How could the impacts of crowdshipping be simulated?	Formalising	4
4	In what way does crowdshipping impact transport use?	Simulating	5

Table 1.1: Sub-questions method overview

The first sub-question is answered in chapter 2 using a literature review. This literature study is based on studies by Rai et al. (2017) and Savelsbergh and Van Woensel (2016), from which search terms are derived. In this review, the focus is primarily on the possible implementation strategies of crowdshipping. Furthermore, in this chapter, the crowdshipping process and involved actors are explained.

The following sub-question comprises the conceptualisation of the system. This mostly consists of transforming the previously explored actors into relevant agents for the model. Agents have rules (decisions) and states (artefacts) which are identified here. The result of this chapter is a detailed conceptual model of the crowdshipping system. The conceptualisation is covered in chapter 3.

Sub-question three is answered by formalising and implementing the model, which is elaborated in chapter 4. Included in the model formalisation is the search for a supplementing transport model to support the simulation in spatial- and parcel related data. The implementation of the model is described in this chapter as well. Following the model build, the model is validated and verified in three steps. At first, a conceptual validation is performed to check the coherence of the conceptual model in relation to the research goal. Secondly, the model verification tests the implemented model regarding the conceptual model to build confidence in the computed outcomes. Finally, the model validation tests to what extend these computed outcomes contribute to the research goal. A more elaborate explanation of the validation and verification is given on the following page.

The final sub-question is covered in chapter 5, which includes simulating the model. First, a base run is performed and interpreted after which four experiments are set up. These experiments are performed to assess the efficiency of crowdshipping and focus on different implementation strategies.

This research ends with the conclusion in chapter 6 in which the main research question is answered, followed by the discussion in chapter 7. In the discussion, the results are discussed, limitations are given, and recommendations on future research are stated.

Figure 1.1: Research Flow Diagram

2

Crowdshipping exploration

To explore crowdshipping, three steps are taken. First, the concept and storyline of crowdshipping are identified in section 2.1. Next, in section 2.2, all actors in the system are identified. Finally, in section 2.3, the state of the art researches on various crowdshipping implementations is reviewed. At the end of this chapter, a choice is made on which crowdshipping types are further studied.

2.1. How crowdshipping works

In section 1.1, a brief explanation of crowdshipping is given and the definition is set. Here, the concept and process of crowdshipping are elaborated further. To start, crowdshipping needs to be managed by a crowdshipping platform. This platform should set the conditions and communicate the possibilities to the retailers. The retailer (consignor) is now able to offer crowdshipping as a delivery option and the customer could place an order with crowdshipping as a delivery method. After this order is done, the retailer should redirect the order to the platform which then has some interactions back and forth with the traveller. At first, the traveller should communicate their trip to the platform after which the platform proposes suitable shipment possibilities to the traveller. The traveller could now decide whether and which offers to accept and communicate this back to the platform. At the moment of acceptance, the traveller becomes an occasional carrier. The platform receives the accepted offer and notifies the consignor. Now, the occasional carrier collects the parcel at the consignor and delivers it to the customer. A schematic overview of this process is given in figure 2.1.

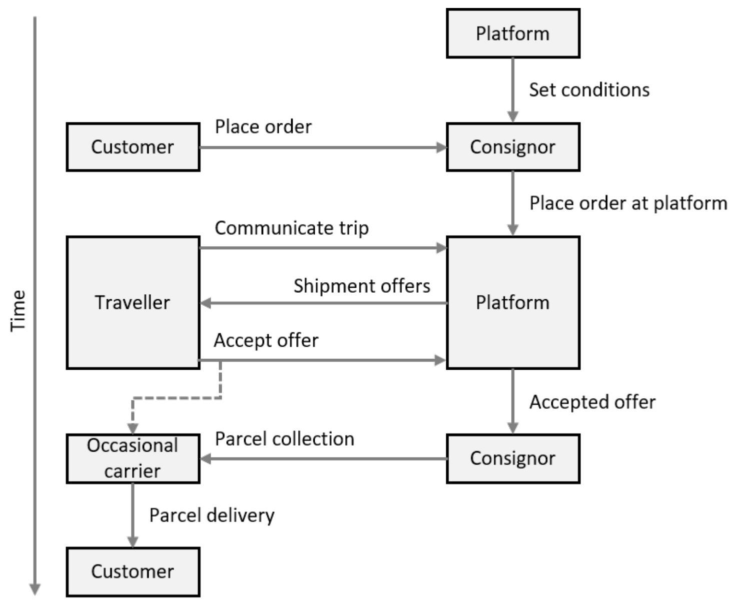


Figure 2.1: Crowdshipping process overview

2.2. Actor identification

In the case of crowdshipping, various actors are involved. In this section, these actors are identified and a description of their role and their goals are given. The identified actors are the public administration, customers, travellers, occasional carriers, consignors, conventional delivery companies, and finally the crowdshipping platform. A visual representation of the actors including their interactions is finally is given in figure 2.2.

The first and most important actor for this research is the **public administration** (could be national, regional or local) since the expected externalities of crowdshipping mostly affect this actor. The administration has no direct leverage on the crowdshipping process but could set rules (policies) to the environment for the way crowdshipping will perform. These policies are based on the expected impacts, which are assessed by certain indicators. Inturri et al. (2019) found that "policies for sustainable mobility generally act on three main factors: (1) the amount of transport activity, i.e., how many kilometres people travel; (2) the number of vehicles needed to transport people, which depends on the capacity of the vehicle and its load factor; (3) the energy to move the vehicle for one km". Because crowdshipping interacts with both the passenger as well as freight transport systems, both network usages are taken into account. The hypothesis is that crowdshipping casuses a decrease in vehicle mileage for delivery vans, which subsequently leads to an increase in mileage for passenger transport (in their desired mode).

The following actor is the **customer**. For simplicity, it is assumed that the customer orders as well as receives the parcel(1) which makes it an important actor in the system. The customer must decide on crowd-shipped delivery. About 70% of respondents to a comprehensive survey select a shipping method based on the price, while 23% choose the method based on a same-day delivery possibility (Joerss et al., 2016). Punel and Stathopoulos (2017) performed a stated choice experiment to find out which shipping attributes influence the customers' choice for a certain carrier specifically focused on crowdshipping. They also found that delivery cost is the leading feature when selecting a shipping option, followed by integrity-related attributes, and speed of delivery. To summarise, the goal of customers is to receive their ordered parcels as cheap and quickly as possible.

The next actor of interest is the **traveller**. Crowdshipping is done along trips that travellers already (plan to) make. All travellers could turn into an occasional carrier and therefore all travellers are actors of the crowdshipping system. Besides, the travellers make use of the transport infrastructure, which is of interest to the public administration. The goal of the traveller is to have low travel times.

This leads to the next actor, the **occasional carrier**. This is a regular traveller who voluntarily opts to deliver a parcel. Serafini et al. (2018) performed a stated preference research to examine the willingness of travellers to become an occasional carrier at metro users in Rome. They found that the location of the pick-up point was considered most relevant followed by the remuneration. Besides, young people and residents of urban areas were more willing to become carrier compared to old and suburban residents. The consideration for a traveller to become an occasional carrier could have multiple reasons. It would most likely be environmentally or financially driven. The goals of the occasional carrier could therefore be stated to reduce delivery emissions and make money.

The latter triggers an ambiguous discussion in the sharing economy. Frenken and Schor (2019) put the sharing economy in a social perspective. Services that start with a sharing concept, could develop into a new business model for the providers of their idle capacity. Two examples are given; Uber started with ride-sharing but is becoming 'ride-hailing' (Warzel, 2015) with dedicated 'taxi' drivers with financial incentives providing the services. Secondly, Airbnb started under the notion that homeowners could rent their asset when not utilized during for example holidays or business trips. When, however, a person was to buy a second home and rent it out via Airbnb, the service changes into commercial lodging. For crowdshipping, measures may be taken to prevent changing the sharing economy service into a socially undesired business concept.

The following actor in this system is the retailer, called **consignor** for the purpose of this research. This actor should offer the option for crowdshipping to their customers. They might offer this dispatching option for sustainability reasons, cost reduction or to provide their customers flexibility in delivery options. However, the consignor might need to change their dispatching processes. Most passenger trips occur between residential areas and either working or recreational areas, yet distribution centres may not be located on the route of these trips. Therefore, dispatching the parcels from the local shops might be more sustainable for crowdshipping. The goal of the consignor is to reduce delivery emissions or shipping costs and to offer flexibility in delivery options.

Conventional delivery companies are the following actor of interest. Usually, consignors have closed a deal with delivery companies to fulfil all deliveries for them. With an added option for crowdshipping, there is less supply for these companies. However, companies could co-operate with the crowdshipping platform to assign certain parcels for the occasional carriers or the delivery company could run the platform themselves to fully integrate crowdshipping with conventional services. For these conventional delivery services, the goal is to retain their market share.

The final actor is the **crowdshipping platform** who matches the demand for parcel transport with the supply of occasional carriers. The platform should therefore perform a carrier selection process to find the optimal carrier for a certain delivery. Furthermore, it is mostly administrative tasks the platform should fulfil; the payment from the consignor to the carrier is done via the platform and they are responsible for the various privacy and quality concerns. Next, the platform should provide customers, consignors and occasional carriers an (online) interface where they could interact with the platform. Finally, the platform may, depending on the implementation method, also need a physical location to collect and distribute parcels. A platform will have either an economical or environmental sustainability motive.

The identified actors interact with each other or with the system. To portray, when a customer places an order at the consignor, they must decide whether this will be a conventional or crowdshipping delivery. In case of the latter, the crowdshipping platform should match a consignor's order to a traveller's trip to form a match. This match is communicated back to both parties and the delivery can take place. The public administration, as said, is not interacting in this process but could set certain rules to the system. A representation of these interactions between the actors could be found in figure 2.2.

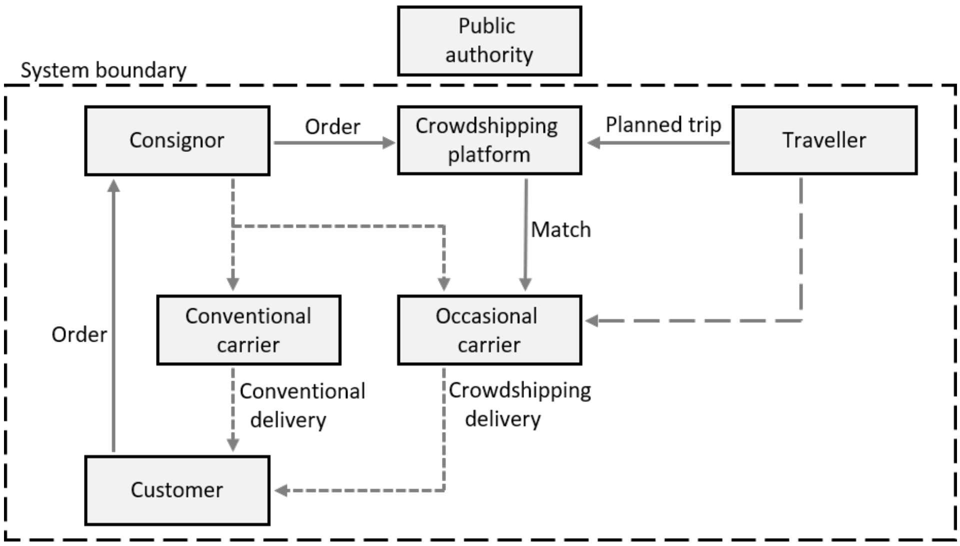


Figure 2.2: Actor overview with interaction

2.3. Review of crowdshipping implementations

Within the above-mentioned crowdshipping structure, still, various implementation methods are possible. To find out the possible implementation strategies, a literature study is done. This study is based on studies by Rai et al. (2017) and Savelsbergh and Van Woensel (2016), from which search terms are derived. The result is listed below. At first, the route options are discussed, followed by infrastructure usage, compensation schemes, carrier selection method and finally, other dependencies are elaborated.

Route options

Walmart experiments with their employees who at the end of their working day deliver packages around their homes (Lore, 2017). Archetti et al. (2016) also assume that the carrier has the same origin as the parcel, yet assumes the opportunity that customers could be carriers as well. Lee and Savelsbergh

(2015) suggest that occasional carriers (crowdshipping carriers) should not necessarily have the same origin as the parcel. This results in a larger group of potential carriers. Instead of a full trip made by the occasional carrier, Wang et al. (2016) see an opportunity where crowdshipping is only done for a certain part of the parcel transport. This could be done using pick-up points where conventional parcel service takes care of most part and the 'last mile' will be done by the occasional carrier.

Crowdshipping where carriers and the consignor have the same origin, is a variant from the implementation where both the origin and destination are different for carrier and parcel(2). The former has an advantage that the detour to pick up the parcel falls away. For this research, the latter is assumed. The effectiveness of pick-up points highly depends on the overlap between the parcels and carriers routes. When a lot of overlap exists - and so the detour is limited - pick-up points might not be necessary. This is a cost-benefit consideration.

Infrastructure usage

Most literature assumes crowdshipping is done by private vehicles (Rougès and Montreuil, 2014), here the modal choice of the occasional carrier determines the used infrastructure. On the other hand, there are a few pilots where existing passenger transport infrastructure is used for crowdshipping. Both Li et al. (2014) and Chen and Pan (2016) review cases where taxis are shared by parcel and passenger transport. van Duin et al. (2019) and Schäfer (2003) describe case studies with the usage of busses to transport parcels. Quadrifoglio et al. (2008) suggest using the tram for crowdshipping. Finally, Trentini and Mahléné (2010) propose an idea where all transport is shared for both passenger and freight transport.

In this research, the impact on the overall transportation system is assessed. For this, multiple transport modes are included. For simplicity, it is assumed that no mode or trip changes will occur because of crowdshipping possibilities(3). This means occasional carriers could use any mode they want to ship the parcels, yet only if their initial trip would have been made with this transportation mode as well.

Compensation

As described in the first chapter, the crowd participates voluntarily but are compensated for their effort. There are four main options for the compensation;

- The first option is to compensate for the distance to be travelled by the parcel, independently of the origin and destination of the occasional carrier. This has the practical advantage that the crowdshipping company does not need to know the route of the carrier, yet it does not take into account the extra effort by the occasional carrier (Archetti et al., 2016).
- The second option is thus to compensate for the extra time/distance the occasional carrier has incurred to deliver the parcel.
- Third, the platform may choose to set a fixed compensation for all parcels, or base the amount on shipment characteristics.
- Finally, a variable compensation could be provided based on supply and demand (Rougès and Montreuil, 2014).

Compensation and cost of shipping are important factors in both the customers' and consignors' consideration in shipping methods. Commonly, a products price is the result of a complex supply and demand interaction. For crowdshipping, it is expected to happen the same; prices are as low as possible with the constraint that there is enough supply of occasional carriers to fulfil the demand. This is hard to simulate and is very data-dependent. Therefore, the compensation is based on the parcel trip length(4).

Matching

When a parcel needs to be shipped, consideration needs to be made for which passenger may transport this parcel. There are three matching procedures described in the literature to select the occasional carrier;

- At first, Wang et al. (2016) describe an assignment method where the system finds the most feasible occasional carrier who then must accept the job. If the carrier refuses the job, the system will look for the next best candidate and so on.
- Another method is given by Kafle et al. (2017), they describe a bidding process where potential occasional carriers place their bid on available parcels and the system selects the best option.

- The third and final method is to apply the simple first-come, first-serve principle. Here travellers could 'claim' certain parcel shipments and the first to claim may do the shipment.

For this system, the last option is chosen to implement in the model. The optimal parcels are found for each traveller who could then 'claim' that parcel(5). The platform could offer certain parcels to the traveller to choose from. This matching process is further described in section 3.1.1.

Other dependencies
These four themes are widely covered in literature, yet there are more implementation variations that would probably determine the success of the crowdshipping implementation. First, Ermagun and Stathopoulos (2018) note that not only **shipping characteristics**, but also the **socio-economic and built environment** characteristics of both the trip origin and the trip destination affects the availability of crowd-resources. Secondly, it should be considered that crowdshipping is an alternative service for parcel delivery and would most likely work side to side with conventional delivery services. On this matter, **integration and corporation** with conventional parcel delivery should be taken into account. Next, the **delivery time window** could impact success. The time window varies from same-day delivery (Dayarian and Savelsbergh, 2020) to long term pre-specified time windows (Dahle et al., 2019). Finally, some **preconditions** are mentioned by Varshney (2012), mostly related to privacy and reliability concerns. Rai et al. (2017) add criterion related to the platform provider and crowd.

2.4. Summary of the crowdshipping concept

The actors involved in the system are the public administration, customer, traveller and therefore the occasional carrier, consignor, conventional delivery companies, and crowdshipping platform. See table 2.1 for the overview of actors and their goals in this system. The actors' goals are a rough simplification to their full goals(6).

Furthermore, this chapter answers the first sub-question 'Which implementation strategies of crowdshipping exist and which will be analysed?'. In this research, an implementation is researched where at first both the origin and destination are different for both the carrier and parcel. For the parcel, this origin is at a pick-up point which might be at the consignor's location, and the destination is the customer. Next, the traveller is free to choose their mode but is not able to shift mode because of the crowdshipping opportunity. The compensation is based on the trip distance of the parcel. The platform tries to match a parcel to each traveller, who could choose a parcel on a first-come, first-serve basis.

Actor	**Goals**
Public administration	Reduce emissions Reduce congestion
Customer	Cheap delivery Quick/flexible delivery
Traveller	Low travel times
Occasional carrier	Make money Reduce delivery emissions
Consignor	Reduce delivery emissions Reduce shipping costs Offer dispatching flexibility
Conventional delivery companies	Retain market share
Crowdshipping platform	Maximise profit Maintain viability

Table 2.1: Actor overview with their goals

3

Model conceptualisation

This research aims to to explore the interactions between travellers and parcel shipments in various strategic crowdshipping contexts and assess their impact on transport use. In the previous chapter, the actors are identified and strategical crowdshipping contexts are identified. In this chapter, the system is conceptualised to explore the interactions between travellers and parcel shipments. This involves formalising the concepts in the model. These concepts are formalised by transforming the relevant actors into agents, which are elaborated in section 3.1. In section 3.2, a system diagram is constructed using the XLRM framework. Finally, in section 3.3, a proof of concept is shown to explore the model behaviour.

3.1. Agents

In section 2.2, involved actors are analysed and summarised in section 2.4. Within the crowdshipping concept, some of these actors do not interact in the system. At first, since the system is modelled without interventions, the public administration has no interactions in the system and so this actor is not modelled explicitly in this system. Next, the consignor has no impact on the crowdshipping process. In the crowdshipping process, as showed in figure 2.1, the consignor's task is just to redirect the orders. This task is not necessary for the model and so this actor is not taken into account. With these actors removed, the process modelled process has changed slightly. In figure 3.1, the new process is shown. For modelling purposes, all other actors are from now on be identified as agents.

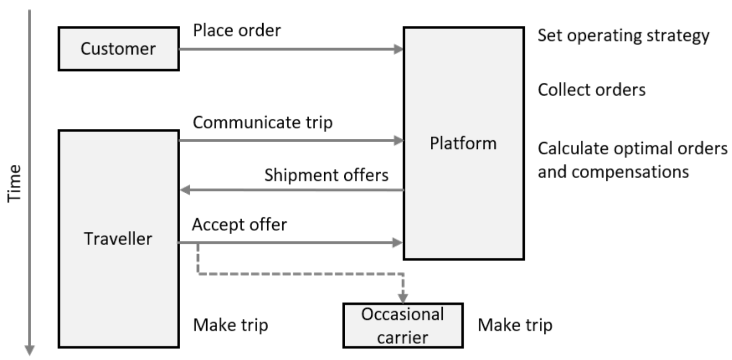


Figure 3.1: Crowdshipping process overview

All agents in the system can be described following the same structure. Agents have states, rules and interactions with other agents and the environment. States are things an agent owns, for example, the amount of money a customer has. Before this agent could buy a product, the agent should calculate how much it could spend (based on their state 'money'). Calculating this would be a rule. The interactions taking place with another agent could be placing the order at a company which on its turn interacts back to the customer with a confirmation followed by the product. These agent properties could be easily captured in a schematic 'actor model layout' as shown in figure 3.2. These properties and model layouts are made for each agent in the system.

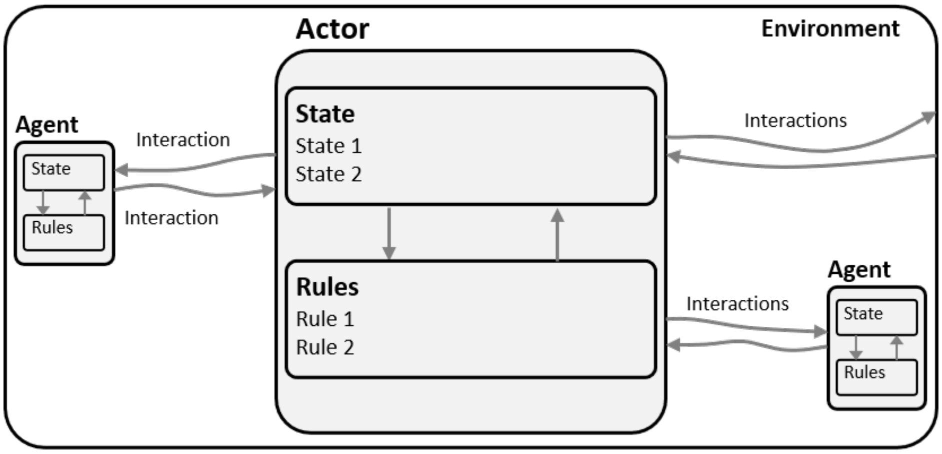


Figure 3.2: General agent model layout

3.1.1. Platform

The platform performs a key function in the system: matching the demand of parcel transport to the supply of travellers. The agent model layout could be found in figure 3.3. To fulfill their matching function, the platform has five states: an *operating area & method*, an *optimisation strategy*, a *detour threshold*, a *compensation formula* and finally an *orders administration*. The first of these includes the spatial demarcation and the chosen implementation method. The other states are elaborated below.

The first rule of the platform is to collect and manage the parcel shipment orders. All customers order their parcel at the platform which keeps a list of these orders. When a traveller accepts an offer, this should be managed by the platform as well. The following rule of the platform is to calculate the optimal parcels for a traveller when the traveller announces their planned trip, which is explained in the optimisation strategy below. The final rule is to calculate the compensation for the optimal parcels, again elaborated below.

Interactions mostly takes place back and forth to the traveller by communicating trip possibilities. Yet another interaction takes place at the beginning of the process when the customer places an order at the platform.

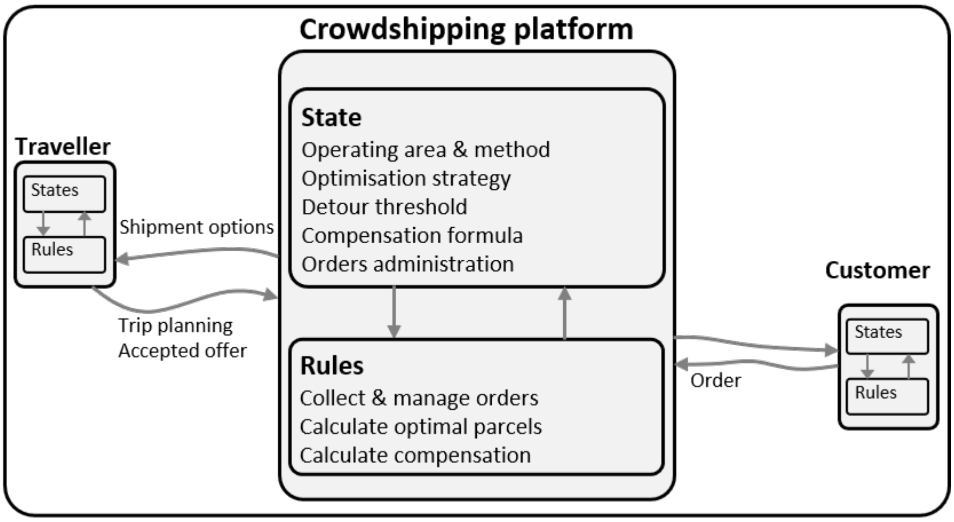


Figure 3.3: Actor model layout - Platform

Orders administration

The orders administration includes an overview of all ordered parcels by the customers. Furthermore, from this administration, some statistics could be taken which includes indicators for the platform's performance. The administration includes the parcel's origin and destination, its distance, a status (*ordered* or *carrier found*), in case of the latter status the traveller who carries the parcel including their modal choice detour and provided compensation.

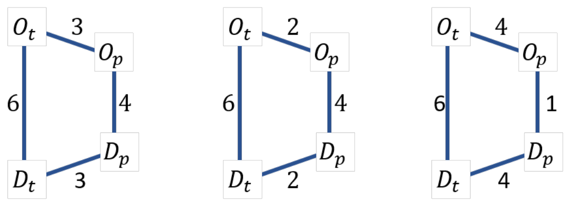
When, after all willing travellers announced their trip, no match could be found for certain orders, these parcels will yet be delivered by conventional delivery services. The distance travelled for these conventional deliveries follows from the supplementing transport model, as described in section 4.1.

Optimisation strategy

In the real use case, parcels are ordered throughout the day and travellers make their trips continuously during the day. This leads to a dilemma for the platform when an order suits a currently available driver, yet a better suitable driver might become available in the future. Agatz et al. (2011) describe this problem as a rolling horizon strategy. The platform must set a certain strategy in offering certain parcels to travellers. In this model, the orders and travellers are not modelled dynamically over the day. All orders are placed first, followed by the travellers making their trips(7). Furthermore, travellers will sequentially report their trip at the platform and the most suitable parcels are offered without taking into account possible future travellers(8).

The most suitable parcels are determined by the detour a traveller should make to deliver the parcel, relative to the parcel trip distance itself. This 'relative detour' should be minimised. The equation for this relative detour could be found in equation 3.1 below. This concept becomes more clear with a few small examples which could be found in figure 3.4. The definition of a detour could be found at the traveller agent conceptualisation in section 3.1.3.

$$relative\ detour\ rd_{p,t}(-) = \frac{traveller's\ detour(km) - parcel\ trip\ distance(km)}{parcel\ trip\ distance(km)} \tag{3.1}$$



Traveller's detour	10 - 6 = 4	8 - 6 = 2	9 - 6 = 3
Parcel trip distance	4	4	1
Relative detour	$\frac{4-4}{4} = 0$	$\frac{2-4}{4} = -0.5$	$\frac{3-1}{1} = 2$

Figure 3.4: Examples relative detour. In each figure clockwise: origin traveller, origin parcel, destination parcel, destination traveller

The platform offers its three most suitable parcels to the traveller. These are the three parcels with the lowest relative detour for this traveller. Furthermore, a threshold is set to the relative detour. Only parcels with a lower relative detour than the threshold are offered to the traveller. In the base settings of the model, this detour threshold is set at 0. This means that the detour may not be longer than the parcel distance. This optimisation strategy could be found in equation 3.2 below. P is the set of all ordered parcels (p_1 to p_n), where all parcels have a relative detour for a certain traveller $rd_{p,t}$. P_t is a union set with three parcels with the lowest relative detours if that relative detour is lower than the threshold.

$$\begin{gathered} P = \{p_1, p_2, ..., p_n\},\ f : p \rightarrow rd_{p,t}\ \forall\ p \in P \\ offered\ parcels\ (P_t) = \cup_{i=1}^{3}(p(min(rd_{p,t}\ if\ rd_{p,t} < detour\ threshold)))_i \end{gathered} \tag{3.2}$$

Compensation calculation

The compensation provided by the platform is of importance for the acceptance of the traveller. Higher remuneration will lead to more accepted orders. Yet, crowdshipping must be economically viable and so the payment to the traveller should be less than the payment by the consignor. Last year, in the Netherlands, the average price of parcel delivery in the business to consumer market was €3,35 (Autoriteit Consument & Markt, 2020). To be competitive with these conventional services, this is the maximum price for the crowdshipping service as well.

Travellers are compensated for the parcel trip distance. The maximum compensation (for the longest parcel trip) is equal to the consignor's price (€3,35). The compensation for short trip lengths should be enough to cover the travellers' pick-up and drop-off times. No research could be found on the minimum desired compensation for travellers. For this research, this is set to €1,50. To further represent the compensation scheme, a simple mathematical formula could be used as formulated below in equation 3.3. Using the natural logarithm, smaller trip lengths are compensated better per kilometre, to overcome the pick-up and drop-off times. The corresponding graph to this function could be found in figure 3.5.

$$compensation(€) = log(distance(km) + 5) \tag{3.3}$$

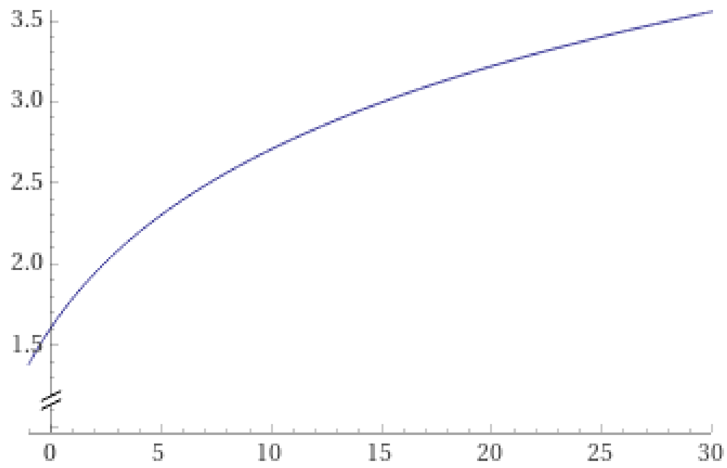


Figure 3.5: Compensation according to equation 3.3. Distance (kilometres) on x axis, compensation (€) on y axis

3.1.2. Customer

The customer has a fairly simple model layout. This agent has three states being the *parcel demand*, their *crowdshipping willingness*, and the *location* of the agent. The former two determine the number of parcels and whether the customer wants their parcel delivered by an occasional or regular carrier. The determination of the customers' willingness is elaborated below. The latter determines the destination of the parcel, following assumption 1 that the parcel destination is at the customer's location (i.e. not at a pick-up point).

The rules the customer follows in the system is at first to *choose the delivery method* - based on the above-mentioned state crowdshipping willingness. In this system, it is assumed that the customer chooses the delivery method. In the case of crowdshipping, while there is no occasional driver available, the platform may choose for regular delivery in stead(9). The following rule is to *order the parcel* at a consignor. A random consignor is chosen to order the parcel(10). Furthermore, customers do not have a time window for the delivery(11).

Customers interact with only one other agent in the system, being the platform. This interaction occurs at the order of the parcel. The customer has no interactions with the environment.

Customer's willingness

Customers have a certain willingness to choose crowdshipping as a delivery method (Punel and Stathopoulos, 2017). Gatta et al. (2019) performed stated preference research on this willingness. They created hypothetical alternatives and presented those to a large number of respondents. These alternatives always compared a conventional (typical) shipping method to a crowdshipping method. The attributes

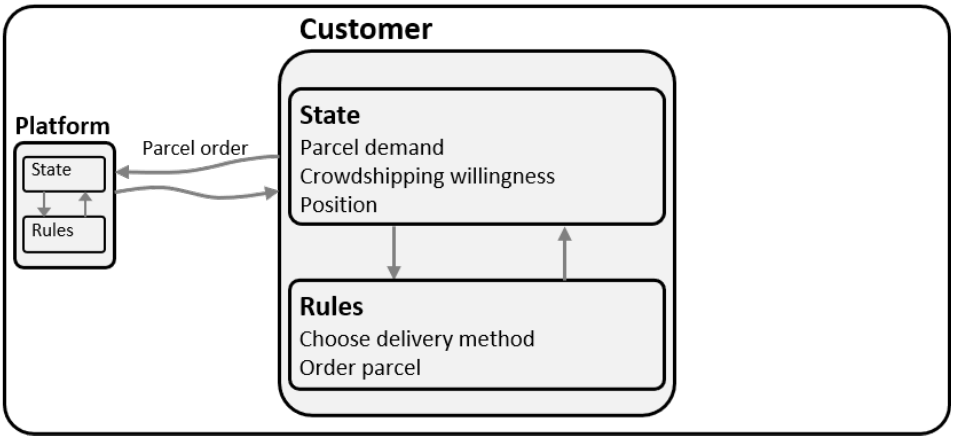


Figure 3.6: Actor model layout - Customer

characterizing the hypothetical alternatives are: shipping cost (typical, lower than typical), shipping time (typical, lower than typical), parcel tracking availability (yes, no), and delivery schedule date/time flexibility (yes, no). Depending on those attributes, the probability of choosing a crowdshipping service ranges from 16% to 66%. There is large uncertainty in the shipping time and flexibility since this is highly dependent on the availability of travellers. The presence of parcel tracking and lower shipping costs is assumed for this research. This means the adoption rate used in this research is 30%. Furthermore, the consignor must be able to provide parcel pickup from their local stores. It is expected that about 20% of all parcels have this possibility[1]. This means that a total of 6% of all parcels is eligible for crowdshipping in this research.

3.1.3. Traveller

The traveller has an important role in this system. Their states are the *planned trip* and a certain *willingness to ship*. The planned trip includes several factors like the origin, destination and modal choice. Just like the customer's willingness to choose for crowdshipping, the willingness to ship needs to be searched in literature as well. Finally, travellers should choose from available parcel options to ship based on certain *choice preferences*, which includes both the *pick-up / drop-off times* and *Value of Time*. Both the willingness and parcel preference are elaborated below.

Actions taken by the traveller consists of *considering shipping* in the first place. When the traveller decides to ship, it should *communicate their planned trip* to the platform. After the platform returns possible crowdshipping options, the traveller should *consider the shipping options* provided by the platform. This is based on the parcel preferences described above. The final action a traveller should take is to *make their trip*.

The traveller interacts with just one other agent in the system being the platform. The trip is communicated which results in shipment offers by the platform. Finally, the traveller should communicate their accepted offer. When an offer is accepted, this agent turns into an occasional carrier and all states are transferred, this is no real interaction. Another interaction is taking place with the environment. By moving from origin to destination, infrastructure is used using an available mode. This infrastructure usage is important for the impact assessment of crowdshipping.

For this research, the impact on the overall transport use is assessed. For this, there are no restrictions on one individual transport mode. As stated already in assumption 3, no mode changes will occur because of crowdshipping possibilities. This means occasional carriers could use any mode they want to ship the parcels, yet only if their initial trip would have been made with this transportation mode as well.

Traveller's willingness to ship

The willingness to ship has been studied several times. At first, Dai et al. (2020) found in China that 83.7% of car owners are willing to act as an occasional carrier; under the conditions of (1) carrying 0.4 m3 of goods per vehicle, (2) the crowdshipping carrier earns 30 yuan (3,84 euro) per trip, and (3) the

[1] No research could be found on this matter. This is a rough estimate

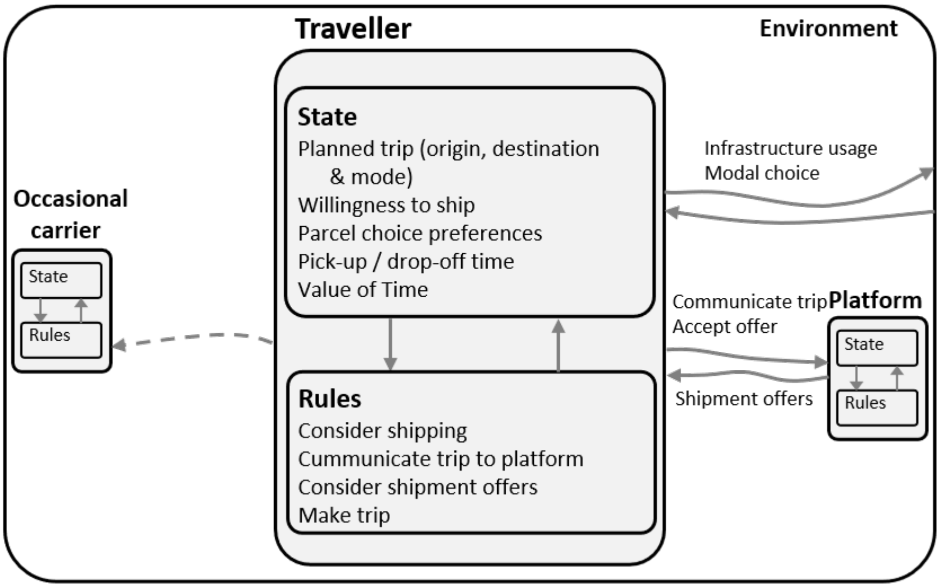


Figure 3.7: Actor model layout - Traveller

activity is beneficial to environmental protection. Another stated preference research by Serafini et al. (2018), performed at metro users in Rome results in a range from 12.8% - 86.4%. The exact number depends on the pickup point location and remuneration. Given the conceptualisation of this research, the third scenario of Serafini et al. suits this research best. This scenario provides high remuneration and includes a detour for pickup. This scenario results in a 'probability to act as a crowdshipper' of 46%. Finally, Allahviranloo and Baghestani (2019) performed quantitative research in Los Angeles County in which individuals are found suitable to become a potential carrier based on their activity pattern and found that 19% of their participants had potential.

An important note on the first two studies is that the average respondent is relatively young. In the first research, by Dai et al., 35% of respondents is between 20 and 29 years old. The second research is filled in by 32% students (who represent 7% of the population). All studies vary in their method to determine the willingness to ship, and so does the resulting percentage. For the continuation of this research, a rough estimation of 30% is taken as percentage of willing travellers. Due to the lack of data, no distinction could be made in different modalities.

Parcel choice preferences

A willing traveller gets three parcel options offered by the platform. The traveller has two goals when considering these delivery options. On the one hand, they will aim to optimise their compensation and are thus inclined to take the longest parcel trips. On the other hand, they would minimise their travel time and thus time spent to deliver this parcel. These two factors are both considered in the travellers' utility. The utility for a parcel (p) and a certain traveller (t) is calculated as shown in equation 3.4.

$$utility_{p,t}(€/h) = \frac{provided\ compensation_p(€)}{detour\ time_{p,t}(h) + 2 * drop\text{-}off\ time_t(h)} \tag{3.4}$$

To finally choose a parcel, the parcel with the highest utility is compared to the value of time of the traveller. When the maximum utility is higher than the value of time, the traveller accepts that offer; when the utility is lower, the traveller will not ship any parcel. This choice process is shown in equation 3.5. P_t is the set of three offered parcels (p_1 to p_3), where all parcels have an utility $u_{p,t}$ (as calculated in equation 3.4).

$$\begin{gathered} P_t = \{p_1, p_2, p_3\},\ f : p \rightarrow u_{p,t}\ \forall\ p \in P_t \\ chosen\ parcel_t = p(max(u_{p,t}\ if\ u_{p,t} > value\ of\ time_t)) \end{gathered} \tag{3.5}$$

In both the platform's consideration of which parcels to offer and the traveller's consideration of the optimal parcel, the detour is used. This detour is defined as the distance or time the occasional carrier travels when delivering the parcel minus the original traveller's trip distance/time (without delivery). In other words, the detour is the extra distance/time a traveller spends when delivering a parcel compared to the originally planned trip. The formula of this detour definition is given in equation 3.6.

$$\begin{aligned} Traveller's\ detour(km) = {} & d(traveller\ origin \rightarrow parcel\ origin) + \\ & d(parcel\ origin \rightarrow parcel\ destination) + \\ & d(parcel\ destination \rightarrow traveller\ destination) - \\ & d(traveller\ origin \rightarrow traveller\ destination) \end{aligned} \tag{3.6}$$

Furthermore, two other undefined variables appear in the parcel choice preference. The drop-off time and value of time. The pick-up and drop-off times are times occasional carriers spend to either pick up the parcel at the consignor or drop off the parcel at the customer. This includes time for parking the vehicle, administrative tasks and possibly waiting. A study by McLeod et al. (2020) found that the drop-off time for delivery vans is about 2 minutes per parcel. This halves when using a bicycle, mostly because of less time spent parking the vehicle. On parcel pick-up, no data could be found. It is assumed that the parcel pick-up will take as long as the parcel drop-off(12).

The second undefined variable is the value of time. This is a conversion of travel time into monetary units. For The Netherlands, the value of time is most recently estimated by Kouwenhoven et al. (2014) in a stated preference study. They found values for the value of time for different modes and purposes. The value of time for car drivers is €9.00 per hour and €7.50 for public transport users. No specific outcomes are given for bicycle data, so the total average of €8.75 is used for this mode.

3.1.4. Occasional carrier

The final agent in this model is the occasional carrier. This is actually the traveller becoming an other agent type. The states and rules will therefore highly overlap between these agents. The states of the occasional carrier are the *planned trip* and the *chosen parcel*. Compared to the traveller, the willingness and choice preferences are discarded since these are not relevant anymore for the occasional carrier.

The only rule for this agent is to *make their trip*. For this trip, the originally planned trip is combined with the origin and destination of the chosen parcel. The trip will now take place as follows: occasional carrier origin - parcel origin - parcel destination - occasional carrier destination.

The occasional carrier does not interact with other agents. The agent does however interact with the environment, the same way the traveller does. By moving from origin to destination, infrastructure is used using an available mode. This infrastructure usage is most important since this agent makes a detour and thus for this agent, extra infrastructure usage takes place. It is this detour usage which makes the difference in the passenger transport system.

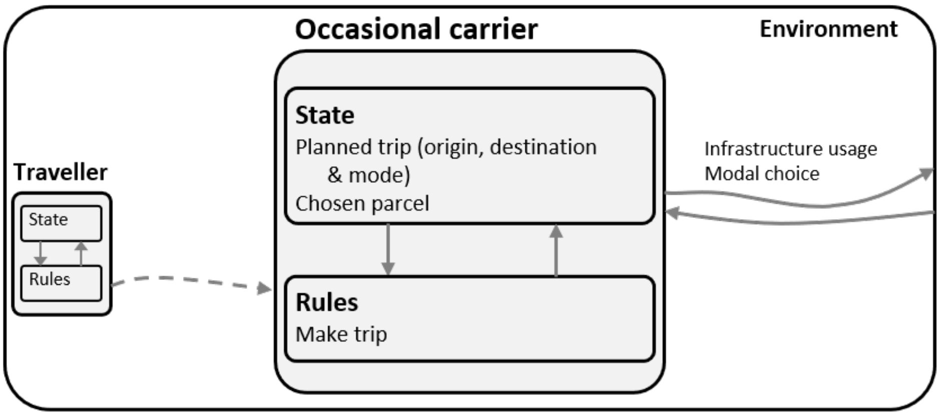


Figure 3.8: Actor model layout - Occasional carrier

In this model, the occasional carrier is limited to carrying only one parcel(13). This is a modelling choice, mostly because of computational limits. Gdowska et al. (2018, p.97) created a heuristic method to find multiple suited parcels matching the capacity of the carrier. Carrying multiple parcels and smartly combining their routes could increase the utility and efficiency of crowdshipping.

3.1.5. Environment

The environment in this system is set as the physical environment where the simulation takes place. This includes the geographical demarcation of the system, social-economical data and the infrastructure. The latter is used by the travellers and occasional carriers to make their trips. With these trips, the environment keeps track of the travelled distance and their modality usage.

The same environment is used to simulate conventional parcel transport as well. The hypothesis is that crowdshipping relieves the demand for conventional services and thus change the infrastructure use for these services. For this part of the model, the environment keeps track of the same indicators as mentioned above.

3.1.6. Summary of agents

This section covers all agents in the conceptual model. To summarise, table 3.1 gives an overview of the agents, goals, states and rules in the system.

Agent	Goals	States	Rules
Platform	Maintain viability Maximise profit	Operating area & method Optimisation strategy Detour threshold Compensation formula Orders administration	Collect & manage orders Calculate optimal parcels Calculate compensation
Customer	Cheap, quick and flexible delivery	Parcel demand Crowdshipping willingness Position	Choose delivery method Order parcel
Traveller	Low travel times	Planned trip Willingness to ship Parcel choice preference Pick-up / drop-off time Value of Time	Consider shipping Communicate trip to platform Consider shipping offers Make trip
Occasional carrier	Reduce delivery emissions Make money	Planned trip Chosen parcel	Make trip
Environment		Travelled distance Mode usage	

Table 3.1: Agents overview

3.2. System diagram

With all agents explored and concepts formalised, the model could now be captured in a system diagram. For this, A slightly adapted version of the XLRM Framework is used. The XLRM framework is set up by Lempert et al. (2003, p.70) in their book on long-term policy analysis. This tool groups the elements of a model into four categories. Policy levers (L) are actions that contain the strategies by policymakers to be explored in the model. Exogenous uncertainties (X) are factors outside the control of those policymakers which impacts the system. Measures (M) are the performance indicators for the system, to rank the experiments. Relationships (R) describe how the factors relate to one another.

In this study, the real policymaker, the public administration, does not interact with the system. Yet, the crowdshipping platform could be seen as the policymaker in this system, since this agent sets strategies on the system performance. The policy levers (L) will thus be interpreted as strategies by the crowdshipping platform. All model elements are grouped in their category which could be found in table 3.2 on the following page.

L: Strategies
Operating area & method Detour threshold Compensation formula

↓

X: Uncertainties		R: Model		M: Outcomes
Parcel demand Crowdshipping willingness Willingness to ship Value of Time Pick-up & drop-off times	→	Agent interactions as described in 3.1	→	Travelled distance Mode usage Provided compensation Percentage delivered parcels

Table 3.2: System diagram

All uncertainties and strategies have been covered before in the agent conceptualisation. This also included the agent interactions which are the relationships in the model. However, the outcomes for this model are not clearly defined yet. The travelled distance and mode usage are both states of the environment, which is caused by trips made by the travellers and occasional carriers. The provided compensation and percentage delivered parcels is extracted from the platform's orders administration. When a match is made, the order gets a new status and the provided compensation is noted. This could be used to compute the outcomes relevant to the viability of the crowdshipping service.

3.3. Proof of concept

To inspect the potential of the above-mentioned agent-based structure, this conceptual model has been implemented in a small-scale environment using the Mesa (ABM) library in Python. This small-scale implementation will guide as a proof of concept for the conceptual model. In this simulation, travellers dynamically move from their origin to destination and could choose to participate in crowdshipping on their way.

Furthermore, some sliders have been added to the thresholds and number of travellers and customers. With these sliders, the operation of the conceptual model could be inspected. A screenshot of the proof of concept model could be found in figure 3.9. In this figure, the sliders could be found on the left. In the frame on the right, all agents could be found. Travellers are represented by orange dots, of which occasional drivers are filled. Blue dots are the consignors and customers (origin and destination of the parcels). The consignors are in dark blue and customers in lighter blue. Finally, the parcels are shown with an icon, with a label added saying 'ordered', 'carrier found', 'parcel picked up' or 'parcel delivered'.

An important notion for this model, is that it is not data-driven. When setting up the model, all agents (customers, consignors, travellers) are created and randomly assigned in the confined space. For the travellers, a destination is randomly chosen. The customer orders a random parcel at a random consignor. The purpose of this proof of concept is just to inspect the behaviour of the conceptual model and for behaviour validity.

As stated before, this proof of concept simulation is dynamic. At model setup (time step 0), the agents are created. In the first time step, customers order their parcels. Following, from the second time step, travellers move to their destination. From this moment, they could decide to carry a parcel along their way. In practice, travellers would no later than step 2 decide to take a parcel since the detour length increases over time and thus the utility decreases. Travellers and occasional carriers have a limited travel speed which makes their movement visual in the simulation. the visual inspection helps to gain understanding and building confidence in model behaviour.

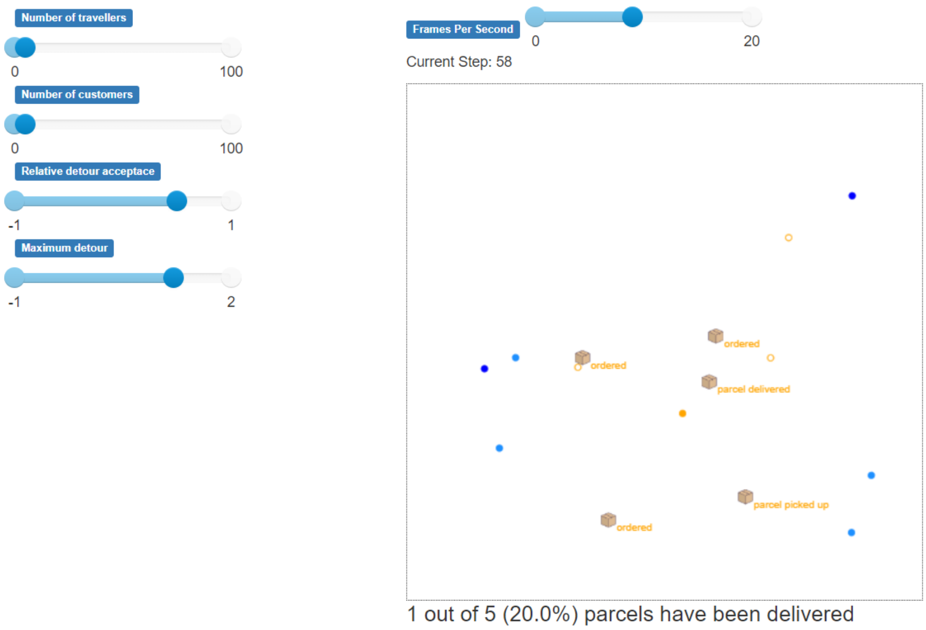


Figure 3.9: Proof of concept. Orange dots represent travellers (filled ones are occasional travellers), light blue dots represent customers and dark blue dots are consignors

3.4. Conclusion

In this chapter, the conceptual model is made by identifying the agents. Next, the agents' states and rules are captured in a XLRM framework to give an overview of the model. Finally, a proof of concept is shown to inspect model behaviour and build confidence in the conceptual model.

The sub-question aimed to answer in this chapter is 'What interactions take place between agents in the freight and passenger transport systems through crowdshipping?'. The interactions are as follows. At first, the customers order their parcels at the platform. Following, the travellers communicate their trip to the platform who offers them three parcel options in return. The traveller could pick one of them and communicates their choice back to the platform. Furthermore, there is an interaction with the environment by both the traveller and occasional carrier. By making their trips, they use infrastructure in a certain mode.

These interactions provide the model with four outcomes. The **travelled distance** by travellers and occasional carriers and their **used mode**. Through the platform's orders administration, the **provided compensation** and **percentage delivered parcels** can be extracted.

In the following chapter, this conceptual model is implemented into a computing model from which the expected impacts of crowdshipping are simulated.

4

Model implementation

In the previous chapter, a conceptual model is built to understand the interactions between the agents. To continue, and find the impact of these interactions, this model is implemented in a computational model. The model implementation is covered in this chapter. The first step was to review transport models to supplement the simulation, which is covered in section 4.1. In section 4.2, the model outline is described and in section 4.3, the implementation is covered. Finally, section 4.4 covers the validation and verification of the simulation model.

4.1. Transport models

The crowdshipping model can be supplemented by existing freight transport models. Either for parcel demand data, spatial data or implemented crowdshipping attributes.

Several review studies have been done over the years on freight transport modelling. Chow et al. (2010) give a wide analysis of several models including an aggregate commodity flow model, a disaggregated regional logistics model and a hybrid regional logistics model with a truck touring model. Holguín-Veras et al. (2013) also made a review and categorised the models into simulation, hybrid and analytical models. Finally, an older review by Davidsson et al. (2005) gives an overview of agent-based approaches in transport logistics. However, all models in the mentioned reviews lack any connection with the crowdshipping concept, which is understandable since this was already stumbled on in the research gaps. For this reason, the search for supplementing transport models will focus on parcel demand data or spatial data for the Netherlands.

In the Netherlands, Rijkswaterstaat, the Dutch executing agency for the Ministry of Infrastructure and Water Management, uses a 'basismodel' for freight transport; BasGoed. BasGoed describes the freight transport by road, rail and waterways on an aggregated level (Wesseling et al., 2018). The goal of this model is to calculate the effects of measures to freight flows. Different flows are taken into account in this model, yet parcel transport is not part of the BasGoed model. For this reason, BasGoed is not usable to supplement the crowdshipping model.

Finally, Significance is currently developing a new agent-based simulation model "Mass-GT" (de Bok and Tavasszy, 2018) with its primary use case in the Netherlands. Mass-GT mostly is about large freight transport, but also contains a parcel module that could be used as a basis run for crowdshipping. Therefore Mass-GT is used to supplement this crowdshipping simulation.

Mass-GT

To elaborate further on Mass-GT, it consists of three modules: a shipment synthesizer, a tour formation model and a network model (de Bok et al., 2020). As part of the shipment synthesizer module, the parcel demand module generates the demand for parcels and the parcel scheduling module simulates the allocation of parcels to vehicles and creates delivery tours. The input for the first is household data over the zones and the average parcel demand per household of 0.195, which outputs to a set of parcels with an origin and a destination which is then inserted into the scheduling module. The scheduling module simulates the formation of distribution tours for the delivery of these parcels. This module is used for calculating the impact of freight transport (conventional delivery) use.

Mass-GT is applied on a spatial demarcation of the Metropool Regio Rotterdam Den Haag. For this, it uses the Verkeersmodel Metropool Regio Rotterdam Den Haag (VMRDH) v2.6 by Metropoolregio Rotterdam Den Haag (MRDH) (Goudappel, 2018). The study area covers most of the province of South Holland in the Netherlands with an area of 1,125 square kilometres. This area is divided into 5925 zones with geographical as well as socio-economical data for each of them. This study area is shown in figure 4.1. The geographical data includes their zone location and a skim matrix for the travel distance between the zones as well as the travel time for car travel. For the socio-economical data, the household data is most important; in the study area, 2.3 million residents live spread over 1.1 million households. The study area for this research is equivalent to the area of VRMDH, being most of the province of South Holland in the Netherlands[(14)].

Figure 4.1: Study area VMRDH

4.2. Model outline

To understand the model implementation, first, a general outline of the process is given. This outline is supported by a flowchart of the model structure, which could be found in figure 4.2 on page 24. In the figure, a distinction is made between the model input, the model run and the output. This same distinction is used in the elaboration below:

Model input

At first, the model input covers all variables noted in the system diagram made in section 3.2. The strategies and uncertainties are input for the model and should thus be entered into the model. These inputs follow either from the conceptual model (crowdshipping data), Mass-GT (parcel demand data) or VRMDH (spatial data). Table 4.1 gives an overview of the variables and their data source.

For the parcel demand, a total of 6% of all parcels is eligible for crowdshipping, so the crowdshipping parcel demand is 0.0117 parcels per household. The number of parcels eligible for crowdshipping transport within the study area is thus estimated at 13,000 parcels per day. For these parcels, the destination is known (the household in a certain zone), yet the origin must be determined as well. For

Variable	Unit	Data source
Crowdshipping willingness	%	Conceptual model
Willingness to ship	%	Conceptual model
Value of time	€ / hour	Conceptual model
Pick-up & drop-off times	hour	Conceptual model
Operating method	-	Conceptual model
Detour threshold	-	Conceptual model
Compensation formula	€	Conceptual model
Parcel demand	parcels / household	Mass-GT
Spatial demarcation (zonal data)	-	VMRDH
Social-economical zonal data	-	VMRDH
Household data	households / zone	
Retailer data	retail jobs / zone	
Travellers O/D matrices	-	VMRDH

Table 4.1: Input data sources

the parcel demand module in Mass-GT, this is assumed to be the closest consolidation centre. For the crowdshipping parcels, the parcels' origins are distributed over all zones in that municipality to the ratio of the number of retail jobs in those zones[(15)], assuming that this number roughly represents the pick-up points of the parcels.

The input data for the travellers supply is gathered from the VMRDH. Within the study area, 2.3 million car trips are made, over 450,000 public transport users and just below 1.8 million cycle trips each day. For these modes, an origin-destination matrix for all 5925 zones is available. The travel times for car trips is known using the skim matrix. The time skim matrix for cycling trips could easily be computed by dividing the distance by the average cycling speed of 12 km/h (Molnár, 2002). For public transport, however, no travel time skim matrix is available and for this reason, public transport travellers are not taken into account in this research.

Model run

When the model input is loaded and generated, the model run starts. This corresponds to the 'crowdshipping' part in figure 4.2 and starts with the travellers communicating their trips to the platform. This is done by looping over the modalities (car and bike) and the travellers within the mode. When the trip is communicated, the platform makes a list of all possible parcels. In generating this list, a filter is applied as follows: first, parcels that have already been taken are not considered. Next, either the traveller's origin or destination should be in the same municipality as the parcel. The final filter is that the parcel trip should be at least half the length of the traveller's trip. These filters (except for the first) are mostly to reduce computation time for the model run, yet it is expected that the filtered-out parcels would not be worth the effort for the traveller.

For the resulting parcels, the relative detour is calculated as shown in equation 3.1. If the relative detour for a certain parcel is lower than the threshold, the compensation is calculated and the parcel is saved as an option to offer this to the traveller. When all parcels are evaluated, the three with the lowest relative detour are picked and presented to the traveller.

The traveller now calculates their utility per offered parcel following equation 3.4 and chooses their favoured one (with the highest utility). If this utility higher than the threshold, the traveller opt for this parcel, reports this choice back to the platform and becomes an occasional carrier. The platform stores this match and the loop for this traveller is over.

The above-mentioned process is done for all willing travellers. In the end, this results in some travellers who did and some who did not opt to ship a parcel. This is all registered by the platform and not-taken parcels should be handed over to conventional carriers to still be able to deliver the parcels.

Model output

The key performance indicators are the total travellers' detour and their modality, the average compensation and the percentage of delivered parcels for the platform. These indicators are thus generated automatically by the model. Furthermore, the expected mileage decrease for regular delivery companies is calculated separately. For this, the not-delivered parcels are exported and added to the Mass-GT parcel demand and shipment synthesizer module.

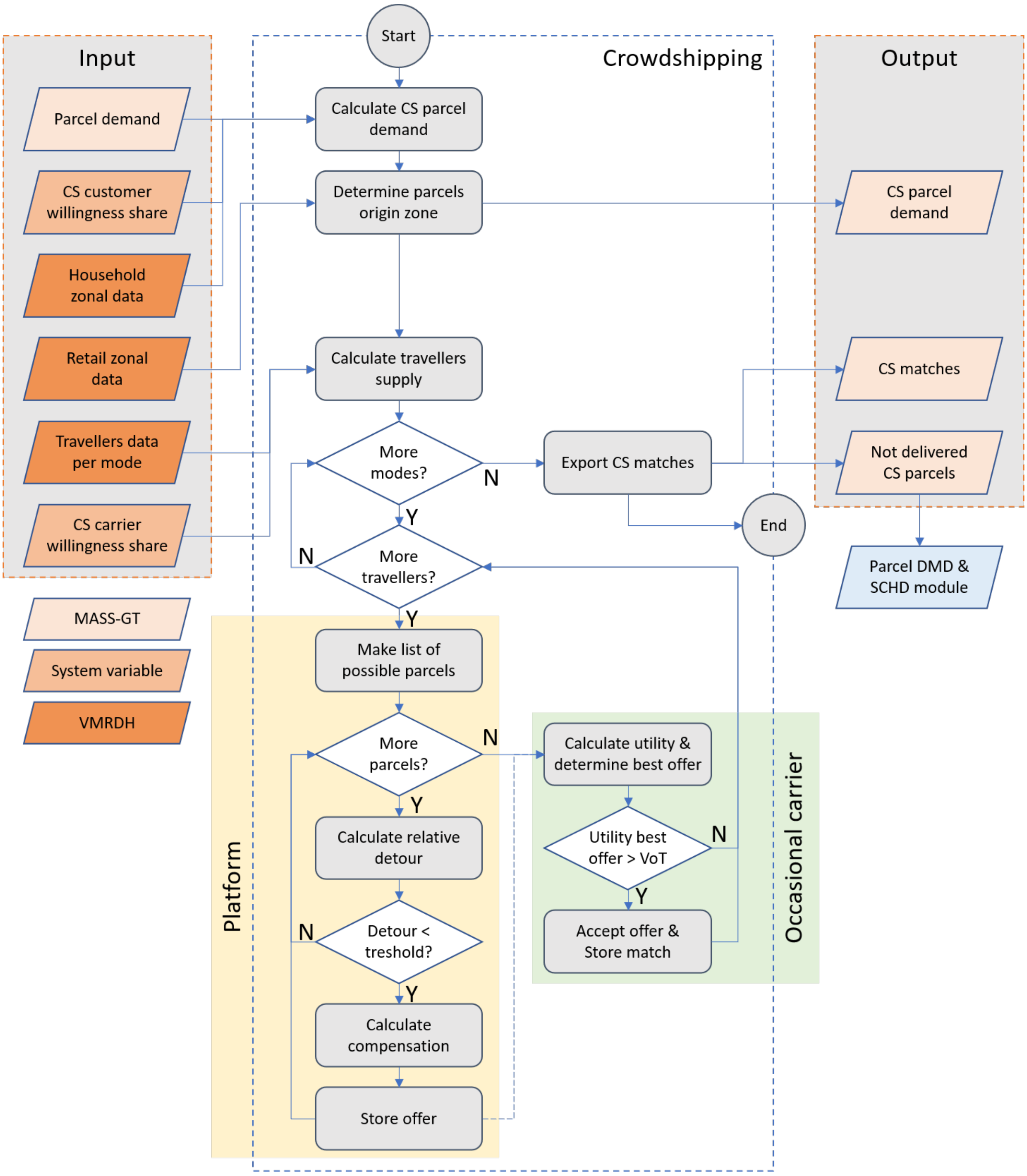


Figure 4.2: Flowchart model implementation

4.3. Model implementation

In this section, the implementation is explained. The model is implemented using Python because of the convenient interaction with Mass-GT. The full Python code for this implementation could be found in appendix D.

The Python implementation follows the flowchart as previously given in figure 4.2. The first step is to calculate the parcel demand. For this, a CSV file with household data is combined with the crowdshipping demand. This step starts with a simple multiplication of the demand and the number of households per zone. Following, a random origin is taken within the municipality to the ratio of retail jobs. The parcels are stored in a NumPy array. At this point, the parcel demand is exported to a CSV and GEOJSON file, to reuse the same demand in various experiments. A visualisation of the parcel demand could be found in figure 4.3. The assumption that the parcel originates within the municipality could easily be seen here.

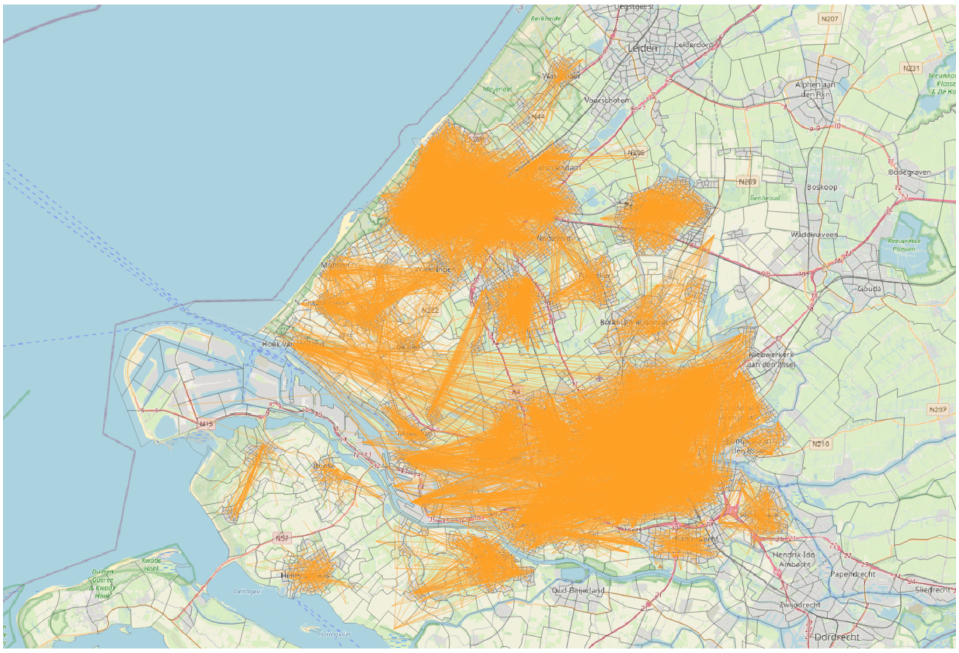


Figure 4.3: Visualisation of parcel demand

The travellers supply is constructed from the origin/destination matrices from VMRDH. These OD matrices first get multiplied by the travellers' willingness percentage. Next, the model loops over each cell in the matrices and creates a traveller for each input in that cell. Also, the municipalities of the origin and destination are looked up, to enable quick filtering of the travellers. Just like the parcels, the travellers are exported to a CSV file to easily reuse this data.

After the parcel demand is generated and the travellers supply is loaded, the travellers loop starts. This is a computationally-intensive process since the platform calculates the optimal parcels for all 750,000 travellers. The travellers are looped in order of creation, which is in order of origin zone number. Test runs have been performed using a randomized loop order, yet this did not lead to significant differences in outcomes.

After looping the travellers, the model will export all generated data for further exploration and interpretation of the results. Again, the data is exported to CSV files and where possible to GEOJSON files as well. The exported data includes the parcel demand, travellers supply and parcels administration including the taken detours by the occasional carriers. Using the exported GEOJSON files, the results could be visualised from which qualitative insights are found.

At the end of the model run, a small qualitative report is given. This report consists of the number of parcels in the system, the crowdshipping eligible parcels, and the number of delivered crowdshipping parcels. Furthermore, the average detour taken by the occasional carriers to deliver the parcels is given as well as the average compensation provided by the platform. Finally, the figures are split between the different modalities. An example of these outcomes could be found in listing 4.1.

```
A total of 221,207 parcels ordered in the system. 13,163 are eligible for CS of which 12,837
    have been delivered (97.52%).
The average distance of CS parcel trips is 5.99km. For the delivered parcels, the average
    detour is 2.45km.
For the crowdshipping deliveries, 31400 extra kilometres are driven. The detours are
    distributed to modes as follows
Bike: 9094 parcels, total of 14900km (1.64km average)
Car:  3743 parcels, total of 16490km (4.41km average)

The average provided compensation for the occasional carriers is 2.32 euro.
```

Listing 4.1: Qualitative results summary from Python

4.3.1. Calibration

The model needs to be fed with data. As explained before, most of the spatial data come from Mass-GT and VMRDH, yet the crowdshipping specific data is derived from literature. The specific literature is mentioned in section 3.1. An overview of the parameters is given here.

In the calibration table below, a distinction is made between uncertain and strategic parameters. Uncertain parameters are variables that are external factors, so these could not be changed within the system boundaries. These include the parcels per household, the share of customers' crowdshipping willingness, the travellers' willingness, drop-off times and the value of time. Opposing are the strategic parameters which include the variables which could be set by the platform. These are the threshold of accepted detour distance (equation 3.1) and the compensation formula.

Table 4.2 gives an overview of the input parameters and their base value. These values are used as the base settings. These settings are the standard used in the experiments and sensitivity analysis.

Parameter type	Variable	Base value
Uncertainty	Parcel demand	0.195
	Crowdshipping willingness	6%
	Willingness to ship	30%
	Value of time	8.75 (bike), 9.00 (car)
	Pick-up & drop-off times	1/60 (bike), 2/60 (car)
Strategy	Detour threshold	0
	Compensation formula	log((parcel distance) + 5)

Table 4.2: Base input parameters

4.3.2. Preliminary results

The preliminary results are given here, for the purpose of validation and verification in the following section. The full results and analysis are given in chapter 5. These results follow from a run in the model's base settings.

In total, 221,000 parcels are ordered from which slightly more than 13,000 are eligible for crowdshipping. A total of 4 million trips are made by travellers of which 51% are made by car and 49% by bike. About 30% of these travellers are willing to carry a parcel on their trip, which is 750,000 travellers.

The results show that 97.5% of all eligible parcels gets delivered by an occasional carrier. The average provided compensation is 2.32 euro. For these deliveries, 31,400 extra kilometres are travelled by the carriers which are equally divided by car and bike. Through the decrease in conventional delivery demand, a reduction of 2,300 kilometres is achieved for delivery vans. These results could be found in table 4.3.

Delivered parcels	12,837 (97.52%)
Average compensation	2.32 euro
Freight transport reduction	2,261 km (delivery van)
Passenger transport increase	31,400 km (2.45 / parcel)
of which by bike	14,900 km
of which by car	16,490 km

Table 4.3: Results CS base run

4.4. Validation and verification

In this section, the validation and verification are described. This is a process of evaluation to determine to what extend the simulation model contributes to the research goal. In other words: *is the model fit for its purpose?* The full process of validation and verification can be found in appendix B. The main conclusions are given here.

The evaluation process consists of three steps, which are derived from a study by Robinson (1997). First, a conceptual validation is performed to reflect on the conceptual model. Secondly, the model verification is done to verify the correct implementation of the conceptual model. Finally, the model validation is performed to reflect the simulation model to the research goal. In the process, various tests are used which are picked from an extensive set by Senge and Forrester (1980). These tests were originally developed for system dynamics modelling, yet Qudrat-Ullah (2005) suggests these tests can be used for agent-based modelling as well because of the strong similarities in both approaches.

The goal of this research is to explore the interactions between travellers and parcel shipments in various strategic crowdshipping contexts and assess their impact on transport use. The conceptual model covers the interactions between travellers and parcel shipments via the platform. Furthermore, various service strategies could be implemented by the platform. Finally, the output of the conceptual model includes passenger and freight transport use. Therefore, the conceptual model is suitable to answer this research question. This is affirmed by two expert reviews[1] on the conceptual model.

Several assumptions were made in the conceptualisation, which are listed in appendix C. Three assumptions were found most impactful. The first is that no mode or trip changes occur because of crowdshipping possibilities (assumption 3), which excludes 'dedicated carriers' in the model. The second is the matching strategy, which is set to find the optimal parcel per traveller (assumption 5). This limits other implementations where the platform optimises per parcel and find the optimal carrier. The final impactful assumption is that an occasional carrier could only carry one parcel (assumption 13).

The most important boundary of the conceptual model is in the route options choice. In the conceptual model, only the 'last leg' of the parcel trip is considered[(16)]. The crowdshipping parcel's trip is assumed to originate from a retailer, pick-up point or postal service distribution centre. This means the supply, or 'first leg' of the parcel trip from the warehouse to one of these 'origins' is excluded. This is visualised in figure 4.4 below.

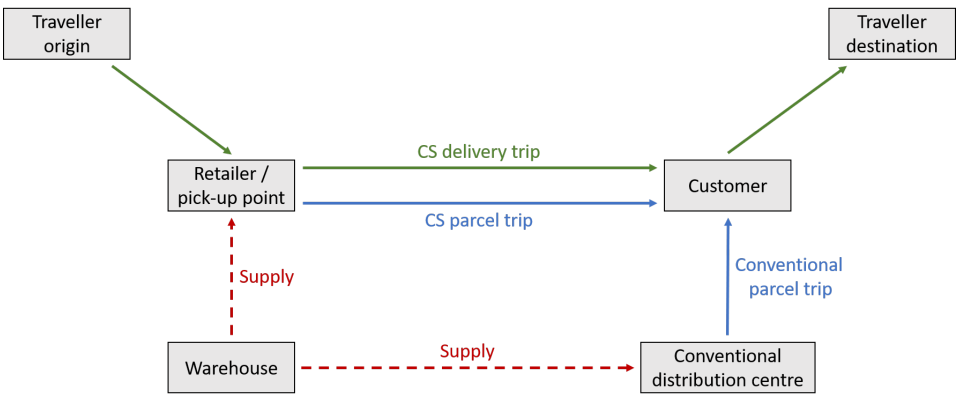


Figure 4.4: Visualisation assumption last lig delivery:
The supply of the parcels to either retailer, pick-up point or conventional service provider (shown in red) is not taken into account.

The model is verified by a dimensional consistency test, which found no unit errors in the model. Secondly, an extreme conditions test was performed to test the system's behaviour at extreme input settings. This test set limits to the input range of each parameter and built confidence in the model behaviour within these limits. The final verification test is the individual agent behaviour test. Within a carefully designed test run, an individual traveller is followed in their matching process. Figure 4.5 gives an overview of the test run. In this test, the travellers followed the manually calculated behaviour and therefore this test is passed as well.

[1] Jackson Amankwah (Nimber) and Rodrigo Tapia (Delft University of Technology)

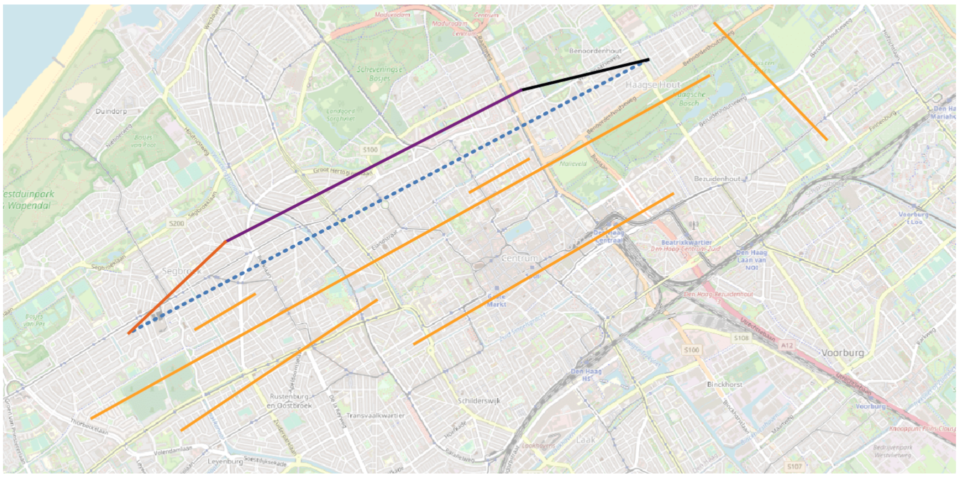


Figure 4.5: Test case individual agent behaviour - The blue dashed line represents the travellers' trip and orange lines are the available parcels. The traveller chooses the parcel in the north (visualised in purple). This parcel has the lowest relative detour and highest utility.

The final validation step is the model validation. This reflects the simulation model to the research goal. A sensitivity analysis was done first, which results could be found in appendix E. The model is stable on most parameters. However, the compensation and value of time have a major impact on the delivery degree of the platform. This is in line with the stated preference research by Serafini et al. (2018) where the remuneration has a high impact on the travellers' willingness. The final performed test is the behaviour-prediction test. The model passes all hypotheses and thus follows expected behaviour. The simulation model is able to calculate the impact on transport use under various crowdshipping implementation and is therefore fit for purpose.

4.5. Conclusion

This chapter covers the sub-question 'How could the impacts of crowdshipping be simulated?' For the model implementation, supplementing model Mass-GT is used for parcel demand and calculating transport use of conventional delivery. Furthermore, the VMRDH model is used for the spatial demarcation and social-economical data. The model is implemented using Python, and through performing experiments, the impacts of crowdshipping can be simulated. The model is carefully constructed and through improving iterations and several validation tests, confidence is built in the usability of this model for the research goal.

5 Results

In this chapter, the results of this research are presented. This consists of three parts; in section 5.1, the reference case is described. Following, the results of the base case are discussed in section 5.2. Finally, in section 5.3, four experiments are performed to test the transport use in different crowdshipping implementations

5.1. Reference case

To understand the crowdshipping results, the reference case is described first. The reference case is a scenario where no crowdshipping takes place. This scenario is described in two areas, the passenger and freight transport systems. The main results from the reference case could be found in table 5.1.

In the passenger transport system, 4.1 million trips are made daily. 57% of these trips are made by car and the other 43% by bike. The car trips account for a total driven distance of 15.5 million kilometres (6.6 km/trip). The driven distance by bike is significantly lower at almost 7 million kilometres (3.9 km/trip). A visual inspection of the trips shows an expected pattern. Most trips between cities are done by car while most inner-city trips are driven by bike.

In the freight transport system, this research only focuses on parcel transport. The parcel transport impact is assessed using the Mass-GT shipment synthesizer and scheduling modules. In the reference case, 221,207 parcels are ordered daily. To deliver these parcels, 1,236 tours are made for 28,214 trips. The total driven distance by the delivery vans is 76,316 kilometres. As discussed in the validation, this only includes the last leg of the parcel transport: from the parcel depot to the customer.

Parcels (total delivered)	221,207
Freight transport distance	76,316 km (delivery van)
Passenger transport distance	6,917,000 km (bike) 15,468,000 km (car)

Table 5.1: Outcomes reference case

5.2. Base case

The base case is a scenario with crowdshipping. In the base case, the system is modelled with the input parameters as shown in table 4.2. The results were briefly given before but were not interpreted. In this section, the results are interpreted. To recall, in table 5.2, the main results could be found.

Delivered parcels	12,837 (97.52%)
Average compensation	2.32 euro
Freight transport reduction	2,261 km (delivery van)
Passenger transport increase	31,400 km (2.45 / parcel)
of which by bike	14,900 km
of which by car	16,490 km

Table 5.2: Outcomes crowdshipping base run

Driven distance

The first figure which stands out is the relatively large increase in passenger transport kilometres compared to a relatively small decrease in freight transport kilometres. For the conventional delivery companies, a decrease in demand of 13,000 parcels only reduces the delivery van distance by 2,261 kilometres, while the occasional carriers travel an extra 31,400 (detour) kilometres for delivering the same parcels. This is due to the inefficiency of the occasional carriers (compared to the efficiency of regular parcel delivery). In the experiments, it is examined how to make the occasional carriers more efficient. The sensitivity analysis showed that the average detour (by the occasional carrier) is highly sensitive to the travellers' value of time and provided compensation, and to a lesser extent to the relative extra distance threshold. Experiments are performed with changes in these parameters to find out how crowdshipping could be more efficient, see section 5.3.

An interesting notion is that for some occasional carriers, the detour is negative i.e., less distance is travelled when a traveller delivers a parcel. This is due to travellers driving the fastest route and not the shortest one. When this traveller opts for a parcel on a slightly more time-consuming yet shorter route, the detour could drop below zero. An example of this could be found in figure 5.1.

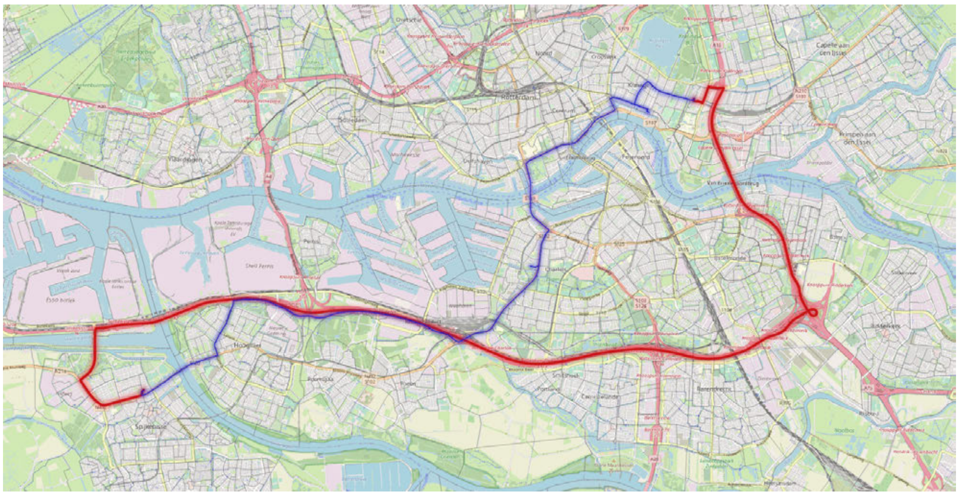


Figure 5.1: Example negative detour occasional carrier. Red route is original travellers' trip, blue is the 'detour' trip for crowdshipping.

Furthermore, the efficiency of regular delivery companies is examined. For this, the parcel demand and scheduling modules from Mass-GT is used. In the reference case without crowdshipping, 0.195 parcels per household are ordered (220,000 parcels) which results in over 68,000 kilometres travelled. The average distance per parcel is thus 0.31 km. This efficiency is caused by two factors: at first the capacity of the delivery van and secondly the parcel-demand density. The former is set at 180 parcels per van. The latter could be extracted from the scheduling module. On average, 7.8 parcels are delivered per zone on the delivery tour. For each van trip (between two zones), on average 2.4 km is travelled, and because of the 7.8 parcels delivered per trip, the average per parcel is relatively low.

Conventional parcel delivery is efficient because their large scale, yet crowdshipping endeavours to take a share of this. To assess the possible effects of a decreasing share of regular parcel shipping, the Mass-GT modules is run at lower parcel amounts. Results could be found in figure 5.2. As could be seen, the travelled distance at 0.195 parcels per household is 0.34 km per parcel. This exponentially increases to 0.48 km per parcel at 0.10 parcels per household (half of the current demand). However, the latter is not expected to happen since the customers' willingness to opt for crowdshipping is found at 30% in literature. Even at full potential (0.135 parcels per household), regular parcel delivery has an advantage of scale and the distance per parcel approaches 0.42 km. Furthermore, the calculated distance per parcel for freight transport is arbitrary in some runs. This is because of the heuristics in Mass-GT which is not always finding the optimal solution.

Crowdshipping viability

For the platform, viability is the most important goal. For this, two indicators are most relevant being the percentage of delivered parcels and the provided compensation. For the base run, the percentage of

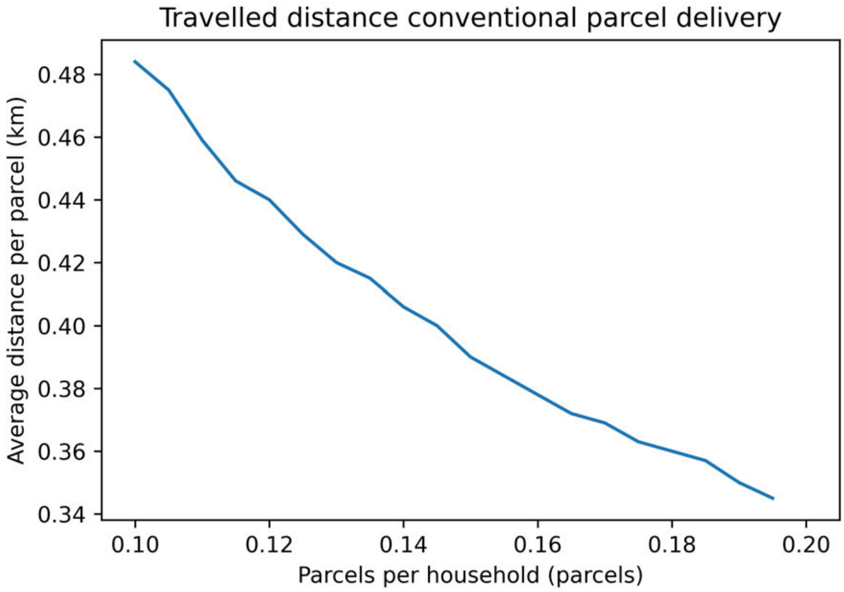


Figure 5.2: Travelled distance regular parcel delivery

delivered parcels is 97.52% which is quite high. This is due to the ratio of willing travellers against the number of parcels. In the study area, 4.1 million trips are made by travellers. The traveller's willingness of 30% found in literature leads to 750,000 willing travellers. This is a relatively high amount compared to the 13,000 parcels eligible for crowdshipping. The ratio of travellers/parcels is at 53.4. It is interesting to explore at what ratio the percentage of delivered parcels drops to an unacceptable level. For this exploration, experiments are set up with changes in the customer's and traveller's willingness.

Secondly, the provided compensation is estimated at 2.32 euro. This is ,based on the travellers' value of time, enough to compensate for the driven detour. The compensation is lower than the average price of conventional delivery, so the service might be compatible. The exact amount of compensation per trip is based on the parcel distance following a logarithmic curve (see equation 3.3). The increasing compensation for longer trips, in combination with a different drop-off time, gives a clear distinction in parcels taken by cyclist and car drivers, which could be seen in figure 5.3. In literature, however, other compensation schemes were suggested like a fixed price independently from the taken parcel or basing the compensation on the expected detour for the particular traveller. In the experiments, these compensation schemes are examined as well to find out the effect of these strategies.

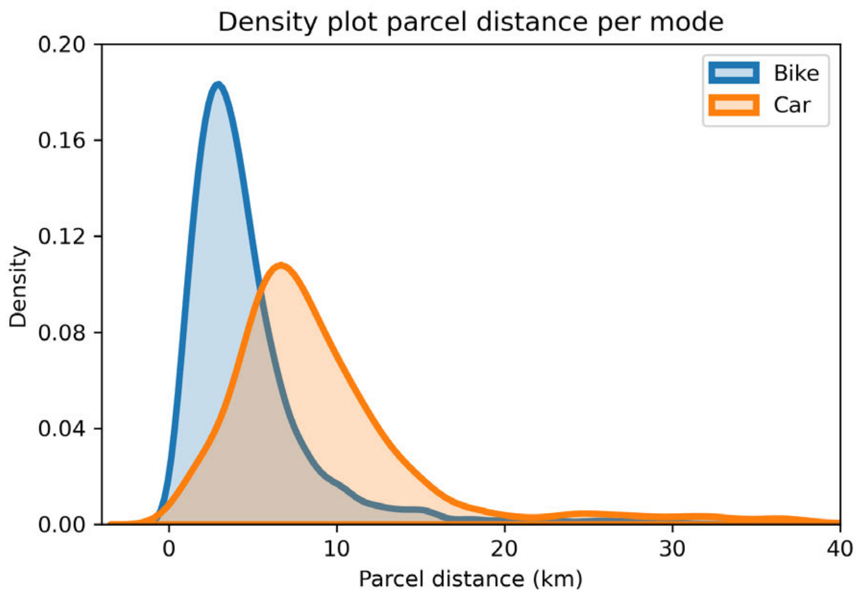


Figure 5.3: Density plot of parcel distance per mode

Finally, the results in this section originate from the model which includes a lot of assumptions. In the previous chapter on validation and verification, it is discussed to what extent these results contribute to the research goal. The main limiting assumption is on the parcel origin; the current model assumes the origin to be within the same municipality and the parcel originates in a shop. Both assumptions limit the crowdshipping demand to a specific type of parcels. In the experiments, the use of pickup points is tested, and parcel origins are spread over the study area to examine the impact of this platform's strategy.

5.3. Experiments

From the interpretation of the base case, some experiments were set up. The first experiment aims to make crowdshipping more efficient by the platform's strategies. Secondly, the willingness uncertainties were tested to inspect what ratio between travellers and customers is needed to perform well. The third experiments test other platform compensation strategies. Finally, a different operating strategy is tested by changing the parcels' origin. An overview of these experiments could be found in table 5.3.

Experiment	Changing parameters	Runs
More efficient crowdshipping	lowering compensation	9 runs
	lowering detour threshold	20 runs
Ratio travellers per parcel	increasing crowdshipping share	14 runs
	decreasing willingness to ship	14 runs
Alternative compensation schemes	compensation formula	5 runs
Changing parcel origin	operating strategy	5 runs

Table 5.3: Experimental setup

5.3.1. More efficient crowdshipping

The goal of these experiments is to analyse whether crowdshipping could be performed more efficiently. Efficiency, in this case, is measured by the amount of detour the occasional carriers travel to deliver the parcels. As elaborated before, the average detour in the base case is 2.45 km compared to 0.31 kilometre per parcel for regular delivery. The aim is to decrease the detour towards the latter. The travellers' value of time and the provided compensation impact the average detour in the same way. The experiments are performed with changing compensations since this is a strategic parameter.

Lowering compensation

For this experiment, the model is simulated at various compensation levels. In the base case, the compensation is determined based on the parcel distance using the formula log(parcel distance + 5). For these experiments, a total of 9 runs were performed for this experiment starting at 90% lowering down to 10% of the original compensation. The table of results for these experiments could be found in table 5.4 on the following page. The most interesting outcomes are visualised in figure 5.4.

The figure shows expected resulting behaviour: by lowering the compensation, fewer detour kilometres are driven. The decreasing compensation also affects the percentage of delivered parcels since the utility of delivery lowers and travellers are less eager to opt for delivery. Two figures stand out from these experiments. At first, the average detour drops below zero at 20% of the original compensation, meaning less distance is travelled when travellers deliver parcels. This is due to travellers driving the fastest route and not the shortest one. When this traveller opts for a parcel on a slightly more time-consuming yet shorter route, the detour could drop below zero. An example of this could be found in figure 5.1. The second notion from this experiment is that at a compensation of 30%, the average detour drops under the amount of regular delivery (under 0.31 km/parcel), yet only 25% of parcels get delivered. This might be an unacceptable level for a platform to maintain its viability. Lowering the compensation might thus be a partial solution of more efficient crowdshipping but could not solve the full gap to regular delivery.

Run	Percentage	Average	Freight km	Passenger km increase		
	delivered	compen-	decrease			
Compensation		sation	Delivery van	Bike	Car	Total (avg)
Base (100%)	97.52%	€2.32	2,261	14,900	16,490	31,400 (2.45)
90%	96.00%	€2.08	2,369	12,590	14,030	26,620 (2.11)
80%	92.46%	€1.84	2,651	10,290	10,590	20,880 (1.72)
70%	86.00%	€1.60	1,658	8,180	6,860	15,040 (1.33)
60%	73.87%	€1.35	1,756	5,950	3,800	9,760 (1.00)
50%	56.17%	€1.11	1,279	3,940	1,230	5,170 (0.70)
40%	38.41%	€0.88	763	2,090	130	2,230 (0.44)
30%	24.79%	€0.65	547	690	-20	670 (0.21)
20%	15.00%	€0.44	563	-60	-40	-70 (- .04)
10%	7.29%	€0.22	107	-230	0	-230 (- .23)

Table 5.4: Results experiment lowering compensation

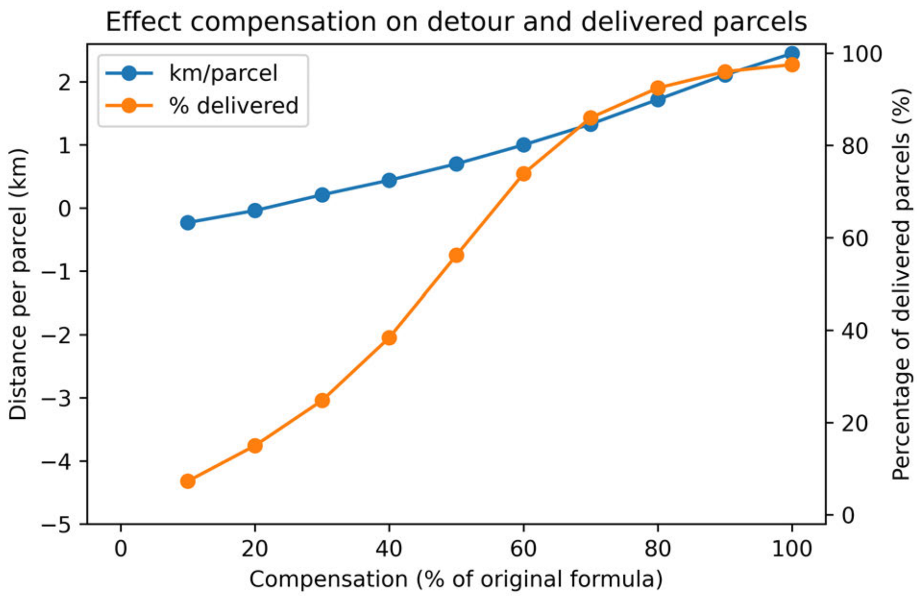


Figure 5.4: Effect compensation on detour and delivered parcels

Lowering detour threshold
Furthermore, the crowdshipping platform has another lever to make crowdshipping more efficient. By lowering the accepted relative detour threshold, better-suited trips are offered to the travellers. These trips might be less viable for the traveller (who optimises for the best utility, which might not be the parcel with the lowest detour), yet leads to less driven mileage. The default threshold is set at 0 i.e., the absolute detour must be the same or lower than the parcel trip length. In this experiment, 20 model runs were performed, lowering the threshold down to -2.0. At this level, travellers are forced to make a negative detour with at least the same length as the parcel trip. The results of this experiment are given in table 5.5 followed by figure 5.5 showing the most relevant outcomes in a graph.

A clear trade-off could be seen in the graph between the percentage of delivered parcels and the driven detour. However, detour decreased more quickly compared to the experiment with lowering compensation. At a threshold level of -0.8, the detour per parcel is only 0.45 km, while still 70% of parcels get delivered. From a set threshold of less than -1, travellers only get trips offered with a forced negative detour. Forcing travellers to travel negative detours might however be undesirable. The current study only inspects the driven distance, but not the place where these kilometres are made. The example of a negative detour in figure 5.1 shows a detour that crosses the city centre of Rotterdam instead of travelling via a highway around the city. More research should be done on this matter to grade certain routes over others.

Run Detour threshold	Percentage delivered	Average compen-sation	Freight km decrease Delivery van	Passenger km increase Bike	 Car	 Total (avg)
Base (0)	97.52%	€2.32	2,261	14,900	16,490	31,400 (2.45)
-0.1	97.04%	€2.32	2,184	14,620	15,880	30,500 (2.39)
-0.2	96.36%	€2.33	2,519	14,220	15,030	29,250 (2.31)
-0.3	95.78%	€2.33	2,245	13,570	13,750	27,320 (2.17)
-0.4	94.36%	€2.33	2,246	12,540	11,930	24,470 (1.97)
-0.5	92.25%	€2.33	2,663	10,860	10,010	20,860 (1.72)
-0.6	88.08%	€2.33	1,725	8,490	7,620	16,110 (1.39)
-0.7	81.11%	€2.34	2,064	5,570	4,610	10,380 (0.97)
-0.8	69.19%	€2.34	1,412	2,870	1,190	4,060 (0.45)
-0.9	55.07%	€2.34	1,000	620	-2,130	-1,510 (-0.21)
-1.0	40.86%	€2.33	705	-230	-4,630	-4,860 (-0.90)
-1.1	30.03%	€2.31	900	-90	-6,070	-6,160 (-1.56)
-1.2	22.66%	€2.29	476	-40	-5,980	-6,020 (-2.02)
-1.3	17.13%	€2.28	563	-20	-5,480	-5,500 (-2.44)
-1.4	12.73%	€2.27	372	-10	-4,750	-4,750 (-2.84)
-1.5	9.35%	€2.27	-56	0	-3,930	-3,930 (-3.19)
-1.6	6.69%	€2.25	-87	0	-3,110	-3,110 (-3.53)
-1.7	4.26%	€2.24	232	0	-2,190	-2,190 (-3.90)
-1.8	2.70%	€2.23	-24	0	-1,500	-1,500 (-4.24)
-1.9	1.74%	€2.22	75	0	-1,030	-1,030 (-4.51)
-2.0	0.94%	€2.19	303	0	-580	-580 (-4.72)

Table 5.5: Results experiment lowering detour threshold

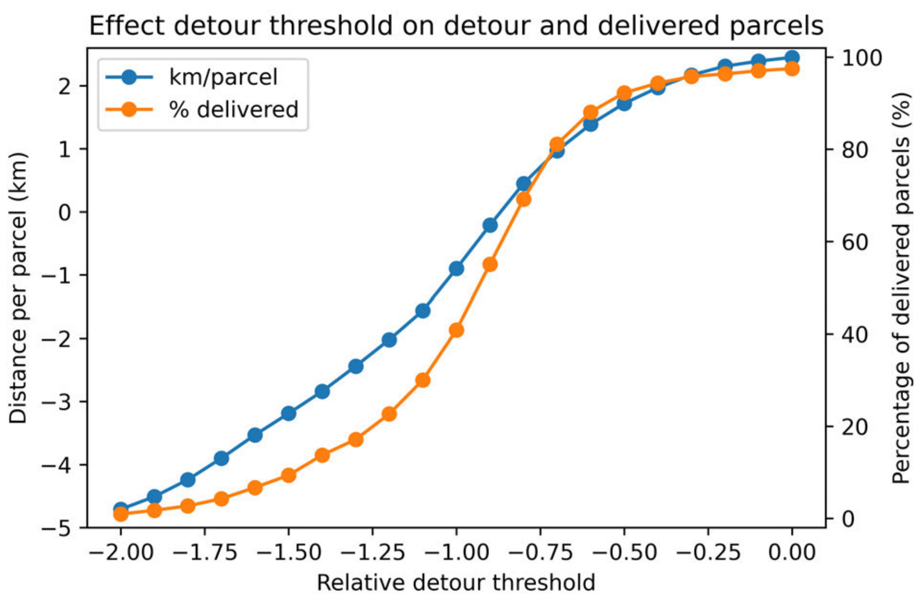


Figure 5.5: Effect detour threshold on detour and delivered parcels

5.3.2. Ratio travellers per parcel

In the base case, 97.5% of all ordered crowdshipping parcels have been delivered by occasional carriers. In these experiments, it is examined how this percentage is affected by a decrease in the ratio of travellers per parcel. In the base case, there are 750,000 travellers to ship 13,000 parcels, which gives a ratio of 53.4 travellers per parcel. The ratio could be decreased by either increasing the crowdshipping share or decreasing the travellers' willingness.

Increasing crowdshipping share

At first, an experiment is performed by increasing the parcel demand. In the base scenario, a CS share of 6% is used. This is a product of 20% eligible parcels and 30% customer willingness. The 6% share corresponds to 13,000 eligible parcels. In this experiment, 14 runs were performed in which the crowdshipping share is gradually increased up to 50%. The results can be found in table 5.6.

In the experiment, the crowdshipping parcel demand goes up to 110,000 parcels. Even at the eightfold of the original parcel demand, over 87% of crowdshipping parcels gets delivered, see figure 5.6. At this level, the ratio decreased to 6.3 travellers per parcel. Due to computational limits, it was not possible to further increase the number of parcels.

Run CS share	CS parcels	Percentage delivered	Average compen-sation	Freight km decrease Delivery van	Passenger km increase Bike	Car	Total (avg)
Base (6%)	13,163	97.52%	€2.32	2,261	14,900	16,490	31,400 (2.45)
8%	17,626	97.50%	€2.32	2,758	19,060	22,960	42,020 (2.44)
10%	22,040	97.05%	€2.32	3,883	22,780	28,360	51,140 (2.39)
12%	26,439	96.70%	€2.32	4,635	26,140	35,940	62,080 (2.43)
14%	30,989	96.11%	€2.31	5,726	29,910	40,150	70,050 (2.35)
16%	35,272	95.77%	€2.32	6,658	32,450	46,620	79,070 (2.34)
18%	39,778	95.38%	€2.31	7,084	36,000	51,510	87,510 (2.31)
20%	44,186	95.04%	€2.31	8,247	38,580	59,300	97,880 (2.33)
25%	55,230	94.01%	€2.31	10,010	45,110	74,260	119,370 (2.30)
30%	66,349	92.25%	€2.30	11,789	50,630	85,940	136,580 (2.23)
35%	77,340	91.27%	€2.30	13,591	55,000	102,620	157,620 (2.23)
40%	88,402	90.07%	€2.30	15,633	60,150	114,390	174,540 (2.19)
45%	99,409	88.40%	€2.29	17,408	64,260	125,700	189,960 (2.16)
50%	110,554	87.33%	€2.29	19,078	68,910	135,720	204,630 (2.12)

Table 5.6: Results experiment increasing share of eligible parcels for crowdshipping

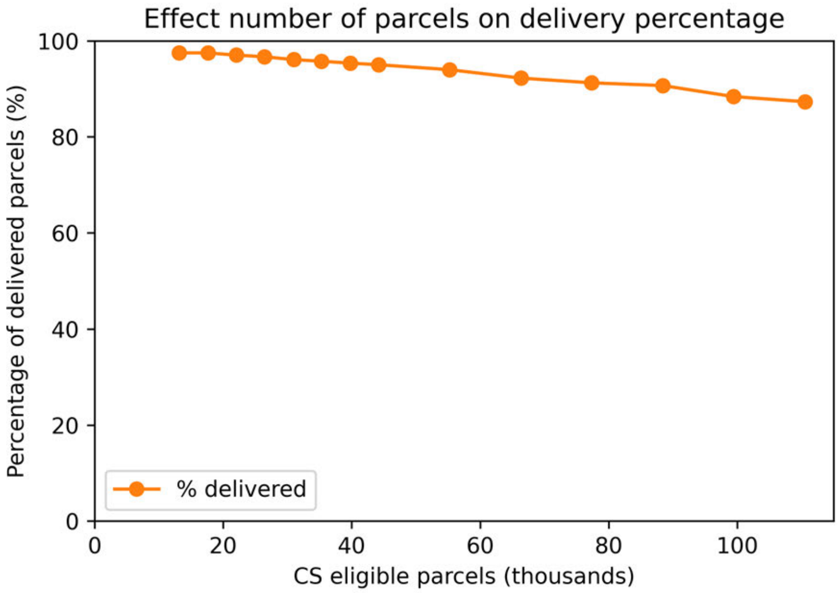


Figure 5.6: Effect crowdshipping eligible parcels on percentage delivered parcels

Decreasing travellers' willingness

A second experiment to test the ratio of travellers per parcel is performed by decreasing the number of travellers. For this experiment, 14 runs were performed, decreasing the number of travellers is decreased from 750,000 to 0. This corresponds to the travellers' willingness from 30% to 0%. Table 5.7 provides an overview of the experiment's outcomes. In addition, the percentage of delivered parcels in these runs is graphed in figure 5.7.

As could be seen from the graph, the relation between the number of travellers and percentage of delivered parcels takes a logarithmic shape. Halving travellers' willingness from 30% to 15% only decreases the percentage of delivered parcels by 4%. Halving again from 15% to 8% drops the delivered parcels by 17%. At a ratio of 6.3 travellers per parcel (6% travellers' willingness), the percentage of delivered parcels is about 65%.

Run Travellers' willingness	Percentage delivered	Average compen-sation	Freight km decrease Delivery van	Passenger km increase Bike	Car	Total (avg)
Base (30%)	97.52%	€2.32	2,261	14,900	16,490	31,400 (2.45)
25%	97.01%	€2.32	2,125	14,240	17,350	31,590 (2.47)
20%	96.13%	€2.32	2,377	13,130	18,110	31,250 (2.47)
15%	93.69%	€2.21	2,269	11,610	18,610	30,220 (2.45)
12.5%	90.37%	€2.30	1,703	10,570	17,650	28,220 (2.37)
10%	84.64%	€2.28	1,796	9,150	16,450	15,600 (2.30)
9%	81.01%	€2.27	2,105	8,260	15,380	24,010 (2.25)
8%	76.89%	€2.26	1,737	7,970	14,590	22,560 (2.23)
7%	71.52%	€2.25	1,838	7,250	13,660	20,910 (2.22)
6%	64.87%	€2.24	1,379	6,400	12,210	18,610 (2.18)
5%	56.70%	€2.23	1,347	5,410	10,670	16,090 (2.16)
4%	46.78%	€2.22	872	4,450	8,200	12,650 (2.05)
3%	34.25%	€2.20	428	3,240	5,220	8,450 (1.88)
2%	20.46%	€2.18	533	1,930	2,710	4,640 (1.72)
1%	6.15%	€2.12	-12	480	620	1,100 (1.36)

Table 5.7: Results experiment decreasing travellers' willingness

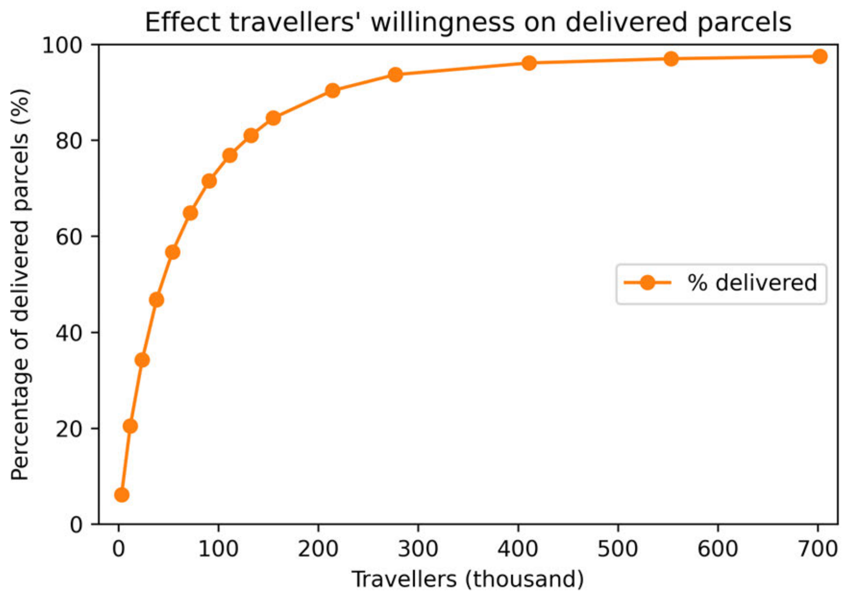


Figure 5.7: Effect travellers' willingness on percentage delivered parcels

An interesting finding comes up when comparing the above experiments. In the former experiment of increasing parcel demand, 83% of parcels is delivered at 6.3 travellers per parcel. In the latter experiment of decreasing travellers willingness, at this same ratio, this percentage of delivered parcels is 65%. It is expected that this difference is caused by the larger spread in the former experiment. Both the parcels and travellers outnumbered the latest experiment, and these parcels and travellers are thus better spread throughout the study area which makes matching easier. In the latest experiment (of lower number of travellers), matching would have been more 'luck'.

To get a better understanding of this, visualise a system of 5 travellers and 1 parcel in a confined area. Here, this case of 'luck' is more present for a traveller to find a suitable parcel to ship. When this number goes up to 50 travellers and 10 parcels (same ratio), travellers are more likely to find a suitable parcel. This is tested in the proof of concept model, see figure 5.8. For the first scenario (5 travellers, 1 parcel), in only 27% of runs, this parcel gets delivered. In the second scenario (50 travellers, 10 parcels), on average 74% of parcels gets delivered.

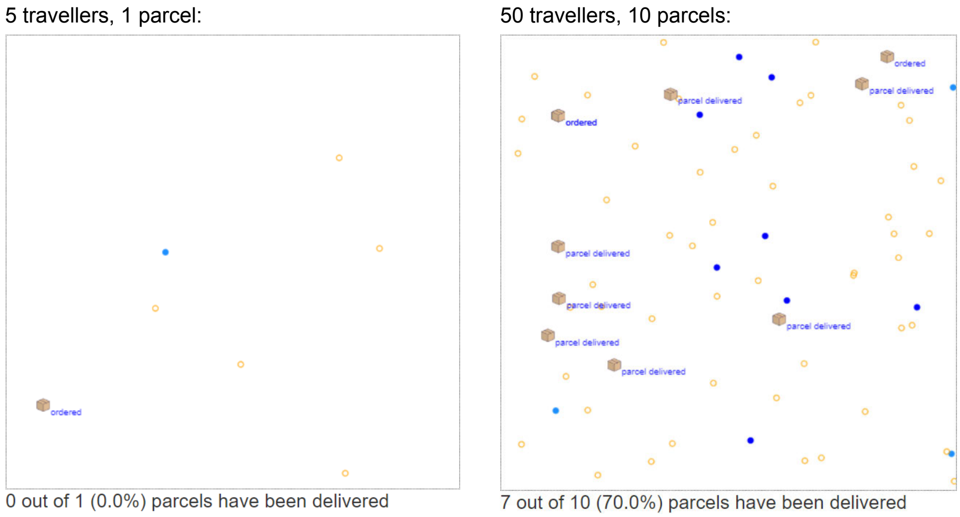


Figure 5.8: Small scale experiments ratio travellers per parcel

Concluding, the ratio of the number of travellers per parcel is important, there needs to be a certain number of willing travellers per available parcel to have a sustainable percentage of delivered parcels. Yet this ratio does not provide the full overview of the success, this is depending on a certain minimum supply/demand as well to achieve a certain spread.

5.3.3. Alternative compensation schemes

This experiment tests other strategies for the platform, in this case, the compensation strategy. First, a strategy of constant compensation is tested. Secondly, a strategy is used based on the detour distance instead of the parcel distance.

For the experiment of fixed compensation, four runs are performed, starting at €2.50, lowering down to €1.00. The full table of results can be found in table 5.8. Providing €2.50 for each trip, most parcels will be delivered (95.66%) and the average detour distance decreased to 2.16 km per parcel. This is mainly because the parcels with longer distance are less attractive to travellers. This could be seen in figure 5.9. In this scenario, parcels with a trip longer than 20 km are not taken while this was the case with logarithmic compensations based on parcel trip length. Three runs are performed with a fixed compensation of €2.00, €1.50 and €1.00. At these prices, the delivered percentage went down to respectively 91.29%, 77.59% and 45.38%. The average detour went down to 1.67, 1.07 and 0.56 km. This average detour decreases again because only the shorter distance parcels are being taken by the carriers.

The experiment with compensation based on the expected detour distance turns out worse compared to other scenarios. In this scenario, 91.74% of parcels get delivered and the average detour is 2.37 km. Just like the previous scenario of fixed compensation, travellers benefit from shipping parcels with lower distance. In the end, it seems undesirable to implement this scenario since the percentage of delivered parcels decreased by quite a lot while this does not lead to decreasing detour distance.

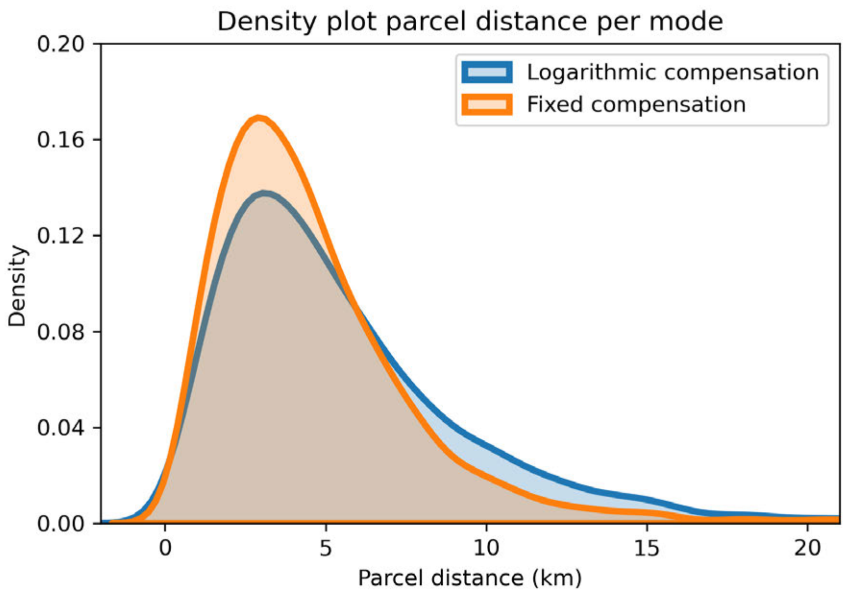


Figure 5.9: Density plot of parcel distance with logarithmic and fixed compensation strategies

Experiment Compensation	Percentage delivered	Average compen-sation	Freight km decrease Delivery van	Passenger km increase Bike	 Car	 Total (avg)
Base (based on parcel trip length)	97.52%	€2.32	2,261	14,900	16,490	31,400 (2.45)
Fixed €2.50	95.66%	€2.50	2,168	15,380	11,760	27,140 (2.16)
Fixed €2.00	91.29%	€2.00	2,387	11,560	8,470	20,020 (1.67)
Fixed €1.50	77.59%	€1.50	1,904	7,200	3,750	10,950 (1.07)
Fixed €1.00	45.38%	€1.00	628	3,090	240	3,330 (0.56)
Based on traveller's detour trip length	93.74%	€1.94	2,269	11,480	15,350	26,830 (2.37)

Table 5.8: Results experiment compensation strategies

5.3.4. Changing parcel origin

In these experiments, the assumption of the parcels' origin is changed to test how the system behaves with other implementation methods. At first, the use of pickup points is discussed and secondly, the assumption that parcels would only be eligible for crowdshipping within their municipality is changed to the whole study area.

Pickup points

The use of pickup points is discussed in literature, for example by Wang et al. (2016) and Serafini et al. (2018). This could be especially interesting when crowdshipping is combined with conventional parcel delivery where the delivery company takes care of the trip towards the pick-up point and crowdshipping is used for the last mile. Another in literature discussed application would be to place pickup points at public transport hubs so occasional carriers would take their parcels along an (efficient and environmentally friendly) public transport trip. The latter could however not be tested in this model since skim data for public transport is unavailable.

For this experiment, the impact is assessed to a smaller study area, being the city of The Hague. In The Hague, four different cases are compared: no pickup points (the regular study, yet now only focusing on The Hague as reference), 1 central pickup point, 3 spread points and finally 6 pickup points. The position of the pickup locations is arguably chosen based on a fair spread in the city and can be seen below in figures 5.10. The full experiment's results are given in table 5.9 on the following page.

No pickup points

1 pickup point (zone 606)

3 pickup points (zones 83, 499, 1029)

6 pickup point (zones 121, 255, 468, 736, 922, 1029)

Figure 5.10: Parcel demand for pickup experiments

In the municipality of The Hague, a total of 49,000 parcels are being shipped each day. With the customers willingness of 6%, the number of eligible parcels for crowdshipping is 3,092. In the base scenario, the average distance of the parcel trip is 6 kilometres which decreases to 4.4 with one pickup point, 3.1 with three and 2.3 with six pickup point. It could therefore be expected that the taken detours would go down as well. Without pickup point, the average detour is 2.89. For one pickup location this is 2.34km, 1.88 for three and 1.5 at six pickup points. Added to this, the number of delivered parcels went up the more pickup points become available. Growing from 98.64% towards 100% at the use of six pickup points.

Not bound to municipality
This is the final experiment performed for this research. An assumption has been made to only simulate inner-city crowdshipping parcels. This experiment will test the implications of this assumption by removing the municipality constraint of parcels. More specifically, the parcel destination is the same (the customer, based on households per zone, and the number of parcels per household), yet the origins are distributed over all zones to the ratio of the number of retail jobs in those zones.

The results show that long trips and detours are made to deliver the parcels. 72.87% of all parcels have been delivered with an average detour of 5.26 km per parcel. Furthermore, this is the only experiment where more parcels are being shipped by car (66%) compared to bike (34%). This is due to the longer parcels' trips of 21 kilometre on average - which was 6 km with the municipality constraint.

Run	CS parcels	Percentage delivered	Average compen-sation	Freight km decrease	Passenger km increase		
Parcel origin				Delivery van	Bike	Car	Total (avg)
Base (no pickup)	3,092	98.64%	€2.35	692	3,100	5,700	8,810 (2.89)
1 pickup	3,092	99.09%	€2.21	570	2,440	4,720	7,150 (2.34)
3 pickup	3,092	99.42%	€2.09	565	3,710	2,060	5,770 (1.88)
6 pickup	3,092	100%	€1.98	603	3,880	710	4,590 (1.50)
Spread through province	13,163	72.87%	€3.01	1,397	6,940	43,540	50,470 (5.26)

Table 5.9: Results experiments changed parcel origin

5.4. Conclusion

The outcomes of the simulation model give insights into the external effects of crowdshipping and its viability. In the base case, a reduction of 2,300 kilometres by delivery vans through the decrease in regular delivery demand is found. On the other side, passenger transport increased by 31,400 kilometres, which contains the detours made by the occasional carriers. Furthermore, for 97.5% of eligible parcels, a suitable occasional carrier could be found. The average provided compensation is €2.32, which is below the average price consignor currently pays for delivery services (of €3.35).

Four experiments were performed. The first shows that through strategic choices in provided compensation and detour threshold, crowdshipping could be more efficient. Lowering the detour threshold gives a better result in percentage delivered parcels, compared to lowering the compensation. The second experiment tests the effect of ratio travellers per parcel by changing both customers' and travellers' willingness. This shows that a certain ratio of travellers per parcels needs to be maintained to ensure sustainability. Furthermore, there needs to be a certain spread in the travellers to increase the chance of delivery for a parcel. In experiment three, other compensation strategies were tested. Both a fixed compensation and compensation based on detour turned out worse for the platform's viability since fewer parcels were delivered. The final experiment changed the platform's strategy concerning the parcels' origin. The use of pick-up points led to a decrease in detour kilometres and at the same time, the percentage of delivered parcels increased. Another strategy tests crowdshipping over the whole study area. In this scenario, the average detour tripled while the number of parcels delivered went down substantially.

6 Conclusion

In this report, a research is described to find possible effects of crowdshipping services on passenger and freight transport use. Various studies have been performed on crowdshipping, yet a research gap was found integrating the pricing, matching and routing problems. Also, these researches are mostly written from the perspective of the platform, to test the viability and determine optimal implementations for them. This research, however, is focused on the impact of these services. The goal of this research is to to explore the interactions between travellers and parcel shipments in various strategic crowdshipping contexts and assess their impact on transport use.

Sub-questions
To structure this research, a main question is divided into sub-questions which are covered first before the main research question is answered.

1. **Which implementation strategies of crowdshipping exist and which will be analysed?**

The implementation strategies were researched in literature and are categorised in route options, infrastructure usage, compensation methods and matching strategies. For this research, the most inclusive implementation is chosen as base implementation. In the experiments, other implementations are covered as well. The base implementation includes a route option from the consignor to the customer, without the use of pick-up points. For infrastructure usage, it is assumed that occasional carriers could use any mode, yet they will not change mode because of a contingent delivery. The compensation in this research is based on the distance of the parcel, yet other compensation schemes are tested as well in the experiments. On matching, a method is chosen to find the optimal parcels for each traveller who reports their trip after which the traveller could decide to opt for a certain parcel. Other shipment characteristics and characteristics in the socio-economic and built environment are taken into account.

2. **What interactions take place between agents in the freight and passenger transport systems through crowdshipping?**

In the conceptual model, customers, crowdshipping platform, travellers and occasional carriers are considered as agents. Between these four agents, several interactions take place. At first, the customers place their orders at the platform. After this process, a few interactions take place back and forth between the travellers and the platform. First, the traveller communicates their planned trip after which the platform searches through the orders and calculates the optimal ones for this traveller. Now the traveller may pick their favoured offer and accepts this delivery offer, or denies them all. When an offer is accepted, this is communicated back to the platform and the traveller becomes an occasional carrier who now will make their trip with an additional detour.

3. **How could the impacts of crowdshipping be simulated?**

For the model implementation, supplementing model Mass-GT is used for parcel demand and calculating transport use of conventional delivery. Furthermore, the VMRDH model is used for the spatial demarcation and social-economical data. The outputs of the model are the difference in driven distance compared to the reference case, the mode used for the detour, the average provided compensation and the percentage of delivered parcels. The model is implemented using Python, and through performing experiments, the impacts of crowdshipping can be simulated. The model is carefully constructed and through improving iterations and several validation tests, confidence is built in the usability of this model for the research goal.

4. **In what way does crowdshipping impact transport use?**

To assess the impact of crowdshipping, four experiments were set up. The first experiment aims to make crowdshipping more efficient by changing the platform's levers. Secondly, the number of parcels and travellers were altered to inspect the effect of the ratio between travellers and parcels. The third experiment tests other platform compensation strategies. Finally, a different operating strategy is tested by changing the parcels' origin.

The first experiment assessed the impact of the detour threshold and compensation amount on the travelled distance for crowdshipping. These input parameters are both strategical levers for the platform to tweak the matching process. It was found that the platform is able to influence the travelled detour distance by the occasional carriers. Lowering the detour threshold is more effective compared to lowering the compensation in decreasing the detour distances. For both levers, a trade-off must be made between maintaining a high delivery degree and lowering the detour.

The second experiment is performed to test the effect of the number of parcels and travellers on the travelled distance and the delivery degree. The outcomes of these experiments show that the detour distance per parcel does not depend on these input parameters. Besides, the ratio of travellers per parcel positively impacts the percentage of delivered parcels, where a higher ratio leads to a higher delivery degree. Furthermore, a certain spread in both parcels and travellers is needed to maintain a proper delivery degree.

In the following experiment, the effect of compensation strategies on the travelled distance is evaluated. It is found that for a strategy of fixed compensation per parcel and compensation based on detour distance, the detour distances went down. This is because the delivery degree went down and only the parcels of lower distances are being shipped. Considering this, a strategy of detour based on parcel trip length is most effective.

The final experiment covers the effect of route strategies on the travelled distance and delivery degree. The use of pick-up points for the parcel origin leads to a decrease in the travelled distance, while the delivery degree increased. A strategy of implementing crowdshipping on a province scale results in both increased detours and decreased percentage of delivered parcels.

The experiments show large fluctuations in outcomes between the different experiments. The base case makes clear that crowdshipping without interventions could turn out worse for the environment and congestion. Even while these problems were the initial motive to seek innovative solutions for parcel delivery. In some experiments, the taken detours were limited while maintaining a proper delivery degree.

Main research question

The covered sub-question contributes to answer the main question of this research:

How could sustainable crowdshipping impact freight and passenger transport use?

The implementation of crowdshipping in this study area could be viable. The average provided compensation is lower than the price consignors currently pay for conventional delivery. Besides, the delivery degree seems acceptable to get a decent level of service. Through crowdshipping, the travelled distance in the passenger transport system will increase because of the detours taken by occasional carriers. This increase subsequently leads to a decrease in freight transport distance through a decreased demand in conventional parcel demand. However, the passenger transport increase exceeds the freight transport decrease.

The crowdshipping platform could limit the taken detours by making strategic choices in their implementation. This might be at the expense of their delivery degree. This research, therefore, affirms the findings by Simoni et al. (2019), that limiting the deviation of crowdshippers' delivery trips from their original trips is a necessity to reduce negative externalities. It is advised for the public authority to set boundaries for the platform and stimulate strategic matching choices based on these possible externalities.

7

Discussion

The goal of this research was to explore the interactions between travellers and parcel shipments in various strategic crowdshipping contexts and assess their impact on transport use. In this chapter, it is discussed to what extent this goal is achieved and recommendations on possible future research are given.

Results
The results show that crowdshipping in this study area could be viable. Most eligible parcels are delivered by occasional carriers and the provided compensation is below the average cost price of conventional delivery. However, crowdshipping leads to an increase in driven distance for travellers which is way higher than the opposing decrease in freight transport. Without interventions, crowdshipping could turn out worse for the environment and congestion; two factors which were the initial motive to explore crowdshipping. The experiments show that through strategic choices of the crowdshipping implementation, these negative externalities could be limited.

These strategic choices may not be economically beneficial for the crowdshipping platform and so they should be stimulated. It is thus advised for the public authority - who is the problem owner for environmental and congestion issues - to set boundaries for the platform and stimulate strategic matching choices based on the possible externalities.

Some interesting results showed up at the experiment of making crowdshipping more effective, where the detour threshold and compensations were altered. When lowering either of these parameters, the travellers' detour could turn out (or sometimes even forced) to be negative. This seemed rather surprising yet on second thought this would be possible due to travellers taking shortcuts to pick up and deliver parcels. With the currently defined outcomes, this turns out positive because fewer travelled distance would mean less congestion and fewer emissions. However, when these kilometres are travelled through city centres, where congestion is an ongoing problem and emissions might rise due to acceleration and deceleration at intersections, these negative detour kilometres might be undesirable.

Furthermore, the approach has some shortcomings regarding possible relevant details. At first, to determine the platforms' viability, the compensation is compared to the average price consignors pay for conventional delivery. This is far from a complete view of the costs a crowdshipping platform would have. This would include costs for insurances, operating the technical platform, employing staff and possible operational costs of pick-up points. These costs have not been taken into account in this research and therefore it could not be stated with certainty that the service would be viable. Moreover, sustainability depends on way more than just costs. Rai et al. (2017) provide a full overview of sustainability characteristics obtained in a literature review.

On the other side, for conventional delivery, the exact costs for delivery are also unknown. Besides, the costs could vary between several types of parcels. For example, parcel delivery in an urban area may be cheaper compared to rural area delivery. When a conventional delivery service collaborates with a crowdshipping platform, certain parcels could be chosen strategically to transport with crowdshipping because these would be cheaper using the latter. Comparing costs for conventional delivery in certain areas could be an interesting topic for future research as well as optimising the collaboration between conventional and crowdshipping delivery.

Finally, for both conventional and crowdshipping delivery, only the last leg is taken into account. The 'first leg' is not calculated and could potentially make a difference in efficiency for either of these services. This first leg includes supply from warehouse to shop for crowdshipping or to the distribution centre for conventional delivery, this is illustrated in figure 4.4. It is assumed that the first leg for both services is similar and that this trip must be made with or without crowdshipping and thus does not make a difference. Though, this could make a difference when pick-up points are used. In these experiments, an extra trip must be made from the warehouse to the pick-up point, which is not calculated in this research. This extra trip might be negligible since all parcels could be consolidated into a single trip per pick-up point.

Limitations
These results highly depend on the performed simulations. The simulation model is based on the conceptual model. In appendix B, the verification and validation of the model are discussed extensively, yet the main four limitations of the research are discussed again here. The most important limitation includes the assumptions made for the conceptual model. These assumptions are also covered in the validation chapter mentioned before and the full list could be found in appendix C.

The first assumption discussed here is concerning spatial demarcation (assumption 14). During the demarcation, a choice is made to limit the spatial scope of this research to the province of South Holland and more specifically, the study area of the VMRDH (see figure 4.1). This area could be characterized by a high population density, high percentage of urban area in a polycentric spatial model. Furthermore, an important aspect for the specifically interesting for sustainable crowdshipping is the modal share in this study area. 51% of trips is made by car, 39% are cycling trips and the final 10% is made by public transport. The results found in this study are specific for this case study area and it is unknown what effects crowdshipping would have on other areas.

An assumption with high possible impact is that travellers do not deviate from their planned trips and modalities (assumption 3). This also implies that no 'dedicated occasional carriers' are taken into account in the simulation. These are carriers who make their trip to deliver a parcel and thus the full parcel trip is extra instead of just the detour. These dedicated drivers have changed Uber from a ride-sharing company to 'ride-hailing' (see section 2.2).

Secondly, travellers could only carry one parcel at a time (assumption 13). Picking multiple parcels along the route could potentially save extra detour kilometres and enlarges the utility for the traveller. The latter would increase the travellers' willingness and therefore increase the number of delivered parcels as well. The potential savings are researched by Behrend et al. (2019) who found significant improvements with increased carrier capacities using small scale simulations.

The third potential impactful assumption is the distribution of parcel origins over certain consignors (assumption 10). This, combined with the rough estimation that 20% of all parcels have a physical shop in the customers' municipality is highly uncertain. No information was found on this matter in literature. Experiments have also been performed with the use of pick-up points as parcel origin. These experiments show similar behaviour but with decreased detours (depending on the number of pick-up points). This shows that this assumption has a significant impact on the results.

A final conceptual choice is made in the optimisation by the platform. The assumption is made that first all parcels are ordered and following an optimal parcel is searched for each traveller (assumption 7). This order optimises the trip for each traveller, yet the parcels' trip might not be optimised. Another implementation could have been to iterate over each parcel and find the optimal driver for each of them. This would require a forecast of potential travellers and is therefore not chosen in this simulation, yet a platform might strategically optimise this way and therefore make crowdshipping more environmentally efficient.

Other limitations could be found in the data used for this research. Both the travellers' carrying willingness as well as the customers' order willingness for crowdshipping are uncertain. Both have been researched yet do not provide accurate information for this particular research. At first, the travellers' willingness is based on three stated preference (SP) researches with a skewed distribution over age classes. The samples contained a high number of young people and students, who might be more willing compared to the overall population. Furthermore, these SP researches use attributes not used in this simulation which makes their multinomial logit model less applicable. Secondly, for the crowdshipping demand by customers, more research is done on wider samples, yet here again, attributes are used in the SP research which does not align with this simulation. Examples of these attributes are drivers rating, time window flexibility and tracking possibility. Both the sensitivity analysis and experiments on ratio travellers per parcel show that the outcome of this research is not sensitive to these willingness input parameters. Nevertheless, interpreting these results, the use of partly unreliable input data should be kept in mind.

Another data limitation is the lack of public transport and pedestrian travellers. The use of public transport as a mode for crowdshipping is discussed a lot in literature since this form of transport does not cause any congestion or emissions. In this research' study area, 600,000 public transport trips are made daily, which contains plenty of potential carriers. These travellers could however not be taken into account since the time skim matrix was not available. This was the case as well for bicycles, yet that matrix was easily derived which is not possible for public transport. An especially interesting scenario would have been to position pick-up points at transport hubs to stimulate those travellers to carry a parcel while minimising their detour.

Recommendations

Some recommendations for further research follow from the discussion above. These recommendations will specifically focus on gaining more information on the effects of crowdshipping, either with more extensive data or with other conceptual choices. The goal of these insights is to gain a more complete view of possible effects for more efficient crowdshipping. Furthermore, some policy tools could already be tested based on the outcomes in this research.

More extensive data

At first, the negative detours raise the need for more extensive research in the spatial distribution of occasional carriers' detours. This would consist of two parts. At first to determine which routes are preferential to take. And secondly to find out how the platform could strategically compulse travellers towards the preferred routes while maintaining their viability.

Secondly, more research should be done including public transport travellers given the discussed potential. Furthermore, to better determine effects per modality, a more extensive stated preference research to travellers' willingness per mode would be helpful. This new stated preference study should very much pay attention to the sample size and getting a representative sample.

Conceptual choices

Furthermore, future research could be performed making other conceptual choices. The first suggested research scope is to optimise crowdshipping per parcel and therefore try to find the most efficient driver for each parcel. As stated before, this would require a forecast of potential travellers. This requires a different way of applying agent-based simulation, where more dynamic interactions occur, and iterations would improve model performance. This matching method could possibly show that such strategic processes by the platform lead to fewer negative externalities.

Another conceptually interesting concept is to optimise for collaboration between conventional and crowdshipping delivery. This would especially helpful combined with the use of pick-up points. Certain parcels could be chosen strategically to transport using occasional carriers because these would be more costly or environmentally worse using conventional delivery.

Policy tools

This research concludes with a recommendation specifically focused on the public administration. The model simulation showed that policy intervention is necessary to limit the potential negative externalities of crowdshipping, yet the fulfilment is unknown. Two shortly suggested methods of interventions are stimulating the platform to consider environmental impacts in their matching strategy and limiting certain detours. However, future research could study other - better suited - intervention methods and corresponding legal possibilities.

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A

Appendix: Scientific paper

An agent-based approach to simulate strategical effects of crowdshipping in the Netherlands

Maarten Berendschot

Changing logistic demands let companies search for innovative shipping possibilities. One of these innovations is 'crowdshipping', parcel delivery done by the crowd instead of conventional delivery companies. The goal of this study is to explore the interactions between travellers and parcel shipments in various strategic crowdshipping contexts and assess their impact on transport use in the Netherlands. For this, an agent-based model was built with interactions between the customer, crowdshipping platform, traveller and occasional carrier. Results show a large increase in passenger transport kilometres compared to the decrease in freight transport. The passenger transport increase is equally divided between car and bicycle traffic. The service seems viable with an average compensation lower than the price of conventional delivery and a high number of delivered parcels. Experiments show that these results highly depends on the platform's strategy.

Keywords: crowdshipping, agent-based, simulation, case study

1. Introduction

Logistics has been changing massively in the recent decades; the world is more globally connected, people increasingly live in urban areas and technological innovations cause an exponential rise in e-commerce. The sales are currently doubling every five years which expected continue for the next five years as well (Clement, 2020). Besides, the recent coronavirus pandemic gave an additional boost the growth (Ali, 2020). These increasing e-commerce sales subsequently lead to increasing parcel transport, something noticed in the Netherlands as well. The largest parcel delivery service, PostNL, noted an volume increase of 29.6% in the last quarter of 2020 (PostNL, 2021). At the same time, consumers seek for more flexibility in delivery channels and times (DHL, 2013). Consumers expect logistics services to be smoothly integrated in their daily routine activities, deliveries should be right on time, delivered any time a day at any location.

Unfortunately, parcel delivery leads to various negative effects. These effects mostly consist of congestion in urban areas, air, and noise pollution (Demir et al., 2015). Companies therefore seek innovative solutions for their parcel transport. One of these innovations is "crowdshipping", parcel delivery done by the crowd instead of conventional delivery companies. By making use of existing passenger transport rather than a specially dispatched driver to ship parcels, it is promised that shipping will be economically and environmentally more sustainable (Punel et al., 2018 & Rai et al., 2017).

The impact of crowdshipping, however, is hardly examined in literature. Research has been based on case studies (Paloheimo et al., 2016), quantitative data of start-up crowdshipping firms (Ermagun and Stathopoulos, 2018, Rai et al., 2017), small scale hypothetical data (Macrina et al., 2020) and survey data (Punel et al., 2018). These researches result in small scale analysis which lacks integration of the above mentioned various crowdshipping implementations. This is substantiated by a recent review by Le et al.

(2019). This integration is necessary to assess the impact of crowdshipping on the transport systems. The knowledge gaps are defined as a lack of strategic analyses of the impact of crowdshipping on all actors in the transport systems, and crowdshipping has not yet been integrated into transport models.

To address these knowledge gaps, the goal of this research is to explore externalities of different crowdshipping strategies and assess their potential.

This structure of this paper is as follows; first, the state of the art literature is discussed. Following, the method is described. Next, the results are given and finally, the conclusion is given with possibilities for future research.

2. Literature

Crowdshipping could take place in various ways and the definition varies ambiguously over literature (Mehmann et al., 2015, Rai et al., 2017, Punel et al., 2018). Therefore, the following definition will be used in this report ”Crowdshipping is the transport of parcels done by an undefined and external crowd which is coordinated using an information platform”. Within this definition, various implementation methods are possible. At first, the route options will be discussed, followed by infrastructure usage, compensation schemes, carrier selection method and finally other dependencies will be elaborated.

Route options

Walmart experiments with their employees who at the end of their working day deliver packages around their homes (Lore, 2017). Archetti et al. (2016) also assume that the carrier has the same origin as the parcel, yet assumes the opportunity that customers could be carriers as well. Lee and Savelsbergh (2015) suggest that occasional carriers (crowdshipping carriers) should not necessarily have the same origin as the parcel. This results in a larger group of potential carriers. Instead of a full trip made by the occasional carrier, Wang et al. (2016) see an opportunity where crowdshipping is only done for a certain part of the parcel transport. This could be done using pick-up points where conventional parcel service takes care of most part and the ’last mile’ will be done by the occasional carrier.

Crowdshipping where carriers and the consignor have the same origin, is a variant from the implementation where both the origin and destination are different for carrier and parcel. The former has an advantage that the detour to pick-up the parcel falls away.

Infrastructure usage

Most literature assumes crowdshipping is done by private vehicles (Rougès and Montreuil, 2014), here the modal choice of the occasional carrier determines the used infrastructure. Yet there are a few pilots where existing passenger transport infrastructure is used for crowdshipping. Both Li et al. (2014) and Chen and Pan (2016) review cases where taxis are shared by parcel and passenger transport. van Duin et al. (2019) and Schäfer (2003) describe case studies with the usage of busses to transport parcels. Quadrifoglio et al. (2008) suggest using the tram for crowdshipping. Finally, Trentini and Mahléné (2010) propose an idea where all transport is shared for both passenger and freight transport.

Compensation

As described in the first chapter, the crowd participates voluntarily, but will be compensated for their effort. There are four main options for the compensation; First is the simplest form to compensate for the distance to be travelled by the parcel, independently of the origin and destination of the occasional carrier. This has the practical advantage that the crowdshipping company does not need to know the route of the carrier, yet it does not take into account the extra effort by the occasional carrier (Archetti et al., 2016). The second option is thus to compensate for the extra time/distance the occasional carrier has incurred to deliver the parcel. Third, the platform may choose to set a fixed compensation for all parcels, or base the amount on shipment characteristics. Finally, a variable compensation could be provided based on supply and demand (Rougès and Montreuil, 2014).

Matching

When a parcel needs to be shipped, a consideration needs to be made for which passenger may transport this parcel. There are three matching procedures described in literature to select the occasional carrier; At first, Wang et al. (2016) describe an assignment method where the system finds the most feasible occasional carrier who then must accept the job. If the carrier refuses the job, the system will look for the next best candidate and so on. Another method is given by Kafle et al. (2017), they describe a bidding process where potential occasional carriers place their bid on available parcels and the system selects the best option. The third and final method is to apply the simple first-come, first-serve principle. Here travellers could ’claim’ certain parcel shipments and the first to claim may do the shipment.

Other dependencies
These four themes are widely covered in literature, yet there are more implementation variations which would probably determine the success of the crowdshipping implementation. First, Ermagun and Stathopoulos (2018) note that not only **shipping characteristics**, but also the **socio-economic and built environment** characteristics of both the trip origin and the trip destination affects the availability of crowd-resources. Secondly, it should be considered that crowdshipping is an alternative service for parcel delivery and would most likely work side to side with conventional delivery services. On this matter, **integration and corporation** with conventional parcel delivery should be taken into account. Next, the **delivery time window** could impact success. The time window varies from same-day delivery (Dayarian and Savelsbergh, 2020) to long term pre-specified time windows (Dahle et al., 2019). Finally, some **preconditions** are mentioned by Varshney (2012), mostly related to privacy and reliability concerns. Rai et al. (2017) add criterion related to the platform provider and crowd.

3. Method

To address to the previously stated research goal, an agent-based model is developed to simulate the interactions between the agents in the system. For this agent-based model, first, the involved actors and the crowdshipping process are identified. Following, this process is conceptualised into a system with interacting agents. This conceptual model is finally implemented in a Python based simulation model using a supplementing transport model.

The involved actors are the following. The most important actor is the public administration since this is the problem owner of the possible externalities. Secondly, the crowdshipping platform manages the matching of supply and demand from both the consignor and the traveller, which are both actors in this system as well. When a match is made, the traveller becomes an occasional carrier. Next, customers are an actor in this system since they place the orders and decide for the delivery method. Finally, the conventional delivery service provider takes over the parcels for which no match could be found. Furthermore, the impact of crowdshipping is compared to conventional delivery, where this actor has a key function.

For the conceptual model, only the customers, crowdshipping platform, travellers and occasional carriers are considered as agents. The other actors have no direct relevant interactions in the crowdshipping process. Between these four agents, the following interactions takes place. At first, the customers place their orders at the platform. After this process, a few interactions take place back and forth between the travellers and the platform. First, the traveller communicates their planned trip after which the platform searches through the orders and calculates the optimal ones for this particular traveller. These optimal shipment offers are communicated back to the traveller. Now the traveller may pick their favoured offer and accepts this delivery offer, or denies them all. When an offer is accepted, this is communicated back to the platform and the traveller becomes an occasional carrier who now will make their trip with an additional detour. A schematic overview of these interactions could be found in figure A.1.

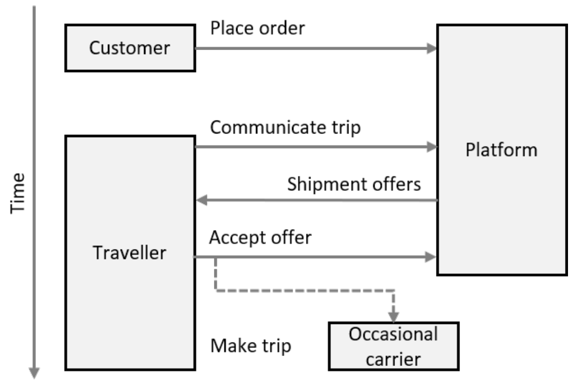

Figure A.1: Agent interactions

The simulation model is implemented using the Python Programming Language. In the simulation, first the parcel demand and travellers supply are generated. Following, a loop iterates over all travellers for which the optimal parcels are calculated. The input for this simulation comes from three sources. First, the conceptualisation of above mentioned agents comes with various states which were studied in literature. Secondly, agent-based simulation model 'Mass-GT' provides this research with parcel demand data as well as outcomes on conventional delivery performance (de Bok and Tavasszy, 2018). Thirdly, the Verkeersmodel Metropool Regio Rotterdam Den Haag (VMRDH) provides this research the spatial demarcation (Goudappel, 2018). The case study will be applied to the study area of VMRDH, which is the province of South Holland in the Netherlands.

Four output indicators were defined for this simulation. First, the difference in driven distance compared to the reference case. This consists of the increase in passenger kilometres through detours made by occasional carriers, and the decrease in freight transport kilometres through lower demand for conventional parcel delivery. The second indicator is the mode in which the detour is taken. From the modality use, the sustainability of the concept could be derived. Thirdly, the average provided compensation to the occasional carriers is calculated to determine the viability of the platform. The fourth indicator is the percentage of delivered parcels, again relevant for the platform's viability.

4. Data & Results

Study area

The study area covers most of the province South Holland in the Netherlands with an area of 1,125 square kilometres. This area is divided over 5925 zones with geographical as well as socio-economical data for each of them. The geographical data includes their zone location and a skim matrix for the travel distance between the zones as well as the travel time for car travel. For the socio-economical data, the household data is most important; in the study area, 2.3 million residents live spread over 1.1 million households.

Within the study area, over 220,000 parcels are ordered each day. Of these parcels, about 6% is eligible for crowdshipping which is about 13,000 parcels. The parcel demand must be matched with the traveller supply. About 4.1 million trips are made each day within the study area by car or bike. 30% of these travellers are willing to carry a parcel which are about 750,000 willing travellers who enter the model. The output of the model are the difference in driven distance compared to the reference case, the mode used for the detour, the average provided compensation, and the percentage of delivered parcels.

Results

To understand the crowdshipping results, the reference case is described first. The reference case is a scenario where no crowdshipping takes place. In the passenger transport system, 4,1 million trips are made. 57% of these trips are made by car and the other 43% by bike. The car trips accounts for a total driven distance of 15.5 million kilometres (6.6 km/trip). The driven distance by bike is significantly lower at almost 7 million kilometres (3.9 km/trip). In freight transport system, this research only focuses on parcel transport. In the reference case, 221,125 parcels are ordered daily. To deliver these parcels, 1,240 tours are made for 28,200 trips. The total driven distance by the delivery vans is 68,200 kilometres. This only includes the last mile of the parcel transport from the distribution centre to the customer.

The base case is a scenario with crowdshipping. In the base case, the system is modelled with the input parameters as found in literature. Of the 220,000 daily ordered parcels, slightly more than 13,000 are eligible for crowdshipping. A reduction of 2,300 kilometres by delivery vans is found through the decrease in regular delivery demand. On the other side, the passenger transport increased with 31,400 kilometres, which contains the detours made by the occasional carriers. Of these passenger kilometres, about half is driven by bike, which does not impact the congestion and emissions, yet the other half is driven by car. The average provided compensation is €2.32, which is below the average price consignor currently pays for delivery services (of €3.35). Furthermore, for most parcels, a suitable occasional carrier could be found. For 97.5% of all ordered crowdshipping parcels, a match is made.

An overview of the most interesting model results can be found in table A.1

Decreasing detour distances

As the above-described figures show, the passenger transport increase is 14 times the decrease of conventional delivery kilometres. Experiments were performed to make crowdshipping more efficient. The platform has two levers to decrease the taken detour by the travellers: the provided compensation and their relative detour threshold. Lowering either of these, causes the detour to decrease yet on the other hand the percentage of delivered parcels drops as well. A trade-off must be found between a low detour and high percentage of delivered parcels. Experiments show that lowering the detour threshold is more effective in decreasing the taken detours, while maintaining an acceptable percentage of delivered parcels.

Furthermore, in tuning the levers, the platform may force occasional carriers to make negative detours. This is caused since travellers usually choose the fastest route, which is not always the shortest one. When a parcels gets offered on a shorter yet slightly more time-consuming trip, the driver could take a shorter route to deliver a parcel. Based on the current outcome indicators, these trips score good. However, these shorter routes with lower travel speeds may however be undesirable because of higher usage of local roads.

Run scenario	Percentage delivered	Average compen-sation	Freight km decrease Delivery van	Passenger km increase Bike	Car	Total (avg)
Base	97.52%	€2.32	2,261	14,900	16,490	31,400 (2.45)
Detour threshold -0.9	55.07%	€2.34	1,000	620	-2,130	-1,510 (-0.21)
Ratio 6.8 110,000 parcels	87.33%	€2.29	19,078	68,910	135,720	204,630 (2.12)
Ratio 6.9 13,000 parcels	64.87%	€2.24	1,379	6,400	12,210	18,610 (2.18)
Fixed compensation €2.50	95.66%	€2.50	2,168	15,380	11,760	27,140 (2.16)
Based on traveller's detour trip length	93.74%	€1.94	2,269	11,480	15,350	26,830 (2.37)
no pickup points	98.64%	€2.35	692	3,100	5,700	8,810 (2.89)
1 pickup point	99.09%	€2.21	570	2,440	4,720	7,150 (2.34)
3 pickup points	99.42%	€2.09	565	3,710	2,060	5,770 (1.88)
6 pickup points	100%	€1.98	603	3,880	710	4,590 (1.50)

Table A.1: Results experiments

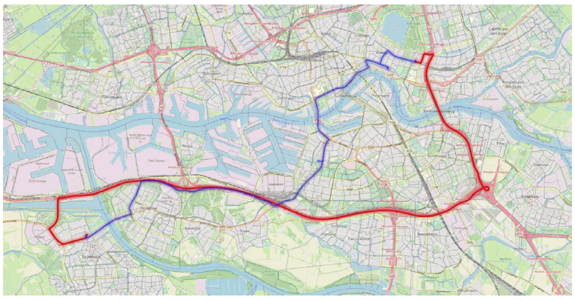

Figure A.2: Example negative detour. In red the planned traveller's trip, in blue the 'detour' trip for crowdshipping delivery

Distribution of parcels and travellers

Another experiment was done to inspect the impact of the ratio travellers per parcel. In the base case, 750,000 travellers were willing to carry 13,000 parcels, 57 travellers per parcel. With this ratio, the percentage of delivered parcels was at 97.5%. The ratio could be decreased in two ways; increasing the number of parcel orders, or decrease the number of travellers. When increasing the number of parcel orders, the percentage of delivered parcels was not affected significantly. However, lowering the number of travellers, the percentage of delivered parcels dropped.

These observations could be explained by the fact that a certain distribution of parcels and travellers is needed for the system to work properly. To get a better understanding of this, visualise a system of 5 travellers and 1 parcel in a confined area. Here, it would be a 'case of luck' to find a suitable parcel to ship. When this number goes up to 50 travellers and 10 parcels (same ratio), travellers are more likely to find a suitable parcel. This is tested in the small-scale environment, see figure A.3. For the first scenario (5 travellers, 1 parcel), in only 27% of runs this parcel gets delivered. In the second scenario (50 travellers, 10 parcels), on average 74% of parcels gets delivered.

5 travellers, 1 parcel: 50 travellers, 10 parcels:

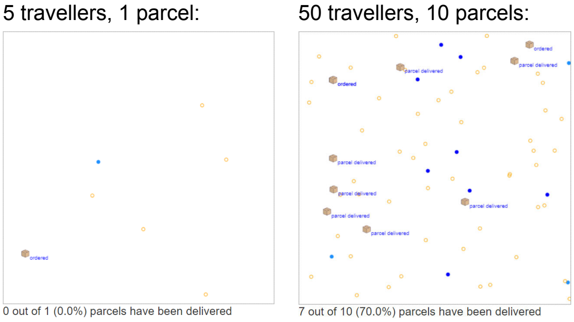

Figure A.3: Small scale experiments ratio travellers per parcel

Pick-up points

The final experiment covers the use of pick-up points. For these experiments, a smaller part of the spatial demarcation is used to perform better qualitative assessments. The use of pick-up points is examined in The Hague. Model runs are performed with 0, 1, 3 and 6 pickup points. The detour decreases from 2.89 km (without pickup) to 1.5 kilometres at 6 pickup locations. At the same time, the percentage of delivered parcels increased up to 100%.

In these experiments, the number of pick-up points and their locations were not optimised. Adding pick-up points would bring extra operating costs, so a trade-off must be made between decreased detour and total cost of operations. Furthermore, Wang et al. (2016) and Serafini et al. (2018) suggests placing pick-up points at public transport hubs. In this research, public transport data was lacking so this placement of pick-up points could not be tested.

5. Conclusion

This research assessed the externalities and viability of crowdshipping. The base case shows a large increase in passenger transport kilometres compared to the decrease in freight transport. The passenger transport increase is equally divided between car and bicycle traffic. The service seems viable with an average compensation lower than the price of conventional delivery and a high number of delivered parcels.

The experiments show large fluctuations in outcomes between the different experiments. The base case makes clear that crowdshipping without interventions could turn out worse for the environment and congestion. Even while these problems were the initial motive to seek for innovative solutions for parcel delivery. In some experiments, the negative externalities were limited while maintaining perspective on viability. This research affirms the findings by Simoni et al. (2019) that limiting the deviation of crowdshippers' delivery trips from their original trips is a necessity to reduce negative externalities. It is advised for the public authority to set boundaries for the platform and stimulate strategic matching choices based on these possible externalities.

Future research

Future research could be done on four areas. At first, the negative detours raise need for more extensive research in the spatial distribution of occasional carriers' detours. This would consist of two parts. At first to determine which routes are preferential to take. And secondly to find out how the platform could strategically compulse travellers towards the preferred routes, while maintaining their viability.

Secondly, more research could be done on the externalities of crowdshipping including public transport, especially in the case of pick-up points. Furthermore, to better determine effects per modality, more extensive stated preference research to travellers' willingness per mode would be needed. This new stated preference study should pay attention to the sample size and getting a representative sample.

Thirdly, an conceptually interesting concept is to optimise for collaboration between conventional and crowdshipping delivery. This would especially helpful combined with the use of pick-up points. Certain parcels could be chosen strategically to transport using occasional carriers because these would be more costly or environmentally worse using conventional delivery.

Finally, this research showed that implementing crowdshipping leads to an increase in driven mileage and possibly emissions. The problem owner of these externalities, the public administration, might set policies to limit the effects. Two shortly suggested methods of interventions are stimulating the platform to consider environmental impacts in their matching strategy, and limiting certain detours. However, future research could study other, better suited, interventions and corresponding legal possibilities.

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B

Appendix: Validation and verification

In the process of building a simulation model, many choices and assumptions must be made. During process, it is continuously reflected whether these choices contribute to achieving the research goal. However, some choices are made unconsciously or made with a certain modelling bias. Therefore, to increase confidence in the model, validation and verification tests will be performed. To keep track of the deliberate modelling choices, the assumptions in this report are indicated using a numbered superscript[(i)].

The process of validation and verification is structured as shown in figure B.1, which is derived from a conceptual model by Robinson (1997). The modelling process starts at the top with the research gap which will by addressed by the research goal. The process follows clockwise to a conceptual model followed by the simulation model. In each step, a validation or verification check is done. The conceptual validation takes place after the conceptual model is made and tests to what extent this model contributes to the research goal. Following, the verification takes place after the simulation model is constructed. During the verification, it is tested whether the model is implemented correctly and whether it corresponds to the conceptual model. Following, the simulation model is reflected to the research goal, in the model validation. Finally, it is discussed to what extent the research goal is met and how this contributes to the research gap.

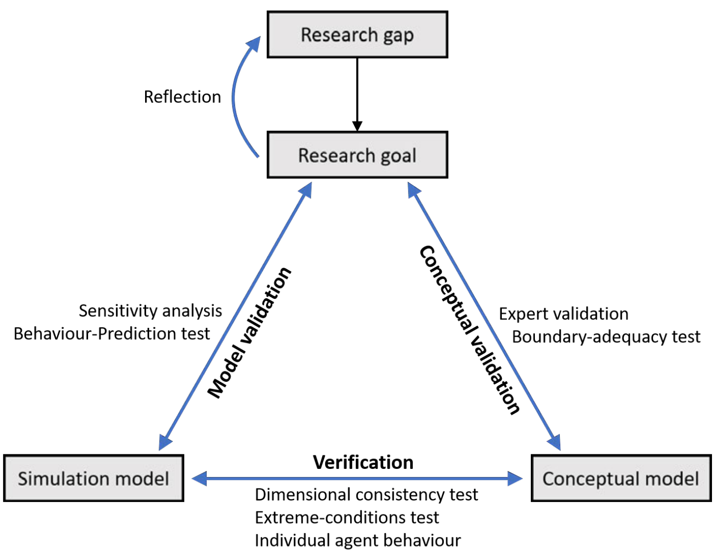

Figure B.1: Validation and verification structure. Adapted from Robinson (1997)

The concept validation is explained in section B.1 and includes an expert validation and boundary adequacy test. The verification follows in section B.2 performing a dimensional consistency, individual agent behaviour and extreme conditions test. The model validation is included in section B.3 where a sensitivity analysis, and a behaviour prediction test are performed. The final reflection can be found in the discussion in chapter 7. These tests are picked from a extensive set by Senge and Forrester (1980). These tests were originally developed for system dynamics modelling, yet Qudrat-Ullah (2005) suggests these tests could be used for agent-based modelling as well because of the strong similarities in both approaches.

B.1. Conceptual validation

The concept of crowdshipping has been conceptualised in chapter 3. With this conceptualisation, many assumptions and abstractions has been made to come to a demarcated model. Yet despite these demarcations, the model must still be able to answer the main questions and therefore contribute to the goal of this research. The confidence that the model is fit for purpose is validation. To recap, the goal (purpose) of this research is *to explore the interactions between travellers and parcel shipments in various strategic crowdshipping contexts and assess their impact on transport use*. The validation will be argued on two different areas. First the validity of individual components and secondly the boundaries of the model are validated.

B.1.1. Expert validation on individual components

The first validation test is to examine the individual model components. For each agent, several abstractions are made which will be assessed. The simplified structure should however still be sufficient to contribute to the research goal. For this, the abstractions are presented to field experts on crowdshipping. These experts could, with their knowledge, judge whether these simplifications represent the crowdshipping concept.

Two experts were interviewed for this validation step. The interviewed experts are crowdshipping expert Jackson Amankwah from Norwegian crowdshipping firm Nimber and scientific expert Rodrigo Tapia from the Delft University of Technology. In these interviews, the overall conceptual model was approved. Several assumptions were highlighted as impactful and some limitations were discovered. These will be covered in the following test.

B.1.2. Boundary adequacy test

In this test, the structural validity of the whole model will be assessed. This includes evaluating the assumptions, note the possible impacts of these and reflect whether the goal could still be achieved by the demarcated model. All assumptions which are made are denoted by a superscript in the text and a list could be found in appendix C.

The first assumptions were made in the literature review, demarcating the crowdshipping concept. This includes the route over which crowdshipping takes place, the modality use, compensation scheme and matching method. The research goal is to explore effects of different crowdshipping strategies, so this demarcation should be as inclusive as possible. Furthermore, in the experiments, other route options and compensation schemes could be examined. Assuming that no mode or trip changes will occur because of crowdshipping possibilities (assumption 3) could not be changed due to the complicated integration in the model. The same goes for assumption 5, where a part of the matching strategy is set, finding the optimal parcel per traveller. This limits other implementations where the platform optimises per parcel and find the optimal carrier.

Other assumptions are made in the agents' identification at the beginning of this chapter. Here, the biggest assumption is is that an occasional carrier could only carry one parcel (assumption 13). This is assumed to limit the computational effort to run the simulation. More advanced algorithms to optimise the number of parcels are researched by Behrend et al. (2019), which are thus not included in this research.

B.2. Model verification

To ensure the conceptual model has correctly been translated into the implemented model, several verification tests are done. At first, the model formulas are checked by their dimensional consistency. Secondly, an extreme value test is performed to inspect model behaviour at their boundaries. Finally, the individual agent behaviour is followed .

B.2.1. Dimensional consistency test

The first test for model verification is to check the dimensional consistency. This test is usually seen as a simple, yet powerful tool to test model structure. To perform this test, simulation software Vensim is used. Because of the deviating purpose of this program, not all model structures could be transposed into Vensim. This was possible for the main part of the model being the modes/travellers loop, see figure B.2. Performing the built-in unit check, no errors occurred so in this part, no structural errors are expected.

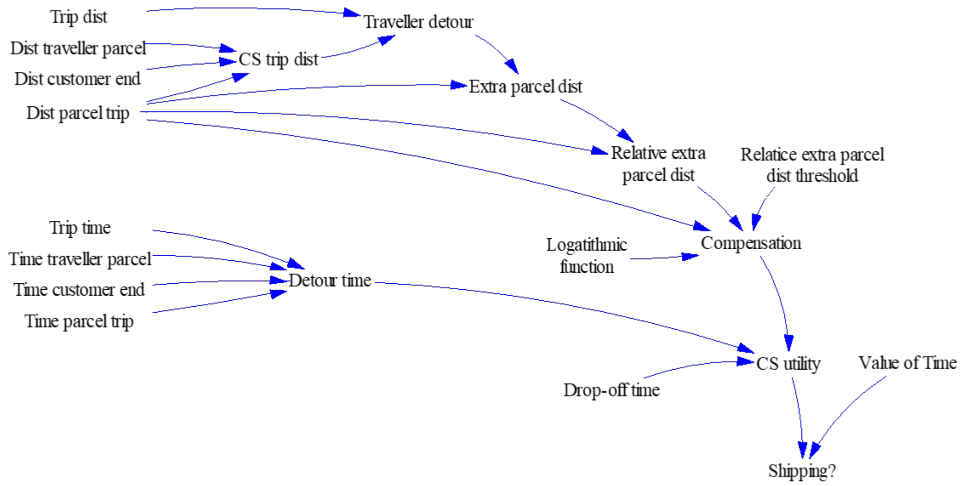

Figure B.2: Rebuilt model in Vensim (Simulated in Vensim Professional 8.1.2)

B.2.2. Extreme-conditions test

The second part of the verification includes an extreme-conditions test. In the conceptualisation and model build, the base behaviour is assumed. This however does not include the full stated of the model. Information is known about the extreme behaviour of the model as well. To test the behaviour of the model in extreme cases, all parameters of the model have been set to their imaginary maximum and minimum. The resulting behaviour for these test runs could be found in figure B.1 and are explained below.

Parameter	**Value**		**Behaviour**
Parcels per HH	min	0	No parcels delivered
	max	1000	Regular model behaviour
Parcels CS share	min	0%	No parcels delivered
	max	100%	Regular model behaviour
Travellers' willingness	min	0%	No parcels delivered
	max	100%	Near all parcels delivered
Drop-off time	min	0	Near all parcels delivered,
	max	1000	No parcels delivered
Value of Time	min	0	Near all parcels delivered, longer detours
	max	1000	No parcels delivered
Rel extra dist	min	-1000	No parcels delivered
	max	1000	All parcels delivered
Compensation	min	0	No parcels delivered
	max	1000	Near all parcels delivered, longer detours

Table B.1: Input settings extreme-conditions tests

In general, the model showed expected behaviour. In seven cases, no parcels were delivered. This is the case either because there is no parcel demand, no traveller supply, the platform does not offer the parcels, or the compensation did not overcome the value of time. Because of these scenarios, some extra checks have been built in the model so there does not occur a division by zero.

Next, there are two cases where regular model behaviour occurs; if the parcels CS share is 100% and when the parcels per household increases to 1000. In both cases, the percentage of delivered parcels drops, which is expected because of the ratio travellers/parcels drops. The other output parameters stayed roughly the same.

In all other cases, the percentage of delivered parcels approaches 100% yet there are still a few undelivered parcels - even if €1000 compensation is provided. This is caused by the default detour acceptance threshold by the platform; short parcel trips desire an even smaller detour which is not always possible for these parcels.

Finally, in both the case of extreme low value of time or high compensation, the average detour distance went up. This is caused by travellers who opt for a parcel because the compensation outclasses the value of time even at higher detour times. This causes less efficient drivers taking the parcels away from travellers who enter the system later.

To conclude the extreme-conditions test, the model shows expected behaviour even at unexpected conditions. Because of this test, some extra checks have been built in the model so there does not occur a division by zero. Furthermore, this test gives confidence in the verification of the simulation model.

B.2.3. Individual agent behaviour

This is a specifically designed verification test for agent-based models. In this test, a single agent's story line will be followed and reflected to the conceptual model. For this, a carefully designed test run has been set up where the behaviour could be calculated apart from the model. There is just one traveller supply in this set up combined with a parcel demand of 10 parcels. These parcels have been generated so that two of them are within the same municipality and the others outside. Figure B.3 gives an overview of the parcels in the system. The dashed blue line represents the travellers' trip and orange lines are the available parcels. The traveller chooses the parcel in the north (visualised in purple) which does match the manual calculations. Furthermore, this test provides possibility to check intermediate results as well. This includes the offered parcels by the platform to the traveller (top three available parcels based on their relative detour), the compensation calculation, the choice of the optimal parcel by the traveller (based on utility) and the resulting choice (compared to the value of time). Based on the intermediate and end results, there has been built confidence that the constructed simulation model represents the conceptual model.

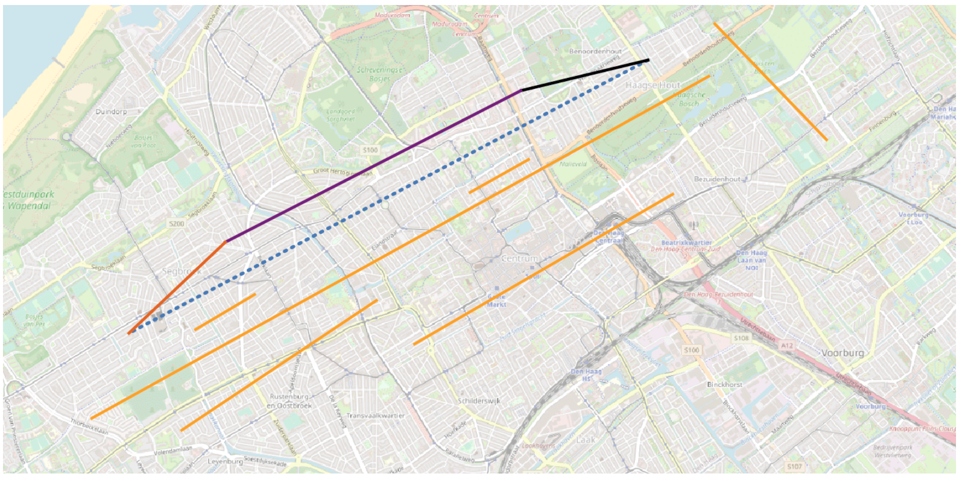

Figure B.3: Test case individual agent behaviour

B.3. Model validation

Besides the in previous section covered verification, the implemented model must be validated as well. This mostly includes behaviour validation, which gets tested in two tests. The first is a sensitivity analysis, to inspect the magnitude of change. The second test is a behaviour-prediction test; to discover whether the model produces expected direction of causalities.

B.3.1. Sensitivity analysis

For the sensitivity analysis, all input parameters will be changed by a certain factor, and the change in output parameters will be interpreted. The model run with inputs as shown in table 4.2 will be used as reference for this analysis. The parameters will be changed by 20% up and down to determine the effects on the output. For the relative extra distance (calculated by the platform), this is not possible since the base for this variable is 0. Here, -0.2 and 0.2 will be used for the lower and upper sensitivity analysis.

To recall from the preliminary results in section 4.3.2, the results of the base scenario are as follows. In total, 208,000 parcels are ordered from which slightly more than 13,000 are eligible for crowdshipping. From these, 97.52% was delivered with an average of 2.45 km detour per parcel. This could be split up in bike and car trips; 70% is carried by bike with an average of 1.44km detour compared to an average detour of 3.79km for occasional carriers using their car.

All numeric results of the sensitivity analysis could be found in appendix E. The most interesting outcomes will be discussed here. The first three parameters tested are the number of parcels per household, the crowdshipping share of those and the traveller's willingness. All these parameters have neglectable impact on the outcomes, change was only noticeable in the percentage of delivered parcels with a maximum change of 0.5%. The following parameter is the drop-off time for a parcel, which again changes the percentage of delivered parcels with about 0.4%, yet also impacts the average driven detour with 0.1 km. Next up are the compensation and value of time to which the model is significantly more sensitive to. The percentage of delivered parcels would change up to 5% and the average detour changes with about 0.6 kilometres. Finally, the detour threshold by the platform impacts the system less significant, with 1% change in percentage delivered parcels and neglectable change in driven detours.

To conclude the sensitivity analysis, the model is stable on most parameters. However, the compensation and value of time have a major impact on the success of the platforms service. This is in line with the stated preference research by Serafini et al. (2018) where a change in remuneration of €2,00 leads to a willingness change of 34%. The experiments (section 5.3) will be performed with substantial change in input parameters to be able to find model behaviour.

B.3.2. Behaviour-prediction test

Besides the magnitude of change in the previous test, the direction of change is relevant as well. For this, two tests are usually possible, either a behaviour-reproduction or behaviour-prediction test. The former tries to match generated behaviour to observed behaviour of the real system. Since crowdshipping is not implemented at this scale, this is not possible and the latter test will be used. For the behaviour-prediction test, the outcomes of the model will be tested against hypothesis. For these hypothesises, there is no strive to 'point prediction' where future values are predicted yet the goal is 'pattern prediction' where qualitative patterns are examined.

The following hypotheses of expected system behaviour are tested:

- **An increase of willing travellers leads to a higher number of delivered parcels and negatively impact the detour per parcel.**
  The increase in percentage of delivered parcels could also be seen in the model. In the model, this is just tested by the increase in travellers' willingness, yet the same goes for increasing number of travellers. The expected negative detour per parcel does not follow from the travellers increase. This was hypothesised because the platform could strategically obscure certain parcels from travellers, knowing that better travellers will follow for that parcel. However, this strategic behaviour by the platform is not modelled in this system.

- **The amount of provided compensation positively impacts likeliness travellers opting for a parcel.**

This hypothesis follows from stated preference researches on the willingness of travellers. Higher compensations should lead to more travellers willing to take an offered parcel. This behaviour is also seen in the model and as shown in the sensitivity analysis, the willingness is highly sensitive to the compensation.

- **Travellers are willing to make a detour to deliver a parcel.**
  This is again an outcome of literature studies. These show that travellers are willing for various reasons including environmental benefits, social help and the provided remuneration. In the model, only the provided remuneration is taken into account, yet the behaviour is still present. To elaborate further on this, the compensation highly impacts the amount of detour the travellers are willing to make.

- **Crowdshipping relieves pressure off regular parcel delivery.**
  This hypothesis is tested by the Mass-GT parcel demand and scheduling module. With a slice of all parcels delivered by occasional carriers, the demand for regular parcel delivery decreases. This leads to a slight decrease in driven mileage by them.

C

Appendix: List of assumptions

A list of all deliberate made assumptions can be found below. These assumptions are indicated throughout the report using a numbered superscript$^{(i)}$. The most important and impactful assumptions are covered in appendix B on validation and verification.

D

Appendix: Python code

This appendix shows the full Python code used for the simulations. The code is written in Python 3.8.6 using Spyder 4. For clarity, the code is shown in segments with a small explanation per segment.

The first part of the code sets the simulation environment and loads the VMRDH data.

```
import pandas as pd
import numpy as np
import os.path
from sys import argv
import time
from __functions__ import read_mtx, read_shape
import math
import random
import seaborn as sns
import matplotlib.pyplot as plt

total_start_time = time.time()
start_time = time.time()

def get_traveltime(orig,dest,skim,nZones,timeFac):
    return skim[(orig-1)*nZones+(dest-1)] * timeFac / 3600

def get_distance(orig,dest,skim,nZones):
    return skim[(orig-1)*nZones+(dest-1)] / 1000

# Define datapaths
datapath = os.path.dirname(os.path.realpath(argv[0]))
datapath = datapath.replace(os.sep, '/') + '/'
datapath = datapath[:-5]
datapathI = datapath + 'data/2020/'

skimTravTimePath = "<user_folder>/MassGT_v10/data/LOS/2020/skimTijd_new_REF.mtx"
skimDistancePath = "<user_folder>/MassGT_v10/data/LOS/2020/skimAfstand_new_REF.mtx"
segsPath = datapathI + 'SEGS2020.csv'

#--- import data
zones = read_shape(f"{datapathI}Zones_v4.shp")
zones = zones.sort_values('AREANR')
zones.index = zones['AREANR']

segs              = pd.read_csv(segsPath)
segs.index        = segs['zone']

nIntZones = len(zones)
nSupZones = 43
zoneDict  = dict(np.transpose(np.vstack( (np.arange(1,nIntZones+1), zones['AREANR']) )))
zoneDict  = {int(a):int(b) for a,b in zoneDict.items()}
for i in range(nSupZones):
    zoneDict[nIntZones+i+1] = 99999900 + i + 1
invZoneDict = dict((v, k) for k, v in zoneDict.items())
```

```
zone_gemeente_dict = dict(np.transpose(np.vstack( (np.arange(1,nIntZones+1), zones['
    Gemeentena']) )))

#skim with travel times between all zones
skimTravTime = read_mtx(skimTravTimePath)
skimAfstand  = read_mtx(skimDistancePath)
nZones    = int(len(skimTravTime)**0.5)
timeFac = int(1)

skimTravTime = skimTravTime.reshape(nZones,nZones)
skimTravTime[6483,i] = 1000
for i in range(nZones):
    skimTravTime[i,i] = 0.7 * np.min(skimTravTime[i,skimTravTime[i,:]>0])
skimTravTime = skimTravTime.flatten()
skimAfstand = skimAfstand.reshape(nZones,nZones)
for i in range(nZones):
    skimAfstand[i,i] = 0.7 * np.min(skimAfstand[i,skimAfstand[i,:]>0])
skimAfstand = skimAfstand.flatten()

print("Loading data: " + str(round(time.time() - start_time, 2)) + " seconds")
```

The second part is used to set the model input parameters. These are grouped here to easily run the experiments.

```
datapathO = datapath + 'output/Test/'
scenario = 'test'

create_new_demand = False
parcelsPerHH    = 0.195
parcelshareCS   = .3 * .2

create_new_travellers = False
modes = {'fiets': {}, 'auto': {}, }

modes['fiets']['willingness'] = .3
modes['fiets']['dropoff_time'] =1/60
modes['fiets']['VoT'] = 8.75

modes['auto']['willingness'] = .3
modes['auto']['dropoff_time'] = 2/60
modes['auto']['VoT'] = 9

relative_extra_parcel_dist_threshold = 0
def get_compensation(dist_parcel_trip):
    compensation = math.log( (dist_parcel_trip) + 5)
    return compensation
```

The following part creates the parcel demand.

```
start_time = time.time()
parcelsCS_cols = {'id': 0, 'orig': 1, 'dest': 2, 'orig_skim': 3, 'dest_skim': 4, 'gemeente':
    5, 'X_ORIG': 6, 'Y_ORIG': 7, 'X_DEST': 8, 'Y_DEST': 9, 'TravelTime_car': 10, '
    TravelDistance': 11, 'vector': 12, 'status': 13, 'traveller':14, 'modal choice': 15, '
    detour_time': 16, 'detour_dist': 17, 'compensation': 18}
if create_new_demand == True:
    zones['parcels']    = np.round(segs['1: woningen']*parcelsPerHH,0)
    zones['parcelsCS'] = np.round(zones[:5925]['parcels']*parcelshareCS,0)
    zones['parcelsCS'] = zones['parcelsCS'].fillna(0)
    zones['parcels']    = np.round(zones['parcels']*(1-parcelshareCS),0)
    nParcels            = int(zones[:5925]["parcels"].sum())
    nParcelsCS          = int(zones[:5925]["parcelsCS"].sum())

    gemeente_zone_dict = {}
    for gemeente in np.unique(zones[:5925]['Gemeentena']):
        gemeente_zone_dict[gemeente] = zones.loc[zones['Gemeentena'] == gemeente]['AREANR'].
    to_list()

    count=0

    parcelsCS_array = np.zeros((nParcelsCS,len(parcelsCS_cols)), dtype=object)
```

```
    for index, zone in zones[:5925].iterrows():
        n = int(zone['parcelsCS'])
        if n > 0:
            dest = zone['AREANR']
            dest_skim = invZoneDict[dest]
            gemeente = zone['Gemeentena']
            x_dest = zones.loc[dest]['X']
            y_dest = zones.loc[dest]['Y']
            status = "ordered"
            possible_origins = gemeente_zone_dict[gemeente]
            ratio_origins = []
            for origin in possible_origins:
                for x in range(int(segs.loc[origin, '6: detail'])):
                    ratio_origins.append(origin)
            for N in range(n):
                parc_id = N + count
                orig = random.choice(ratio_origins)
                orig_skim = invZoneDict[orig]
                x_orig = zones.loc[orig]['X']
                y_orig = zones.loc[orig]['Y']
                trav_time = get_traveltime(orig_skim,dest_skim,skimTravTime,nZones,timeFac)
                trav_dist = get_distance(orig_skim,dest_skim,skimAfstand,nZones)
                vector = [x_dest-x_orig, y_dest-y_orig]
                parcelsCS_array[parc_id] = [parc_id, orig, dest, orig_skim, dest_skim,
    gemeente, x_orig, y_orig, x_dest, y_dest, trav_time, trav_dist, vector, status,0,0,0,0,0]
        count += n

    parcelsCS_df = pd.DataFrame(parcelsCS_array, columns=parcelsCS_cols)
    parcelsCS_df.to_csv(f"{datapathO}{scenario}_ParcelDemand.csv", index=False)

    parcelsCS_df['gemeente'] = parcelsCS_df['gemeente'].str.replace("'",' ')

    #----- GeoJSON ---
    Ax = np.array(parcelsCS_df['X_ORIG'], dtype=str)
    Ay = np.array(parcelsCS_df['Y_ORIG'], dtype=str)
    Bx = np.array(parcelsCS_df['X_DEST'], dtype=str)
    By = np.array(parcelsCS_df['Y_DEST'], dtype=str)
    nTrips = len(parcelsCS_df)

    with open(datapathO + f"{scenario}_ParcelDemand.geojson", 'w') as geoFile:
        geoFile.write('{\n' + '"type": "FeatureCollection",\n' + '"features": [\n')
        for i in range(nTrips-1):
            outputStr = ""
            outputStr = outputStr + '{ "type": "Feature", "properties": '
            outputStr = outputStr + str(parcelsCS_df.loc[i,:].to_dict()).replace("'",'"')
            outputStr = outputStr + ', "geometry": { "type": "LineString", "coordinates": [['
            outputStr = outputStr + Ax[i] + ', ' + Ay[i] + ' ], [ '
            outputStr = outputStr + Bx[i] + ', ' + By[i] + ' ] ] } },\n'
            geoFile.write(outputStr)

        # Bij de laatste feature moet er geen komma aan het einde
        i += 1
        outputStr = ""
        outputStr = outputStr + '{ "type": "Feature", "properties": '
        outputStr = outputStr + str(parcelsCS_df.loc[i,:].to_dict()).replace("'",'"')
        outputStr = outputStr + ', "geometry": { "type": "LineString", "coordinates": [ [ '
        outputStr = outputStr + Ax[i] + ', ' + Ay[i] + ' ], [ '
        outputStr = outputStr + Bx[i] + ', ' + By[i] + ' ] ] } }\n'
        geoFile.write(outputStr)
        geoFile.write(']\n')
        geoFile.write('}')
else:
    parcelsCS_df = pd.read_csv(f"{datapath}output/REF/ref_ParcelDemand.csv")
    parcelsCS_array = parcelsCS_df.to_numpy()
    nParcelsCS = len(parcelsCS_array)
    nParcels = 208016

print("Load / create parcel demand: " + str(round(time.time() - start_time, 2)) + " seconds")
```

The fourth segment loads the origin/destination matrices and converts them into a list of travellers.

```
start_time = time.time()
```

```
modes['fiets']['OD_path'] = str(datapathI + 'MRDH_2016_Fiets_Etmaal.csv')
modes['fiets']['skim_time'] = skimAfstand / 1000 / 12 * 3600
modes['fiets']['n_trav'] = 0
modes['auto']['OD_path'] = str(datapathI + 'MRDH_2016_Auto_Etmaal.csv')
modes['auto']['skim_time'] = skimTravTime
modes['auto']['n_trav'] = 0

if create_new_travellers == True:
    for mode in modes:
        df = pd.read_csv(modes[mode]['OD_path'])
        df.index = df.index + 1
        df = df.drop(df.columns[0], axis=1)
        df = df.drop(df.columns[5925:], axis = 1)
        df = df.drop(df.index[5925:], axis = 0)
        df = df * modes[mode]['willingness']
        df = df.round(0) #loses about 10-15% of all entries
        df = df.astype(int)
        modes[mode]['OD_array'] = df.to_numpy()

trav_array_cols = {'id': 0, 'orig': 1, 'dest': 2, 'orig_skim': 3, 'dest_skim': 4, 'vector':
    5, 'gemeenten': 6, 'parcel': 7, 'status': 8}
for mode in modes:
    if create_new_travellers == True:
        OD_array = modes[mode]['OD_array']
        trav_array = np.zeros((OD_array.sum().sum(),len(trav_array_cols)), dtype=object)

        start_id = sum(d['n_trav'] for d in modes.values() if d)
        count = 0
        for i, row in enumerate(OD_array):
            for j, n in enumerate(row):
                if i != j:
                    if n > 0:
                        orig_skim = i + 1
                        dest_skim = j + 1
                        orig = int(zoneDict[orig_skim])
                        dest = int(zoneDict[dest_skim])
                        vector = [zones.loc[dest]['X'] - zones.loc[orig]['X'] , zones.loc[
    dest]['Y'] - zones.loc[orig]['Y'] ]
                        gemeente = [zone_gemeente_dict[orig_skim], zone_gemeente_dict[
    dest_skim]]

                        for N in range(n):
                            trav_id = N + count + start_id
                            trav_array[N + count] = [trav_id, orig, dest, orig_skim,
    dest_skim, vector, gemeente, 0, 0]

                    count += n
        trav_array = trav_array[~np.all(trav_array == 0, axis=1)]
        modes[mode]['n_trav'] = int(len(trav_array))
        modes[mode]['trav_array'] = trav_array

        travellers_df = pd.DataFrame(trav_array, columns=trav_array_cols)
        travellers_df.to_csv(f"{datapathO}{scenario}_travellers_{mode}.csv", index=False)

    else:
        travellers_df = pd.read_csv(f"{datapath}output/REF/ref_travellers_{mode}.csv")
        trav_array = travellers_df.to_numpy()
        for traveller in trav_array:
            traveller[6] = [zone_gemeente_dict[traveller[3]], zone_gemeente_dict[traveller
    [4]]]
        modes[mode]['trav_array'] = trav_array
        modes[mode]['n_trav'] = int(len(trav_array))

print("Edit OD matrices: " + str(round(time.time() - start_time, 2)) + " seconds")
```

The next part covers the travellers loop and matching by the platform.

```
start_time = time.time()

for mode in modes:
    skimTravTime = modes[mode]['skim_time']
    dropoff_time = modes[mode]['dropoff_time']
    VoT = modes[mode]['VoT']

    for i, traveller in enumerate(modes[mode]['trav_array']):
        offers_dict = {}
        offers2_dict = {}
        trav_orig = traveller[3]
        trav_dest = traveller[4]
        trip_dist = skimAfstand[(trav_orig-1)*nZones+(trav_dest-1)] / 1000
        trip_time = skimTravTime[(trav_orig-1)*nZones+(trav_dest-1)] / 3600

        for parcel in parcelsCS_array[((parcelsCS_array[:,13] == 'ordered')
                                  & ((parcelsCS_array[:,5] ==  traveller[6][0]) | (
    parcelsCS_array[:,5] == traveller[6][1]))
                                  & ((trip_dist/parcelsCS_array[:,11] < 4) & (trip_dist/
    parcelsCS_array[:,11] > .5))
                                  )]:
            parc_orig = parcel[3]
            parc_dest = parcel[4]
            dist_traveller_parcel   = skimAfstand[(trav_orig-1)*nZones+(parc_orig-1)] / 1000
            dist_parcel_trip        = skimAfstand[(parc_orig-1)*nZones+(parc_dest-1)] / 1000
            dist_customer_end       = skimAfstand[(parc_dest-1)*nZones+(trav_dest-1)] / 1000
            CS_trip_dist = (dist_traveller_parcel + dist_parcel_trip + dist_customer_end)

            traveller_detour = CS_trip_dist - trip_dist
            extra_parcel_dist = traveller_detour - dist_parcel_trip
            relative_extra_parcel_dist = extra_parcel_dist / dist_parcel_trip

            # If the parcel fits the prerequisites of the platform; offer the parcel to
    traveller
            if relative_extra_parcel_dist < relative_extra_parcel_dist_threshold:
                CS_compensation = get_compensation(dist_parcel_trip)  ## other way could be a
     linear approach
                offers_dict[parcel[0]] = {'distance': dist_parcel_trip}
                offers_dict[parcel[0]]['rel_detour'] = relative_extra_parcel_dist
                offers_dict[parcel[0]]['compensation'] = CS_compensation

        if offers_dict:
            offered_parcels = sorted(offers_dict, key=lambda x: (offers_dict[x]['rel_detour'
    ]))[:3]

        #traveller chooses the parcel to ship
            for parcel in offered_parcels:
                parc_orig = parcelsCS_array[parcel,3]
                parc_dest = parcelsCS_array[parcel,4]
                traveller_detour_time =     ( skimTravTime[(trav_orig-1)*nZones+(parc_orig-1)
    ] / 3600 +
                                              skimTravTime[(parc_orig-1)*nZones+(parc_dest-1)
    ] / 3600 +
                                              skimTravTime[(parc_dest-1)*nZones+(trav_dest-1)
    ] / 3600 -
                                              trip_time )
                CS_utility = offers_dict[parcel]['compensation'] / ( (traveller_detour_time +
     2*dropoff_time) )
                offers2_dict[parcel] = {'utility': CS_utility}

            best_parcels = sorted(offers2_dict, key=lambda x: (offers2_dict[x]['utility']),
    reverse=True)[:3]
            best_parcel = offered_parcels[0]
            if offers2_dict[best_parcel]['utility'] > VoT:
                traveller[7] = int(best_parcel)
                traveller[8] = str('shipping')
                parcelsCS_array[best_parcel,13] = 'carrier found'
                parc_orig = parcelsCS_array[best_parcel,3]
                parc_dest = parcelsCS_array[best_parcel,4]
```

```
                traveller_detour_time =     (get_traveltime(trav_orig,parc_orig,skimTravTime,
    nZones,timeFac) +
                                              get_traveltime(parc_orig,parc_dest,skimTravTime
    ,nZones,timeFac) +
                            get_traveltime(parc_dest,trav_dest,skimTravTime,nZones,timeFac) -
                                              get_traveltime(trav_orig,trav_dest,skimTravTime
    ,nZones,timeFac) )
                traveller_detour_distance = (get_distance(trav_orig,parc_orig,skimAfstand,
    nZones) +
                                              get_distance(parc_orig,parc_dest,skimAfstand,
    nZones) +
                                              get_distance(parc_dest,trav_dest,skimAfstand,
    nZones) -
                                              get_distance(trav_orig,trav_dest,skimAfstand,
    nZones) )
                parcelsCS_array[best_parcel,14] = traveller[0]
                parcelsCS_array[best_parcel,15] = mode
                parcelsCS_array[best_parcel,16] = traveller_detour_time
                parcelsCS_array[best_parcel,17] = traveller_detour_distance
                parcelsCS_array[best_parcel,18] = offers_dict[best_parcel]['compensation']

        if i % int(modes[mode]['n_trav']/20) == 0:
            if i == 0:
                print("\n" "Loop " + str(mode) + " travellers at ")
            print(str(int(round((i / modes[mode]['n_trav'])*100,0))) + "% ", end="\r")

print("\n Traveller CS selection loop: " + str(round(time.time() - start_time, 2)) + "
    seconds")
```

Following, the output files are prepared and exported.

```
start_time = time.time()
for mode in modes:

    trav_array = modes[mode]['trav_array']
    #generate tourDF
    tours = pd.DataFrame()
    for i, traveller in enumerate(trav_array[trav_array[:,8] == 'shipping']):
        trav_ORIG = traveller[1]
        trav_DEST = traveller[2]
        parc_ORIG = parcelsCS_array[int(traveller[7]),1]
        parc_DEST = parcelsCS_array[int(traveller[7]),2]
        trav_orig = traveller[3]
        trav_dest = traveller[4]
        parc_orig = parcelsCS_array[int(traveller[7]),3]
        parc_dest = parcelsCS_array[int(traveller[7]),4]
        for j in range(3):
            tours.at[i*3+j, 'TOUR_ID'] = i
            tours.at[i*3+j, 'TRIP_ID'] = str(i) + "_" + str(j)
            tours.at[i*3+j, 'traveller_ID'] = traveller[0]
            tours.at[i*3+j, 'parcel_ID'] = traveller[7]
            tours.at[i*3+j, 'mode'] = mode
            if j == 0:
                tours.at[i*3+j, 'skim_dist']  = get_distance(trav_orig,parc_orig,skimAfstand,
    nZones)
                tours.at[i*3+j, 'ORIG']  = trav_ORIG
                tours.at[i*3+j, 'DEST']  = parc_ORIG
            if j == 1:
                tours.at[i*3+j, 'skim_dist']  = get_distance(parc_orig,parc_dest,skimAfstand,
    nZones)
                tours.at[i*3+j, 'ORIG']  = parc_ORIG
                tours.at[i*3+j, 'DEST']  = parc_DEST
            if j == 2:
                tours.at[i*3+j, 'skim_dist']  = get_distance(parc_dest,trav_dest,skimAfstand,
    nZones)
                tours.at[i*3+j, 'ORIG']  = parc_DEST
                tours.at[i*3+j, 'DEST']  = trav_DEST
    if not tours.empty:
        for i, ORIG in enumerate(tours['ORIG']):
            tours.at[i, 'X_ORIG'] = zones.loc[ORIG]['X']
            tours.at[i, 'Y_ORIG'] = zones.loc[ORIG]['Y']
        for i, DEST in enumerate(tours['DEST']):
```

```
            tours.at[i, 'X_DEST'] = zones.loc[DEST]['X']
            tours.at[i, 'Y_DEST'] = zones.loc[DEST]['Y']

        #----- GeoJSON ---
        # print('Writing GeoJSON...')
        Ax = np.array(tours['X_ORIG'], dtype=str)
        Ay = np.array(tours['Y_ORIG'], dtype=str)
        Bx = np.array(tours['X_DEST'], dtype=str)
        By = np.array(tours['Y_DEST'], dtype=str)
        nTrips = len(tours)

        with open(datapath0 + f"{scenario}_{mode}.geojson", 'w') as geoFile:
            geoFile.write('{\n' + '"type": "FeatureCollection",\n' + '"features": [\n')
            for i in range(nTrips-1):
                outputStr = ""
                outputStr = outputStr + '{ "type": "Feature", "properties": '
                outputStr = outputStr + str(tours.loc[i,:].to_dict()).replace("'",'"')
                outputStr = outputStr + ', "geometry": { "type": "LineString", "coordinates":
     [ [ '
                outputStr = outputStr + Ax[i] + ', ' + Ay[i] + ' ], [ '
                outputStr = outputStr + Bx[i] + ', ' + By[i] + ' ] ] } },\n'
                geoFile.write(outputStr)

            # Bij de laatste feature moet er geen komma aan het einde
            i += 1
            outputStr = ""
            outputStr = outputStr + '{ "type": "Feature", "properties": '
            outputStr = outputStr + str(tours.loc[i,:].to_dict()).replace("'",'"')
            outputStr = outputStr + ', "geometry": { "type": "LineString", "coordinates": [ [
     '
            outputStr = outputStr + Ax[i] + ', ' + Ay[i] + ' ], [ '
            outputStr = outputStr + Bx[i] + ', ' + By[i] + ' ] ] } }\n'
            geoFile.write(outputStr)
            geoFile.write(']\n')
            geoFile.write('}')

parcelsCS_df = pd.DataFrame(parcelsCS_array, columns=parcelsCS_cols)
parcelsCS_df.to_csv(f"{datapath0}{scenario}_Result.csv", index=False)

print("Writing output: " + str(round(time.time() - start_time, 2)) + " seconds")
print("Total model run: " + str(round(time.time() - total_start_time, 2)) + " seconds")
```

Finally, the output is returned qualitative as well in two forms. First, a table is printed in LaTeX language for this report. Secondly the results are given shortly in text for quick inspection.

```
n_parcels_total = nParcels
n_parcels_CS = len(parcelsCS_array)
n_parcels_CS_delivered = (parcelsCS_array[:,13] == 'carrier found').sum()
delivered_percentage =  round(n_parcels_CS_delivered/n_parcels_CS*100,2)
avg_dist =              round(parcelsCS_array[:,11].mean(),2)
avg_detour =            round(parcelsCS_array[:,17].sum()/n_parcels_CS_delivered,2)
total_detour =          int(round(parcelsCS_array[:,17].sum(),-1))
bike_parcels =          len(parcelsCS_array[parcelsCS_array[:,15]=='fiets'][:,17])
bike_km =               int(round(parcelsCS_array[parcelsCS_array[:,15]=='fiets'][:,17].sum()
    ,-1))
bike_km_avg =           round(parcelsCS_array[parcelsCS_array[:,15]=='fiets'][:,17].mean(),2)
car_parcels =           len(parcelsCS_array[parcelsCS_array[:,15]=='auto'][:,17])
car_km =                int(round(parcelsCS_array[parcelsCS_array[:,15]=='auto'][:,17].sum()
    ,-1))
car_km_avg =            round(parcelsCS_array[parcelsCS_array[:,15]=='auto'][:,17].mean(),2)
avg_compensation =      round(parcelsCS_array[parcelsCS_array[:,13]=='carrier found'][:,18].
    mean(),2)


print(f"\\begin{{table}}[H] \\centering \\begin{{tabular}}{{lll}} \\hline" + "\n" +
      f"\\multirow{{3}}{{*}}{{Platform}}  " + "\n" +
      f"& Ordered parcels       & {n_parcels_CS:,}              \\\ \\cline{{2-3}}" + "\n" +
      f"& Delivered parcels     & {n_parcels_CS_delivered:,}  ({delivered_percentage}\\%)
    \\\ \\cline{{2-3}} " + "\n" +
      f"& Average compensation  & {avg_compensation} euro          \\\ \\hline" + "\n" +
```

```
      "\multirow{4}{*}{Public authority} " + "\n" +
      "& Freight transport reduction  & " + "\n" +
      "?? km (delivery van)  \\\ \cline{2-3} " + "\n" +
      "& Passenger transport increase " + "\n" +
      "& \\begin{tabular}[c]{@{}l@{}}" + "\n" +
      f"     {bike_km:,} km (bike)\\\ " + "\n" +
      f" \\underline{{{car_km:,} km}} (car) \\\ " + "\n" +
      f"    {total_detour:,} km ({avg_detour} / parcel)" + "\n" +
      " \end{tabular} \\\ \hline" + "\n" +
      " \end{tabular}" + "\n" +
      f" \\caption{{Results experiment {scenario} }} " + "\n" +
      " \end{table} " + "\n" + "\n"
      )

print("A total of " + str(n_parcels_total) + " parcels ordered in the system. " + str(
    n_parcels_CS) +" are eligible for CS of which "+ str(n_parcels_CS_delivered) +" have been
     delivered (" + str(delivered_percentage) + "%)." + "\n" +
      "The average distance of CS parcel trips is " +str(avg_dist) + "km. For the delivered
    parcels, the average detour is " + str(avg_detour) +"km." + "\n" +
      "For the CS deliveries, " + str(total_detour) + " extra kilometers are driven. The
    detours are distributed to modes as follows" + "\n" +
      "Bike: " + str(bike_parcels) + " parcels, total of " + str(bike_km) + "km (" + str(
    bike_km_avg) + "km average) \n" +
      "Car:  " + str(car_parcels) + " parcels, total of " + str(car_km) + "km (" + str(
    car_km_avg) + "km average) \n \n" +
      "The average provided compensation for the occasional carriers is " + str(
    avg_compensation) + " euro. \n")
```

E

Appendix: Results sensitivity analysis

The sensitivity analysis is performed as part of the model validation as described in section 4.4. All uncertainties and strategies are lowered or raised by 20%. The model outcomes are presented below.

Analysis	CS parcels	Percentage delivered	Average compen-sation	Freight km decrease Delivery van	Passenger km increase Bike	Car	Total (avg)
Base	13,163	97.52%	€2.32	2,261	14,900	16,490	31,400 (2.45)
Parcels per HH - low	10,514	97.72%	€2.33	1,419	12,160	13,350	25,510 (2.48)
Parcels per HH - high	15,856	97.44%	€2.32	2,149	17,140	20,560	37,700 (2.44)
CS share - low	10,474	98.04%	€2.32	1,996	12,180	13,010	25,190 (2.45)
CS share - high	15,920	97.19%	€2.32	2,882	17,500	19,760	37,260 (2.41)
Willingness to ship - low	13,163	96.92%	€2.32	2,339	14,040	17,540	31,580 (2.48)
Willingness to ship - high	13,163	97.92%	€2.32	2,151	15,720	15,130	30,850 (2.39)
Drop-off time - low	13,163	97.79%	€2.32	2,079	15,490	17,260	32,760 (2.54)
Drop-off time - high	13,163	96.99%	€2.32	2,125	14,230	15,160	29,390 (2.30)
Travellers VoT - low	13,163	98.27%	€2.33	2,274	20,520	18,320	38,840 (3.00)
Travellers VoT - high	13,163	93.82%	€2.30	2,090	11,090	11,790	22,880 (1.85)
Compensation - low	13,163	92.46%	€1.84	2,651	10,290	10,590	20,880 (1.72)
Compensation - high	13,163	98.92%	€2.79	2,333	19,370	18,260	37,630 (2.91)
Detour threshold - low	13,163	96.36%	€2.33	2,519	14,220	15,030	29,250 (2.31)
Detour threshold - high	13,163	98.18%	€2.32	2,059	15,240	17,060	32,300 (2.50)

Table E.1: Results sensitivity analysis

F

Appendix: Results experiments

F.1. Results for experiment 'More efficient crowdshipping'

The results in this section belong to the experiment on making crowdshipping more efficient. This experiments is explained in section 5.3.1. Within this experiment, two sub-experiments were performed. First, the compensation is lowered and secondly, the detour threshold in decreased.

Lowering compensation

Following table gives an overview of the experiments performed in lowering the compensation. The experiments are stated in percentage of the original compensation formula.

Run	Percentage delivered	Average compen-sation	Freight km decrease	Passenger km increase		
Compensation			Delivery van	Bike	Car	Total (avg)
Base (100%)	97.52%	€2.32	2,261	14,900	16,490	31,400 (2.45)
90%	96.00%	€2.08	2,369	12,590	14,030	26,620 (2.11)
80%	92.46%	€1.84	2,651	10,290	10,590	20,880 (1.72)
70%	86.00%	€1.60	1,658	8,180	6,860	15,040 (1.33)
60%	73.87%	€1.35	1,756	5,950	3,800	9,760 (1.00)
50%	56.17%	€1.11	1,279	3,940	1,230	5,170 (0.70)
40%	38.41%	€0.88	763	2,090	130	2,230 (0.44)
30%	24.79%	€0.65	547	690	-20	670 (0.21)
20%	15.00%	€0.44	563	-60	-40	-70 (- .04)
10%	7.29%	€0.22	107	-230	0	-230 (- .23)

Table F.1: Results experiment compensation

Lowering detour threshold

Following table gives an overview of the experiments performed in lowering the detour threshold. Two figures stand out from this table. First, the freight transport decrease is arbitrary in some experiments (see the difference in -0.5 and -0.6). This is because of the heuristics in Mass-GT which is not always finding the optimal solution. Secondly, from a detour threshold lower than -1.5, no bicycle trips deliveries will be made. This is because of the large forced negative detour; travellers should in this scenario find a route which is 3 kilometres shorter than their planned trip. On bike, these routes barely exists.

Run	Percentage delivered	Average compen-	Freight km decrease	Passenger km increase		
Detour threshold		sation	Delivery van	Bike	Car	Total (avg)
Base (0)	97.52%	€2.32	2,261	14,900	16,490	31,400 (2.45)
-0.1	97.04%	€2.32	2,184	14,620	15,880	30,500 (2.39)
-0.2	96.36%	€2.33	2,519	14,220	15,030	29,250 (2.31)
-0.3	95.78%	€2.33	2,245	13,570	13,750	27,320 (2.17)
-0.4	94.36%	€2.33	2,246	12,540	11,930	24,470 (1.97)
-0.5	92.25%	€2.33	2,663	10,860	10,010	20,860 (1.72)
-0.6	88.08%	€2.33	1,725	8,490	7,620	16,110 (1.39)
-0.7	81.11%	€2.34	2,064	5,570	4,610	10,380 (0.97)
-0.8	69.19%	€2.34	1,412	2,870	1,190	4,060 (0.45)
-0.9	55.07%	€2.34	1,000	620	-2,130	-1,510 (-0.21)
-1.0	40.86%	€2.33	705	-230	-4,630	-4,860 (-0.90)
-1.1	30.03%	€2.31	900	-90	-6,070	-6,160 (-1.56)
-1.2	22.66%	€2.29	476	-40	-5,980	-6,020 (-2.02)
-1.3	17.13%	€2.28	563	-20	-5,480	-5,500 (-2.44)
-1.4	12.73%	€2.27	372	-10	-4,750	-4,750 (-2.84)
-1.5	9.35%	€2.27	-56	0	-3,930	-3,930 (-3.19)
-1.6	6.69%	€2.25	-87	0	-3,110	-3,110 (-3.53)
-1.7	4.26%	€2.24	232	0	-2,190	-2,190 (-3.90)
-1.8	2.70%	€2.23	-24	0	-1,500	-1,500 (-4.24)
-1.9	1.74%	€2.22	75	0	-1,030	-1,030 (-4.51)
-2.0	0.94%	€2.19	303	0	-580	-580 (-4.72)

Table F.2: Results experiment detour threshold

F.2. Results for experiment 'Ratio travellers per parcel'

The results in this section belong to the experiment on testing the ratio of travellers per parcel. This experiment is explained in section 5.3.2. Within this experiment, two sub-experiments were performed. The share of crowdshipping eligible parcels is increased first. Next, the travellers' willingness was decreased to lower the number of travellers.

Increasing share crowdshipping parcels

The share of crowdshipping parcels is a product of the customers' willingness and a percentage of eligible consignors. In the base case, the willingness is 30% and the number eligible consignors is estimated at 20%. This results in a crowdshipping share of 6%.

Run CS share	CS parcels	Percentage delivered	Average compen-sation	Freight km decrease Delivery van	Passenger km increase Bike	 Car	 Total (avg)
Base (6%)	13,163	97.52%	€2.32	2,261	14,900	16,490	31,400 (2.45)
8%	17,626	97.50%	€2.32	2,758	19,060	22,960	42,020 (2.44)
10%	22,040	97.05%	€2.32	3,883	22,780	28,360	51,140 (2.39)
12%	26,439	96.70%	€2.32	4,635	26,140	35,940	62,080 (2.43)
14%	30,989	96.11%	€2.31	5,726	29,910	40,150	70,050 (2.35)
16%	35,272	95.77%	€2.32	6,658	32,450	46,620	79,070 (2.34)
18%	39,778	95.38%	€2.31	7,084	36,000	51,510	87,510 (2.31)
20%	44,186	95.04%	€2.31	8,247	38,580	59,300	97,880 (2.33)
25%	55,230	94.01%	€2.31	10,010	45,110	74,260	119,370 (2.30)
30%	66,349	92.25%	€2.30	11,789	50,630	85,940	136,580 (2.23)
35%	77,340	91.27%	€2.30	13,591	55,000	102,620	157,620 (2.23)
40%	88,402	90.07%	€2.30	15,633	60,150	114,390	174,540 (2.19)
45%	99,409	88.40%	€2.29	17,408	64,260	125,700	189,960 (2.16)
50%	110,554	87.33%	€2.29	19,078	68,910	135,720	204,630 (2.12)

Table F.3: Results experiment increasing share of eligible parcels for crowdshipping

Decreasing travellers' willingness

By decreasing the travellers' willingness, less travellers are available to carry the parcels. The result is that the percentage of delivered parcels goes down, and travellers intend to carry parcels with shorter trip length (based on the decreasing compensation and detour).

Run Travellers' willingness	Percentage delivered	Average compen-sation	Freight km decrease Delivery van	Passenger km increase Bike	Car	Total (avg)
Base (30%)	97.52%	€2.32	2,261	14,900	16,490	31,400 (2.45)
25%	97.01%	€2.32	2,125	14,240	17,350	31,590 (2.47)
20%	96.13%	€2.32	2,377	13,130	18,110	31,250 (2.47)
15%	93.69%	€2.21	2,269	11,610	18,610	30,220 (2.45)
12.5%	90.37%	€2.30	1,703	10,570	17,650	28,220 (2.37)
10%	84.64%	€2.28	1,796	9,150	16,450	15,600 (2.30)
9%	81.01%	€2.27	2,105	8,260	15,380	24,010 (2.25)
8%	76.89%	€2.26	1,737	7,970	14,590	22,560 (2.23)
7%	71.52%	€2.25	1,838	7,250	13,660	20,910 (2.22)
6%	64.87%	€2.24	1,379	6,400	12,210	18,610 (2.18)
5%	56.70%	€2.23	1,347	5,410	10,670	16,090 (2.16)
4%	46.78%	€2.22	872	4,450	8,200	12,650 (2.05)
3%	34.25%	€2.20	428	3,240	5,220	8,450 (1.88)
2%	20.46%	€2.18	533	1,930	2,710	4,640 (1.72)
1%	6.15%	€2.12	-12	480	620	1,100 (1.36)

Table F.4: Results experiment decreasing travellers' willingness

F.3. Results for experiment 'Alternative compensation schemes'

These experiments are performed to test other compensation strategies by the platform. The results are interpreted in section 5.3.3.

Experiment Compensation	Percentage delivered	Average compen-sation	Freight km decrease Delivery van	Passenger km increase Bike	Car	Total (avg)
Base (based on parcel trip length)	97.52%	€2.32	2,261	14,900	16,490	31,400 (2.45)
Fixed €2.50	95.66%	€2.50	2,168	15,380	11,760	27,140 (2.16)
Fixed €2.00	91.29%	€2.00	2,387	11,560	8,470	20,020 (1.67)
Fixed €1.50	77.59%	€1.50	1,904	7,200	3,750	10,950 (1.07)
Fixed €1.00	45.38%	€1.00	628	3,090	240	3,330 (0.56)
Based on traveller's detour trip length	93.74%	€1.94	2,269	11,480	15,350	26,830 (2.37)

Table F.5: Results experiment compensation strategies

F.4. Results for experiment 'Changing parcel origin'

The final experiments cover a strategy change towards the parcels' origin. In the first four runs, the spatial demarcation is changed to the city of The Hague. The final run covers a strategy where parcels are spread over the whole study area. The interpretation of this experiment could be found in section 5.3.4.

Run Parcel origin	CS parcels	Percentage delivered	Average compen-sation	Freight km decrease Delivery van	Passenger km increase Bike	Car	Total (avg)
Base (no pickup)	3,092	98.64%	€2.35	692	3,100	5,700	8,810 (2.89)
1 pickup	3,092	99.09%	€2.21	570	2,440	4,720	7,150 (2.34)
3 pickup	3,092	99.42%	€2.09	565	3,710	2,060	5,770 (1.88)
6 pickup	3,092	100%	€1.98	603	3,880	710	4,590 (1.50)
Spread through province	13,163	72.87%	€3.01	1,397	6,940	43,540	50,470 (5.26)

Table F.6: Results experiments changed parcel origin