Potential Impact of Car-Based Crowdshipping on Vehicle Mileage and Carbon Dioxide Emission:

An Agent-Based Modelling Study Case

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by

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Preface

"The line between disorder and order lies in logistics", said Sun Tzu, a military general and a philosopher from ancient China, who is also the author of the famous influential book, The Art of War. Drawing a line between disorder and order is a challenging task since everything are vague at the boundary between the two. That is what drew me to the sector of transport and logistics, and eventually, I ended up doing this thesis project, on the subject that I'm really fond of. For many months, I faced various challenges and kept asking myself if what I do is right. Fortunately, everyone around me is so supportive and helpful, especially during this tough and strange period. I'm very grateful for that.

I'd like to express my gratitude to the thesis committee for guiding me from the beginning of this project through the end. First of all, I would like to thank Prof. Lori and Ioanna for getting me on board with this thesis project. The guidance and advice that they gave me really helped me throughout this project. I also would like to thank Sebastian for teaching and guiding me with MATSim, a framework that I'm not really familiar with at the start. Although we have never met in real life due to this strange pandemic period and even both of us live in two different countries, you have provided me with all the help and time you could give and I'm very thankful for that. I would also like to express my gratitude to other supervisors that have helped me throughout this project, Frederik. Thank you for your very constructive feedback in writing the report and your critical view on the subject.

Moreover, I'd also like to thank Rodrigo that has helped me a lot with LEAD parcel modules and python programming. Every time I came back from your office, I always have a new improvement on the coding processes that I was not very fluent in. Thank you also to Sebastiaan from Significance that has helped me in setting up with MASS-GT at the early phase of this project.

On a more personal note, I would like to thank my parents, Mama and Papa, and my brother, Jamie, for providing me with emotional support, although we are separated by 16 hours of flight. Thank you for always motivating me when I'm stressed and down. I hope I could make you proud of this achievement that I fought for.

I would like to also thank Virgia for always giving support and love throughout my study abroad. Thank you for always patiently waiting for me. You are one of my biggest motivations, so thank you, thank you, thank you!

I wouldn't be able to finish this project without the support of my closest friends that always kept me going, Andrian, Nuel, Kanya, Panji, Ranar, Bang Songko, Yannick, and Steven. The laughter we shared always refreshed my mind when I met a dead end. Finally, to those back home that is always there through an online platform to remind me that I still have lovely and loyal friends that are waiting for me, Karina, Adya, Ramzy, Paulus, Dhika, Bayu and Yorre. Can't wait to see you guys soon!

Delft, January 2022

Farizky Wijanarko

Executive Summary

Introduction

In the last decade, B2C e-commerce has grown rapidly, with an expected income of 6.54 trillion US dollars by 2022. The COVID-19 pandemic also significantly increase the growth in the e-commerce sector by 10% compared to the expected value. The increasing popularity of the e-commerce market consequently increases the parcel traffic in the last-mile delivery (LMD) sector, specifically home delivery service, since that is one of the most prominent advantages that e-commerce could offer. LMD sector itself needs to be improved and innovated so that it could be faster, cheaper, and more reliable since this sector still could be accounted for 13% to 75% of the total logistics cost, which means it is not efficient enough. LMD also has a significant impact on urban traffic and carbon emissions, and therefore, an innovation to improve this sector is needed. This is further strengthened by the fact that cleaner urban freight and passenger transport are one of the main concerns of the European Commission, included in the European Green Deal, aiming for a 90% emission reduction produced by the transport sector by 2050.

Crowdshipping emerged as one of the innovations to the traditional LMD method. This innovation works by matching the travelling "crowd" or person (supply) with available parcels to be delivered (demand) with app-based platform technology and utilising the crowd to be an occasional courier. The chosen occasional courier will have to take a detour from their original route to pick up and deliver the parcels. In return for their service, the occasional courier will get a compensation fee, while the sender of the parcels can get a cheaper price for delivering a parcel using a same-day delivery service. Using this delivery scheme, crowdshipping is expected to reduce carbon emissions produced by the LMD sector.

Research Gap

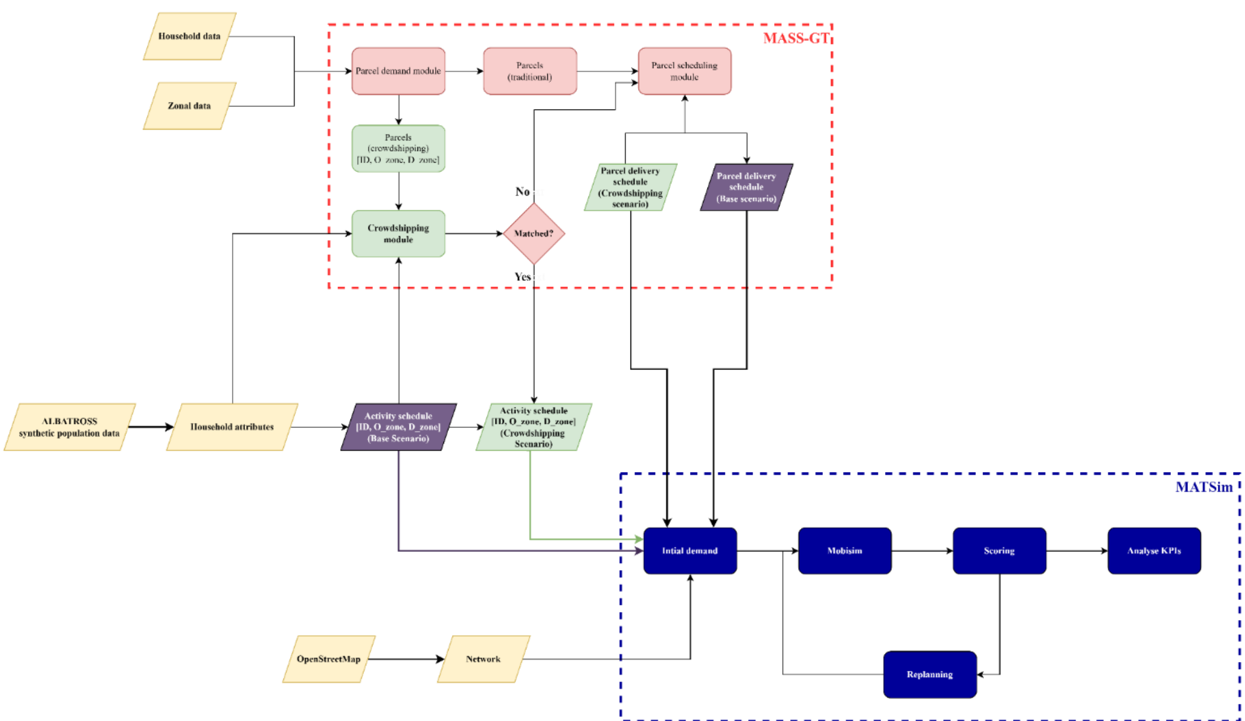
The Crowdshipping concept has been studied or even tried in many countries. Most of the studies focused on the success factors of adopting crowdshipping, factors that need to exist in a crowdshipping platform, willingness-to-pay of the customers, willingness-to-work of the couriers, and matching and routing algorithm of crowdshipping. Moreover, most of the studies conducted mainly discussed the crowdshipping that is performed using public transport or bicycle. Meanwhile, private cars can still be accounted for the majority of the traffic, and they also can be used to perform crowdshipping as well. Although it is logical to utilise the travelling crowds that are using cars to travel as the occasional courier, the impact it could bring such as the local vehicle mileage and the consequential local carbon emission are yet to be explored. Therefore, this research's main objective is to **determine the impact of the interaction between urban freight and passenger transport in the form of car-based crowdshipping in the city centre of The Hague, The Netherlands, on the local vehicle mileage and the resulting carbon emission.** To achieve the research objective, agent-based modelling (ABM) studies are conducted in this study. Two kinds of scenarios are formulated, the base scenario which represents the existing condition without crowdshipping, and the crowdshipping scenarios with different adoption rates of crowdshipping.

Integrated Agent-Based Modelling Frameworks

Two ABM frameworks are used in this study: MASS-GT, an agent-based modelling framework for simulating freights, and MATSim, a microscopic activity-based multi-agent transport simulation software, capable of simulating large-scale scenarios.

LEAD parcel modules of MASS-GT are used to generate the parcel demand, parcel schedule, and assign the parcels to the travelling crowds. The data of the travelling crowd itself is obtained from ALBATROSS, a synthetic population activity data that are generated from the surveyed travel diary of the population. Both data, the parcels and population, are processed based on the scenario, then simulated microscopically using MATSim. MATSim runs for multiple iterations and when the Stochastic User Equilibrium (SUE) condition has been reached, the results can be obtained and analysed.

The two ABM frameworks (MASS-GT and MATSim) that were discussed in the previous paragraph are integrated in this study. The integration process is done by using the output of one framework as the input to another. In general, MATSim needs three input files to execute agent-based simulation; **plan file** which consists of the agents' activity schedule, the **network file** as the spatial context of the simulation, and the **config file** which govern all configurations of the simulation. In this study, the former input is obtained from the processed ALBATROSS travel diary data for the person-agents and processed LEAD parcel module's output for the parcel van delivery schedule. The aforementioned data are processed so that the location variables of both data are in the same format, on the coordinate level, so that they fulfil MATSim's requirement. The network file is obtained from OpenStreetMap (OSM), converted to MATSim's format. The config file itself is written in an XML format. The integrated framework is presented in the figure below.



Scenarios

Two kinds of scenarios are formulated to analyse the results of the simulation: a base scenario which represents the current condition without the existence of crowdshipping, and three crowdshipping scenarios with different crowdshipping adoption rates in each scenario (CS-Reference, CS-C: reduced adoption rate, CS-B: increased adoption rate). All parcels are handled by the traditional delivery vans in the base scenario. Meanwhile, in crowdshipping scenarios, parcels are delivered partially by crowdshipping, assigning parcels to travel crowds in the LEAD crowdshipping module. Not all travelling crowds can be crowdshipper, they have to fulfil the crowdshipper criteria that were found from literatures and a few assumptions that were set. These criteria filter the passenger data based on their attributes (age, household income), transport mode (only those who travel with cars are allowed to be crowdshippers) and trip purpose of the agents (have to be other than "work"). Some of the remaining agents that fulfil the criteria are then matched with the available crowdshipable parcels based on the least detour they have to take to pick up and deliver the parcel using the LEAD crowdshipping module. The final output of the LEAD crowdshipping module is the data of the crowdshipper (person ID, trip ID, origin, destination) with the parcels they are responsible for (parcel ID, parcel origin, parcel destination). In some cases, some crowdshipable parcels are not matched with travellers. These parcels are then being brought back to the parcel demand data so that they can be assigned in the parcel delivery van schedule. The number of matched parcels and travellers depend on the crowdshipping adoption rates that are being used. A larger value in the crowdshipping adoption rate will result in more crowdshippers.

Simulation Results

The four scenarios formulated are then simulated using MATSim. In this study, each simulation is run for 100 iterations, as the result showed the SUE condition has been reached. Two KPIs are formulated to analyse the results of the simulation: vehicle kilometres travelled (VKT) and CO2 emission. The passenger-kilometres travelled per mode provided in the output of the simulation are considered as VKT, since an assumption of one person per vehicle is set in this simulation. The CO2 emission is calculated by multiplying the VKT value with the CO2 emission factor (per mode) and are measured in gram CO2 emitted per kilometres. The transport modes that are included in the calculation are only car and van since these two modes are involved in crowdshipping.

The simulation results of all scenarios are presented in the table below. It can be observed that car-based crowdshipping slightly increased the vehicle mileage and CO2 emission. However, the increase in all scenarios are very small, ranging from 0.07% increase (CS-C) to 0.27% increase (CS-B) on both KPIs. This is mainly caused by the fact that the traditional van delivery service offers a more established and efficient method in delivering parcels due to its capabilities of parcels consolidation and delivering multiple parcels on a single trip. Car-based crowdshipping, on the other hand, can only deliver a single parcel on a single trip and it has to take two extra trips to deliver each parcel, one to pick up the parcel and another to deliver the parcel.

Mode	Base		CS-C		CS-Reference		CS-B	
	pkm (km)	CO2 (gCO2)	pkm (km)	CO2 (gCO2)	pkm (km)	CO2 (gCO2)	pkm (km)	CO2 (gCO2)
car	349,846	44,640,350	350120	44675312	350,619	44,738,984	351,074	44,797,042
van	951	232,995	941	230300	932	228,340	823	201,635
Total	350,797	44,873,345	351,061	44,905,612	351,551	44,967,324	351,897	44,998,677

Conclusion

It can be concluded that car-based crowdshipping would not offer a significant benefit in reducing the CO2 emission produced by the transport sector. If crowdshipping is performed using a more sustainable transport mode such as bicycle or public transport, it could potentially offer more environmental benefits and less vehicle mileage. Car-based crowdshipping by electric vehicles could also offer a better environmental benefit since it emits no local emission on the street level, however, the vehicle mileage would still be increased. Combining crowdshipping with other last-mile delivery innovations such as parcel lockers could also potentially reduce the total detour of the crowdshippers and consequently would reduce the CO2 emission. In conclusion, this study affirms the findings from the study of Rai et al. (2017) that suspects crowdshipping could increase or reduce the traffic congestions and CO2 emissions produced by the transport sectors. Furthermore, the integrated model framework formulated in this study could help in modelling future cases of crowdshipping

Discussion and Recommendation for Future Research

Sets of assumptions and simplifications are formulated to construct the model and simulate the scenarios in this study. These generalisations might hinder the perfect results of the simulation. Assumptions on the buildings function might cause the model to not represent the real-life transportation pattern. Moreover, the enormous difference between the number of parcel van trips with the private car trips caused the model to be relatively unresponsive to the changes in both KPIs. Moreover, the exact value of the car-based crowdshipping adoption rate couldn't be found in the literatures and therefore, the values are assumed in this study. Various assumptions are further made on the supply and demand side of crowdshipping to generalise and simplify the model. The emission calculation made in this study is performed with a simple multiplication of the pkm values with adoption rate, while there are more elegant and comprehensive methods to perform the calculation.

The result of this study could contribute to further studies in crowdshipping. It is recommended to scale up the study scope, since MATSim enables the simulation of large scenarios, for instance, on the level of a city or even a province. Incorporating extension modules of MATSim to conduct a more in-depth study is also recommended, such as utilising the hot and cold emission modules and incorporating other modes such as public transport, taxi, bicycle, etc. Conducting a MATSim simulation while incorporating crowdshipping performed with various modes and see which mode combinations would be the most beneficial or efficient would be an interesting direction of research. The other recommendation is to do a more holistic integration of MASS-GT with MATSim since the model integration in this study took place mostly in Python with Pandas library and Microsoft Excel. Creating a single platform to integrate the two models, for instance, the MASS-GT extension on MATSim might save a significant amount of time instead of going back and forth between platforms. The last recommendation is to incorporate the sender and receiver end of crowdshipping as agents in the model. The crowdshipper takes the parcel directly from its designated origin location. On the other hand, the sender and receiver agents of crowdshipping are not represented by agents in this study. By incorporating these agents, the demand side of crowdshipping would be better represented. Moreover, other methods of crowdshipping, such as picking up/delivering the parcel to a certain pick-up point or parcel lockers could also be incorporated. However, it will possess its own challenges in the crowdshipping matching process and constructing the crowdshipping scenario's schedule file.

List of Abbreviations

3PL	Third Party Logistics Service Providers
ABM	Agent-Based Modelling
ALBATROSS	A Learning-Based Transportation Oriented Simulation System
B2B	Business to Business
B2C	Business to Consumer
CEP	Parcel and Express Company
CO2	Carbon Dioxide
COVID-19	Coronavirus Disease
CS	Crowdshipping
ETP	Expected to be Paid
EU	European Union
FIFO	First-in-first-out
ID	Identity
Kg	Kilogram
Km	Kilometre
KPI	Key Performance Indicator
LMD	Last-Mile Delivery
MASS-GT	Multi-Agent Simulation System for Goods Transport
MATSim	Multi-Agent Transport Simulation
MNL	Multinomial Logit Model
MOD	Mobility-on-Demand
OSM	OpenStreetMap
pkm	Passenger-kilometres
PT	Public Transport
SQ	Sub-question
SUE	Stochastic User Equilibrium
TAZ	Traffic Analysis Zone
VKT	Vehicle-kilometres travelled
V-MRDH	*Verkeersmodel Metropoolregio Rotterdam Den Haag*
WTW	Willingness to Work
XML	Extensible Markup Language

Table of Contents

Table of Figure

List of Table

1 - Introduction

1.1 Background

For the last decade, Business to Customer (B2C) e-commerce has grown considerably in a rapid fashion. This business sector has been predicted to develop by 26.6% in the timeframe of 2013 to 2020, while the expected income is forecasted to be around 6.54 trillion US dollars by 2022 (Vakulenko et al., 2018; Lin et al., 2020). Moreover, the COVID-19 pandemic significantly affected the increase of growth in e-commerce sectors, mostly experiencing more than 10% growth compared to the expected value, as was shown in research in Denmark (Nyrop et al., 2020). Vakulenko et al. (2018) argued that one of the most prominent advantages of e-commerce is the fact that it offers numerous advantages in last-mile delivery (LMD). Several studies have shown that with the increasing popularity of e-commerce, the traffic of parcels deliveries and returns volumes in urban areas have increased significantly due to the home delivery service, which is also the most used method in LMD (Schewel & Schipper, 2012; Iwan et al., 2016; Faugere & Monstreuil, 2017; Vakulenko et al., 2018; Nahry & Vilardi, 2019).

It is an urgent matter to improve and innovate the LMD so that it could be faster, cheaper, and more reliable, as they are a few of the most important success factors for LMD to succeed (Chen & Pan, 2016; Gdowska et al., 2018). The fact that 13% to 75% of the total logistics costs are generated in this last segment of the whole chain just strengthen the urge to innovate on the last-mile delivery (Gevaers et al., 2011). Moreover, LMD also has a significant impact on urban traffic load and carbon emissions, and therefore, a more reliable way to perform this is needed (Gdowska et al., 2018). This necessity is further strengthened by the fact that cleaner urban freight, along with the passenger, transportation is on one of the top lists of European Commission, included in The European Green Deal, aiming for 90% reduction in emission produced in the transport sector by 2050 (European Commission, 2019).

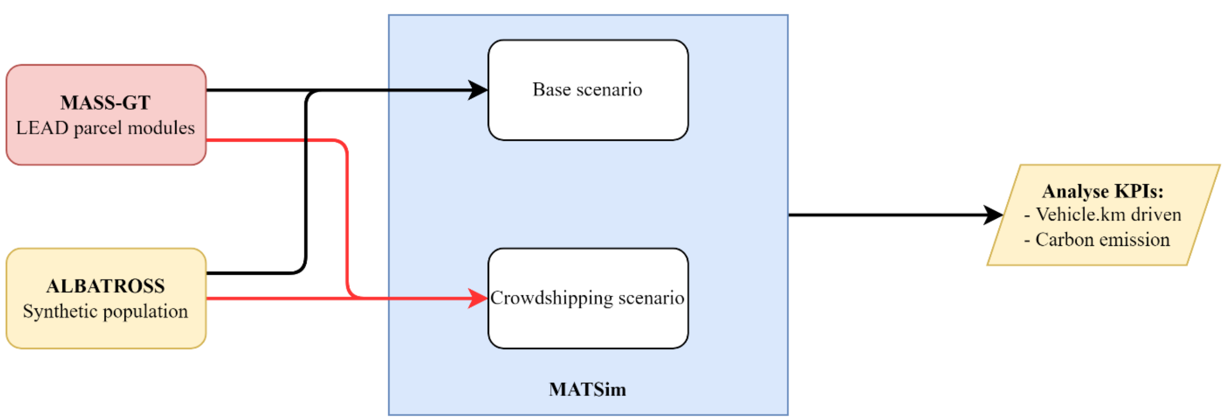
One of the innovations in LMD is crowdshipping. Crowdshipping is based on the emerging sharing economy phenomenon and took the advantage of rapid development in the app-based platform technologies that could match the supply and demand in the city logistics (Le et al., 2019). McKinnon (2016) defined crowdshipping as a personalised freight delivery service based on a crowdsourcing concept that utilises ordinary citizens travelling from an origin to a destination to be an occasional courier, and by doing so, creating new informal logistics networks for the distribution of small items. The individual acting as a courier will get a compensation fee in return for his/her service as a non-professional courier (Simoni et al., 2020). Moreover, crowdshipping is expected to promote sustainable urban freight transport by reducing the number of vehicles that are dedicated to delivering packages and switching them to crowd couriers (Arslan et al., 2018).

The traditional urban freight deliveries (i.e., van deliveries) can be accounted for approximately 0.6% of the local traffic yet their impact on the local emission and traffic could be considered troublesome (Aditjandra et al., 2016; Herold, 2019). With the existence of crowdshipping, the dynamics between the traditional deliveries with the local passenger transportation would be affected, since a few of the "crowd" in passenger transport activities would act as occasional couriers, representing the interaction between urban freight and passenger transport activities. This point of view to crowdshipping has yet to be explored and it could offer interesting insights for the development of the crowdshipping concept, which has the potential to help many actors, either the policy-maker, logistics companies, or the crowdshipping service provider to reduce carbon emission.

To analyse the interaction between both transport activities in the form of crowdshipping, the agent-based simulation could offer interesting insight, since it could simulate each element in a microscopic, disaggregate level, with a piece of detailed information in a spatial and temporal variable, and could allow for detailed and disaggregated analysis (Tchervenkov et al., 2020). Furthermore, the agent-based model is one of the tools that can be used to assess the decision-making in freight transport policy, since this method allows simulations of agent-specific behaviour while also considering the variations of decision-makers (de Bok & Tavasszy, 2018). Two agent-based modellings (ABM) simulation programmes will be used in this study case scenario. The freight flow in the urban area will be simulated using an ABM framework developed by de Bok and Tavasszy (2018) called MASS-GT will be used, specifically, the extension modules on parcel last-mile delivery simulations that are currently being developed by the LEAD project (Kourounioti and Tapia, 2021). The urban passenger transportation activities will be simulated using an ABM platform called MATSim, a microscopic activity-based, multi-agent transportation simulation framework developed by Horni et al., (2016).

The main objective of this research is to analyse the impact of the interaction between urban freight and passenger transport, considering van deliveries and crowdshipping, on the local vehicle mileage and the resulting CO2 emission. The city centre of The Hague, The Netherlands is chosen as the spatial scope of the research. Furthermore, only same-day delivery crowdshipping that are performed using private cars is considered. Two agent-based models are going to be used in this research: MASS-GT (de Bok & Tavasszy, 2018) and MATSim (Horni et al., 2016). The synthetic population's daily activity schedule is provided by ALBATROSS (A Learning-Based Transportation Oriented Simulation System), developed by Arentze and Timmermans (2004). These two platforms provide the activity schedule of the agents in MATSim and have the potential to be used as an input for MATSim to run the simulation. Two scenarios of the last-mile delivery system; only traditional van deliveries (base scenario) and the scenario of the van deliveries with the addition of crowdshipping (crowdshipping scenario) will be formulated and compared. From the MATSim simulation, the vehicle.km driven by both the vans and private vehicles and carbon emission produced in the study area will be observed and used as key performance indicators (KPIs) of the simulation. The workflow of this research is visualized in Figure 1.

Figure 1 The research workflow



1.2 Problem definition

1.2.1 Research objectives and relevance

Various studies have studied the crowdshipping concept from various perspectives. Most of the research focused on the factors for adopting the crowdshipping in the population, for instance, the willingness to pay, willingness to work, what are the factors that need to exist on a crowdshipping platform, matching algorithm between the supply and demand side of crowdshipping, etc. While numerous findings strengthen the idea of crowdshipping and its feasibility to be implemented, the impact of crowdshipping on the local vehicle movements and its consequences to the local carbon emission is yet to be explored. Therefore, the main objective of this research is to **determine the impact of the interaction between urban freight and passenger transport in the form of car-based crowdshipping in the city centre of The Hague, The Netherlands, on the local vehicle mileage and the resulting carbon emission.** ABM simulation approach is used to mimic the behaviour of the logistics service providers and the passenger transport in the study area, which is explained further in detail in Chapter 3. Furthermore, the two ABM frameworks that are used in this research have the potential to be integrated into a framework and this research provides the integration between the two, allowing for the output of one model to be used as an input for the others.

Crowdshipping works by utilising the travelling crowds as the couriers to deliver parcels (Arslan et al., 2018). In this study, the travelling crowds are represented by the person-agents, travelling throughout the day to do their activities in various locations. Meanwhile, the parcels in this study are generated synthetically and delivered in general by the parcel van agents. The interaction between passenger transport activities with the local last-mile parcel delivery transport will be captured by crowdshipping as a case study and limited to the crowdshipping that is performed with private cars, in addition to the regular van delivery services. Moreover, only crowdshipping for the same-day delivery service will be considered. Further assumptions used are explained further in Chapter 5.

This research will contribute to the development of crowdshipping as a developing sustainable last-mile delivery innovation. Furthermore, this research will also contribute to the studies in sustainable urban freight transport. The results from this research could also be useful for LEAD, a project on the sustainable urban mobility of the future funded by the European Union.

1.2.2 Research questions

Considering the research objectives, the main research question can be derived. The main research question of this research is:

What are the impacts of car-based crowdshipping on the local vehicle mileage and its results on the local carbon emission production caused by the transportation activities?

This study focuses on the crowdshipping activities that are performed by private vehicles, specifically private cars. The impact of car-based crowdshipping is measured by conducting an agent-based modelling study of the study area with the condition of with and without crowdshipping. The car-based crowdshipping in this study also represents the interaction between urban freight and passenger transportation.

To help answer the main research question, several sub-questions are formulated, namely:

SQ1. What are the factors that influence the adoption of crowdshipping?

To determine the effect of crowdshipping as the interaction between urban freight and passenger transportation, the relevant underlying theories behind crowdshipping must be explored. A literature review on crowdshipping will be done to answer this research question. The definition of crowdshipping and the factors that can influence the success of crowdshipping implementation will be done as well. The factors and the state of crowdshipping will be used as the model input (SQ3) and to formulate the scenarios (SQ4).

SQ2. How could crowdshipping as the interaction between urban freight and passenger transport be simulated?

This study aims to model crowdshipping as the interaction between urban freight and passenger transport to answer the main research question. This research question will be answered by exploring the two agent-based modelling frameworks that will be used, MASS-GT and MATSim. The relevant theories, modules, and the input needed for both frameworks will be discussed in this study.

Both ABM frameworks (MASS-GT and MATSim) are not integrated yet. Within this research, a conceptual model for the integration between the two will be formulated and implemented to better represent the interaction between the two transport systems. The output of MASS-GT will be used as an input for MATSim for the freight transportation model, and thereby, integrating both frameworks. The passenger travel diaries data are obtained from the output of ALBATROSS. The result will be both transportation systems, loaded on the network. The integrated model then will be run using the crowdshipping parameters found in SQ1 to represent the interaction between the two transport systems.

SQ3. What are the possible scenarios of crowdshipping implementation in an urban area?

To capture the impact of crowdshipping in the integrated model developed in SQ2, scenarios need to be formulated to compare the results. In general, two kinds of scenarios will be formulated in this study, a base scenario that picturises the existing condition without the adoption of crowdshipping, and crowdshipping scenarios to represent the adoption of crowdshipping. The input parameter (SQ1), will be implemented in the integrated model (SQ2) with different values, depending on the scenario.

SQ4. How to measure the local vehicle mileages and the resulting carbon dioxide emission from the simulation results?

The output of the resulting integrated model (SQ2) provides the simulation of both transportation activities on the defined network on a disaggregated level. One of the most important outputs that could be obtained is the total passenger-kilometres travelled observed in the study area. The scenarios (SQ3) developed will be run in the integrated model to measure the impact of car-based crowdshipping. Two key performance indicators (KPIs) will be defined to measure the impact of car-based crowdshipping in terms of the local vehicle mileage and carbon dioxide emission.

1.3 Methodology

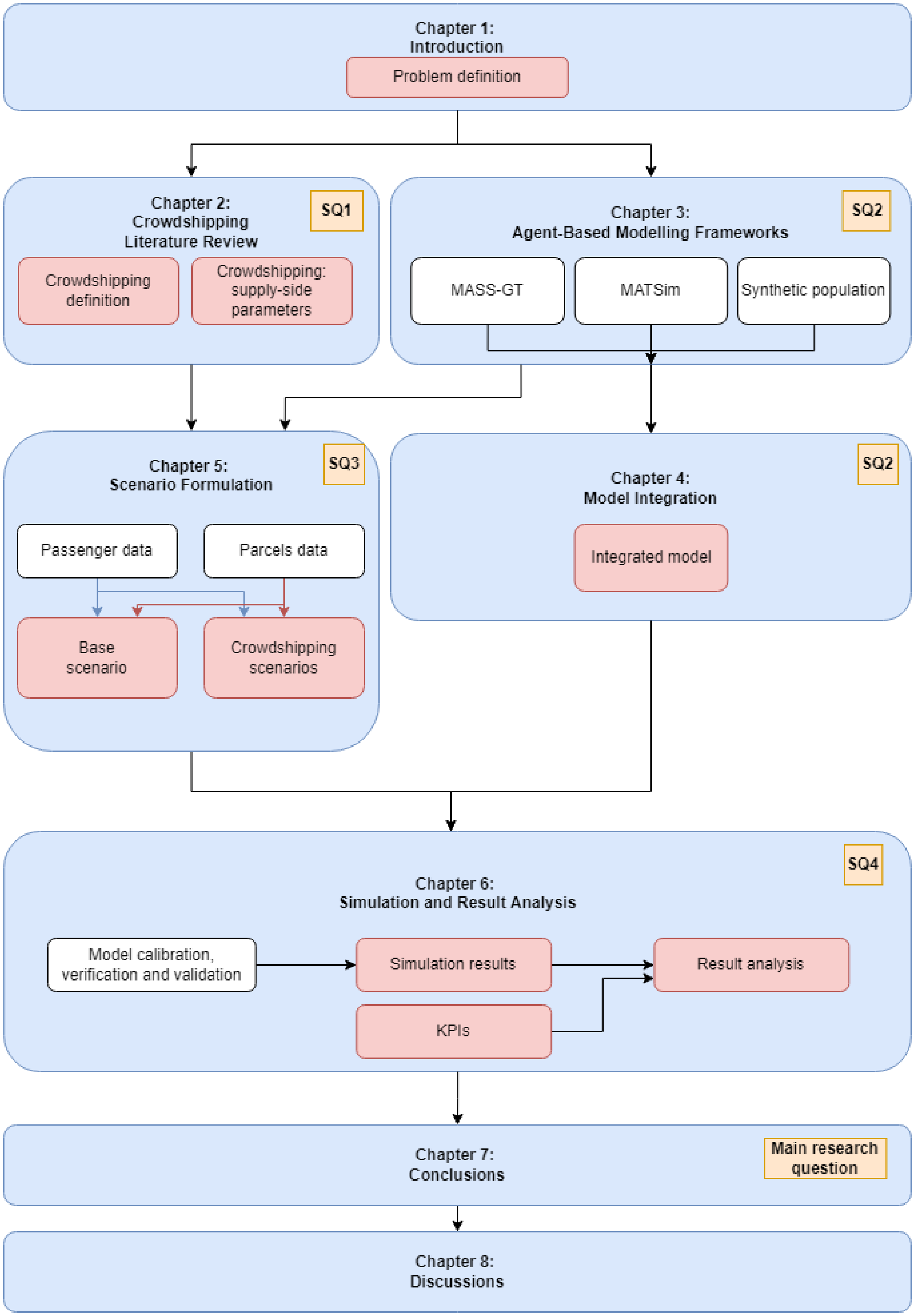


Figure 2 Methodology – research workflow

The methodology used and the workflow of this research are presented in Figure 2. The blue boxes in Figure 2 are the chapter of this thesis. The process done in each chapter is represented by the smaller boxes in each blue box, while the orange box on the corner of each blue box is the research questions answered in each chapter. The red box inside each chapter is the deliverables or the results of the process that takes place in each chapter.

In the first chapter, the problem is formulated, and the research questions are derived from the problem. The first sub-question is about understanding crowdshipping and its implementation. To understand how crowdshipping works and the factors that influence it, the literature review is performed in chapter 2 to answer the first sub-question.

The following sub-question is then about how to model crowdshipping in a simulation environment. Chapter 3 answers this sub-question by identifying the components of the agent-based modelling frameworks used in this study, MASS-GT and MATSim. It is interesting to integrate these two frameworks to capture the interaction between urban freight and passenger transport since that is one of the main goals of this research, assessing the impact of the interaction. Therefore, in Chapter 4, the two models are integrated with an integration framework and implemented in the real modelling, and consequently, covered the sub-question 2.

To run the integrated model, scenarios are needed to compare the scenarios with and without the existence of crowdshipping. To do so, the scenarios are formulated in Chapter 5 by considering knowledge obtained about crowdshipping from Chapter 2 and the model input requirement found in Chapter 3. These scenarios formulated subsequently answer the sub-question 3.

Finally, the scenarios formulated are simulated in the integrated model developed earlier in Chapter 4. The results from the scenario simulation are compared to analyse the impact of crowdshipping and are presented in Chapter 6. The KPIs to analyse the model are also defined in this chapter and sub-question 4 is answered by this chapter.

This research is closed with the conclusions presented in Chapter 7 in which the main research question is answered. Finally, in Chapter 7: Discussions, the results, limitations, and recommendations for further research are presented.

2 – Crowdshipping: Literature review

In the previous chapter, the problem is formulated. To answer the first sub-question, a literature review on crowdshipping to identify the definition and the factors that might influence crowdshipping is done in this chapter.

2.1 Crowdshipping: what and why?

Last-mile delivery is a pivotal segment of the whole supply chain of a product, and it affects the relationship between retailers and customers heavily (Devari et al., 2017). Since it is still one of the segments in which bottlenecks in the supply chain occurs (Wang et al., 2016), innovations that can enable better operational efficiency while reducing the costs at the same time are needed (Devari et al., 2017). Furthermore, LMD transportation activities are still facing various problems, from causing negative impact to the environment, the high number of unattended deliveries, and still not economically efficient (Punakivi et al., 2001). Crowdshipping emerges as one of the innovations that could potentially fulfil those requirements and address the issues in LMD (Rougés & Montreuil, 2014).

Crowdshipping is built upon the idea of sharing economy and is expected to increase the efficiency and sustainability of urban freight transport (Marcucci et al., 2017). Crowdshipping works by outsourcing the logistics services to the crowd instead of the commercial couriers (i.e., FedEx, DHL), connecting them through a platform using smartphone apps that enable instant communication and integration of end-to-end information, and giving monetary benefit to both parties involved (Devari et al., 2017). The occasional couriers that participate in crowdshipping are the people (or 'crowd') that already have an initial origin and destination and will take a detour along their route to pick up and drop off the parcel (Punel et al., 2018). In the scheme of crowdshipping, the service provider company acts as a mediator, providing the IT platform to track communication, manage data, and provide payment gateway for parties involved (Mehmann et al., 2015). Crowdshipping can be done using various modes of transport, from private motorized vehicles (i.e., cars, motorcycles), bicycles, public transport, and walking. Table 1 provides a few crowdshipping cases that have been adopted in the world.

Table 1 Examples of adopted crowdshipping cases

Source	Provider	Description	Country
Gatta et al., 2019	Walmart	Offered same-day delivery for the online customer using a professional fleet and in-store customers as an occasional courier.	USA
Rogués and Montreuil, 2014	DHL MyWays	Commuters that are willing to deliver the package as occasional couriers and the customers are connected through an online platform.	Sweden
	Deliv	Customers can place orders from home and can choose the delivery time of their choice.	USA
Gojek, n.d.	GoSend	The occasional couriers are motorcycle riders, connected through a platform that enables tracking. Customers can choose the level of time urgency of the delivery so that they can choose a suitable price.	Indonesia
van Cooten, 2016	Trunkrs	Car commuters as occasional couriers, picking up parcels from the filling stations and delivering them to the customer along their route home.	Netherlands

Today, most crowdsourced delivery services are exploring the market of food delivery service (i.e., Postmates, Doordash, Grubhub) and grocery delivery services (Walmart, Aldi, Flink), with more and more companies start to explore the usage of crowdsourced delivery in another sector as well, mainly in retail logistics, experimenting the implementation of the same concept to offer same-day delivery service (Galkin et al., 2021). This innovative concept attracts the interest of logistics giants such as DHL and FedEx, which explore the possibility of utilising the crowd to deliver goods (Rogués and Montreuil, 2014).

There are numerous advantages that crowdshipping could offer. Crowdshipping relies on the travellers as the occasional couriers, hence, the number of trips can be reduced, which consequently reduce the traffic congestions as well (McKinnon et al., 2011). The delivery request in the crowdshipping is handled at an individual level, so, the customers could choose the delivery time that suits their preferences (Punel and Stathopoulos, 2017). Moreover, with the reduced number of trips, the crowdshipping have a less negative impact on the environment by having fewer fuel consumptions in cars and CO2 emission, as was shown by a trial study case in Finland done by Paloheimo et al. (2016). This LMD method also has the potential to bring economic benefits for both parties, senders, and receivers, especially for the faster delivery service, particularly same-day deliveries (Arslan et al., 2018). This is due to the utilisation of occasional couriers, which costs less compared to the professionals (Pakarti & Starita, 2019).

Despite the advantages, there are still concerns that need to be addressed. There is a possibility of the rebound effect, in which the travellers generate more distance per vehicle instead of satisfying the shipping demand (Paloheimo et al., 2016). This rebound effect, especially if caused by an increasing number of motorised vehicles used as a means for dedicated crowdshipping could potentially negate the environmental benefits of crowdshipping (Gatta et al., 2019). Furthermore, there are also concerns on safety in crowdshipping, since the higher the value of the delivered goods is, the risk of the courier, a random unknown person in the 'crowd', stealing it may be higher (Zhang et al., 2020). Based on that subject, Varshney (2012) did a study to propose a mathematical model, determining the threshold and how certain people would take the trade-offs between privacy, reliability, and cost.

2.2 Challenges of implementing crowdshipping

In implementing crowdshipping, various challenges need to be overcome. Matching the supply and demand of the crowdshipping is a challenging task. The order for crowdshipping could be scattered around a city, the same goes for the couriers. Various studies tried to find the most efficient way to run the crowdshipping from the delivery routing problem perspective. Arslan et al. (2018) investigated crowdshipping from the delivery routing optimisation perspectives. This study showed that by optimising the unused capacity of a vehicle, taking a small detour to deliver a parcel and paid with small compensation will bring more economic benefits compared to traditional delivery. This study found that crowdshipping will be most beneficial when used in addition to the traditional dedicated delivery service. Moreover, Arslan et al. (2018) argued based on their study that crowdshipping done by the in-store customer to deliver the parcel to the online customer along their route is the most suitable form of crowdshipping, as was explored by Walmart (see Gatta et al., 2019). Wang et al. (2016) studied the crowdshipping model in a network of pick-up points and modelled them as an assignment optimisation problem, to be solved using min-cost problem (minimising the total compensation fee paid to occasional couriers) and found that the crowdshipping is a potential method that could be implemented for handling real-time delivery request in the large scale.

Besides the routing problem, pricing strategy is a vital aspect that needs to be considered in crowdshipping. The pricing strategies of crowdshipping need to be determined for both the customers and occasional couriers. Numerous studies have been done to determine the most attractive pricing strategies in crowdshipping. Many argued that crowdshipping is more cost-efficient compared to the traditional delivery service in terms of 'instant' delivery (within 1 to 2 hours) and same-day delivery (Lozza, 2016; Arslan et al., 2018). Several precedent pieces of research argued that bidding is the most suitable pricing strategy for crowdshipping (Kafle et al., 2017; Punel & Stathopoulos, 2017). Ermagun & Stathopulos (2018) concluded in their study that the bidding strategy will be most suitable for B2C crowdshipping, with the environment and socio-economic characteristics of the domain area play the most important role in securing the supply of the crowdshipping. This bidding strategy is heavily affected by the parcel characteristics as well. On the other hand, there are also other pricing strategies, such as "membership-based pricing", "transaction-based pricing", and "cross-subsidisation" (Kung & Zhong, 2016).

To understand the nature of crowdshipping, simulation studies also have been done previously. Simoni et al. (2019) assessed the last-mile impact of crowdshipping through a hybrid dynamic traffic simulation. Their study considered the macroscopic features of traffic (congestion, spillbacks, and interaction with traffic signals) and combined them with the microscopic features of the delivery operations (tracking each delivery vehicle individually). Moreover, the model is applied to see the impact of same-day delivery using the traditional delivery method and crowdshipping using cars and public transport. The result underlined strongly that the mode chosen to perform crowdshipping is crucial to gain the most benefit in terms of sustainability. While public transport-based crowdshipping is deemed to be beneficial for the city, both in lowering the emission and reducing the traffic, car-based crowdshipping's impact is still yet to be known. Furthermore, the externalities impact such as vehicle kilometres travelled (VKT), congestion, and emission of car-based crowdshipping are not explored thoroughly (Pourrahmani and Jaller, 2021).

Another means of transport that can be used for crowdshipping is the bicycle, as was analysed by Binetti et al. (2019). They concluded that using bike-sharing systems for crowdshipping will provide feasible support for the local postal service. Guo et al. (2019) analysed the feasibility of integrating crowdshipping with traditional delivery services using a simulation approach. It can be concluded from their research that by integrating these two last-mile delivery methods, there is a potential to improve the economic and environmental benefits of last-mile delivery. The agent-based simulation was also used by Chen and Chankov (2017) to analyse the potential performance of crowdshipping in terms of service level and assets utilisation. The simulation showed that with the higher supply/demand ratio, the higher probability that there will be competition amongst the occasional couriers to pick an order, while simultaneously reducing the detour distance per courier. However, the higher supply/demand ratio does not necessarily mean an increase in the number of parcels delivered per courier. Since there might be a shortage of crowd couriers available according to the simulation, Chen and Chankov (2017) suggested that it is of good interest for the crowdshipping company to provide extra compensation fee for increasing the courier's willingness to take more detours, which thereby will increase the total delivery capacity.

2.3 CS Acceptance – Study case in Rome

Considering the advantages and concerns of crowdshipping, Marcucci et al. (2017) and Gatta et al. (2019) conducted studies on the potential of using crowdshipping in Rome. Marcucci et al. (2017) surveyed the students in Rome, Italy on the prerequisite requirements for crowdshipping to be successfully adopted in an urban area. It was found that the acceptance of the idea of crowdshipping is relatively high in Rome. 87% of the respondents are willing to act as crowdshippers if the parcel size is small (shoebox size), with monetary incentives of 5-10 euro per delivery, average maximum detour distance of 2.4 km (or 21% of the actual trip distance), and a proof that the crowdshipping is actually a sustainable method. However, this is relatively deviating from the real application of crowdshipping, in which the monetary incentives are averagely 2-4 euro per delivery and the average urban crowdshipping distance varies from 8 to 30 km. They also found that 93% of the respondents would be willing to use the crowdshipping service if the crowdshipping company and the crowdshippers could be contacted and if the package tracking service is available. In contrast, the crowdshippers highly value their privacy and are unwilling to be traced (57% of respondents).

Gatta et al. (2019) explored the possibility of adopting public transport (PT)-based crowdshipping, with the commuters acting as occasional couriers using stated preferences survey and applied further in multinomial logit model (MNL). The survey was conducted on the metro users and inhabitants in Rome to determine the potential supply and demand of the PT-based crowdshipping, respectively. The underlying idea is to utilise the commuters as occasional couriers, delivering a package for the customers from a package pick-up location in metro stations to their respective places. According to the MNL developed, it was found that the most prominent factor influencing the supply side is the accessibility to the pick-up locations of the package, with the compensation fee of 3 euro per delivery (compared to 1 euro per delivery) paid to the couriers per single delivery is preferred. For the demand side, the most attractive factor of crowdshipping is its capability to provide flexible delivery time scheduling. The respondent of the survey also preferred if the crowdshipping service provider could offer parcel tracking with a lower shipping fee. The survey shows that the potential customers and couriers prefer to use the crowdshipping most in the afternoon by 17:00 (38%) and evening by 21:00 (33%). These findings are in line with the result of studies conducted on determining the demand and supply side of crowdshipping, which are presented in the next chapter (2.2).

2.4 Supply and Demand of Crowdshipping

Le et al. (2019) identified crowdshipping from the supply and demand perspective. The supply means the actor that perform the crowdshipping activities, the crowdshippers. On the other hand, the demand is defined as the people that use the crowdshipping service, hence, the customers. These two sides of the crowdshipping will be discussed in the two following sections.

2.4.1 Supply

The *supply* side of the crowdshipping is represented by the occasional couriers (or crowdshippers) that will get monetary incentives in return for their service. These crowdshippers can access the crowdshipping platform, for instance, a mobile app, and find a delivery demand (Le et al., 2021). Since the majority of these couriers are participating in the crowdshipping market voluntarily, their availability and willingness-to-work (WTW) would heavily influence the *supply* side of the crowdshipping. The WTW of the occasional couriers is mainly influenced by the monetary incentives, good working environment, and good platform operation (Buldeo Rai et al., 2018). Moreover, the size of the parcel also affects the willingness of the courier to deliver it (Punel et al., 2018). According to the study conducted in the USA, commuters that are travelling for leisure purposes or the travellers with more flexible schedules are the most likely to be the occasional drivers (Miller et al., 2017).

The courier's ETP (expected to be paid) value is one of the major drivers of the WTW. Le and Ukkusuri (2018) found in their study in the USA that the majority of potential occasional couriers are expected to be paid $10 or less for a delivery. Their study also found that the potential occasional couriers are willing to work at most times, except weekend evenings or every day after midnight. The ETP value as was found by Le and Ukkusuri (2019) are around $12 per hour. Marcucci et al. (2017), as were discussed in the previous section, concluded that most of the surveyed students in Rome are willing to be the crowdshippers with 5-10 euros per delivery with the maximum detour distance of 2.4 km. Another evidence from the Netherlands shows that the car-based travellers are willing to be the crowdshippers if they were paid 19.6 euros per hour and the bicycle-based travellers with 24 euros per hour increase in travel time (Miller et al., 2017; Wicaksono et al., 2021). Berendschot et al. (2021) used 2.32 euros as the average compensation for the crowdshippers as an input for their model, and this number is still lower compared to the traditional delivery service of 3.35 euros per delivery. The results of the study conducted by Neudoerfer et al. (2021) shows that most respondents are willing to make deliveries for 10 euros per hours in return, with the monetary incentives paid changes by either delivery distance or parcel dimensions. This study also found that most potential couriers are willing to make detours up to 2 km from their original route, similar to the study in Rome has shown.

Galkin et al. (2021) explored the relationship between the potential crowdshippers' age with their willingness to work in Bratislava, Slovakia. Their research shows that with increasing age, the more reluctant they are to perform crowdshipping and would spend their time for a more socially important work instead. Therefore, a productive working age is preferred for the crowdshipper. According to OECD (2021), the prime working or productive age ranges from 22 to 55 years old. From these two literatures, it can be concluded that the most probable age range for potential crowdshippers is from 22 to 55 years old.

2.4.2 Demand

The *demand* for crowdshipping is generated by the individuals in the crowd, taking the role of senders and receivers of goods (Le et al., 2019). These individuals could be in the form of (electronic) retailers, logistics businesses, or even the individuals themselves (Buldeo Rai et al., 2017). The form of the individuals will affect the context of crowdshipping itself, namely: business-to-business (B2B), business-to-customer (B2C), and peer-to-peer (individuals to individuals). Considering the crowdshipping's demand is dependent on the crowd, the network flow of the crowdshipping is the result of matching the sender's location with the courier's planned routes (McKinnon, 2016). The customers' demand for crowdshipping seems to be mainly affected by the usability of the platform and trust towards it (Frehe et al., 2017). Furthermore, the demand is also affected by the quality of the delivery provided (i.e., personalized, punctuality, undamaged parcel condition) and the environmental benefit factor of the crowdshipping (Buldeo Rai et al., 2018).

Punel et al. (2018) conducted research on the potential of crowdshipping usage relative to the socio-demographic characteristics in the US. The result of their study shows that individuals with an income of $59,000 (higher than the average of the US populations' household income) or more would be less likely to use the crowdshipping service. On the other hand, those who work full-time would be more likely to use the crowdshipping service because they might lack free time, especially during business hours.

2.5 Potential market share of Crowdshipping

As the literatures have shown, crowdshipping will be best used as a complimentary means of delivery, instead of as the replacement to traditional van delivery. A study conducted in the Netherlands by Berendschot et al. (2021) shows that th\ere is a potential for crowdshipping to handle 6% of the total parcel volume in an urban area. Another study from Delft, the Netherlands, shows that bicycle-based crowdshipping could even reach 14-26% of the parcel deliveries market share (Wicaksono et al., 2021). No prior studies on the potential market share of car-based crowdshipping is found. Although this study focus on car-based crowdshipping activities, to generalise, the potential number of 10-30% market share for car-based crowdshipping out of total logistics flow will be simulated and analysed in MATSim.

2.6 Impact of Crowdshipping on Externalities

Crowdshipping relies on the road transport system on either side, passenger transport and traditional parcel delivery, and often, it will bring externalities impact. Externalities in road transport include traffic congestion and the environmental impact caused by the transport activities themselves (Santos et al., 2010). Numerous research emphasised on the environmental impact of crowdshipping since that is the major focus on the last-mile delivery development in recent years. The existence of crowdshipping could be a boomerang to the system itself, depending on the mode used, crowdshipping could either increase or reduce the traffic congestions and CO_2 emission produced by the transport system (Rai et al., 2017). The evidence from the literatures showed that if performed using a sustainable mode, crowdshipping will potentially reduce the congestion level and consequently, the CO_2 emission could be decreased (Rouges and Montreuil, 2014; Rai et al., 2019). However, increasing supply and demand of crowdshipping can lead to an increasing transportation demand, and consequently, increase the vehicle traffic in a city.

One of the root cause for the additional traffic is in the inefficiency of crowdshipping in consolidating the parcels, since most crowdshipping trips dedicate a single trip for a single parcel. Traditional parcel delivery companies could consolidate the parcel demand before dispatching the van from the depot, while crowdshipping, relies on the free capacities in private vehicles to deliver one parcel at a time (Rai et al., 2019). Consequently, the parcel delivered by the traditional delivery companies would require fewer trips to deliver the parcels compared to the crowdshipping service. It can be concluded that the externalities impact of crowdshipping depends heavily on the chosen transport mode.

Alho et al. (2020) evaluate the last-mile impact of cargo-hitching, applied to mobility-on-demand (MOD) services, which is similar to crowdshipping, using a simulation approach. One of their findings shows that by implementing the "crowdshipping" to the MOD vehicles, the VKT of both transport activities (MOD and freight transport) could be reduced by 2%. In another study conducted by Ballare and Lin (2020), it was found that the combination of crowdshipping with microhubs could significantly reduce the VKT of parcel vans in an urban area.

2.7 Chapter Overview

Most of the crowdshipping literatures reviewed emphasised that crowdshipping could bring both positive and negative impacts to the existing condition. Crowdshipping could potentially reduce the carbon emission produced by the last-mile delivery system, but it is bounded by the crowdshippers' mode of choice. Most of the prior studies focus on crowdshipping performed by sustainable transport mode such as bicycle, walking, or public transport (Binetti et al., 2019; Gatta et al., 2019; Wicaksono et al., 2021). Yet to be explored thoroughly is the impact of car-based crowdshipping on the externalities (Pourrahmani and Jaller, 2021). From the literature review, a knowledge gap can be identified: **the externalities impact of car-based crowdshipping**. To what extent the car-based crowdshipping will either reduce or increase the externalities, such as vehicle mileage and CO_2 emission produced is yet to be explored and will be answered in this research.

The chosen transport mode is a part of the traveller's choice, which are on the supply-side of crowdshipping. The findings on the supply-side of crowdshipping are presented in the following Table 2. To assess the impact of car-based crowdshipping, one of the methods that can be used is simulation. The chosen simulation platform is explained in the following chapter. These findings presented are useful for running the simulation. How these characteristics of crowdshipping will affect the vehicle mileage and resulting CO_2 emission will be analysed from the simulation result, presented in Chapter 6.

Table 2 Summary of factor influencing crowdshipping – supply side

Criteria	**Findings**	**Sources**
Age	22 to 55 years old	Galkin et al., 2021; OECD, 2021
Trip purpose	More flexible activity	Miller et al., 2017

Compensation	Lower than traditional van, 1.5 – 3.35 euros	Autoriteit Consument & Markt, 2020; Berendschot et al., 2021
Acceptable detour	2 to 2.5 kilometres	Marcucci et al., 2017; Neudoerfer et al., 2021
Potential market share of crowdshipping	• 6% • 14 – 26%	• Berendschot et al., 2021 • Wicaksono et al., 2021

3 – Agent-Based Modelling Frameworks

In the previous section, the research gaps of this research and the relevant key parameters of crowdshipping are found and summarised from the literatures. This research intends to fill the gap by doing an agent-based modelling study of crowdshipping as the interaction of urban freight and passenger transport. Two ABM framework is used in this study, MASS-GT and MATSim

3.1 Agent-Based Modelling

Simulation models are often used in understanding the real world in both descriptive and predictive contexts by mimicking the landscape of the real world in a simulated artificial environment called virtual reality (Chen, 2012). Simpson (2001) stated that: "The combination of virtual reality, spatial modelling, and GIS, integrated into a real-time urban simulation, will allow questions to be asked that were not possible before, and better yet, answers to those questions". One of the simulation approaches that enable the modelling of complex processes and social phenomena is agent-based modelling (ABM). ABM is characterised by the existence of autonomous agents, a computational system that is situated in an environment that is capable of making their individual decision based on the predefined sets of goals (Maes, 1995; Jennings et al., 1998). ABM framework is built from the bottom up, meaning that it is a tool to understand a complex system by considering the behaviour of the smallest entities in the environment, in this case, agents themselves. (Chen, 2012). These agents have two key properties: autonomy and social ability (Chen, 2012). The autonomous characteristic means that the agents can operate, carry out the predefined instructions, and make decisions on their own (Hayes, 1999). The social ability means that the agents are able to interact with other agents in the environment to carry their tasks and involve in helping other agents' tasks (Jennings et al., 1998). With these characteristics, the ABM approach is deemed to be suitable for the application in socio-related studies, including urban transport studies (Chen, 2012).

3.2. MASS-GT

Simulation models are sometimes used as a tool to assess strategic decisions in freight transport policies; however, most operational models do not have sufficient behavioural detail to simulate the impacts of developments in logistic services, policy measures, or planning scenarios in a representative and satisfying manner (de Bok & Tavasszy, 2018). MASS GT is an agent-based logistics simulation model for freight transport in the Netherlands as was developed by de Bok and Tavasszy (2018) using a large dataset with observed freight transport data in The Netherlands. This model is built upon three main principles: commodity-based approach, representing agent-based decision making explicitly, and implementing empirically tested choice model. In this simulation model, there are entities entitled as agents: producing firms, consuming firms, shippers, own account carriers and third-party logistics (carriers), and policy makers.

In several models, shippers and carriers are sometimes distinguished explicitly, but the characteristics of shippers are often neglected. On the other hand, shippers can be classified into two types: shippers that organise the transport themselves (own account carriers) and giving the responsibility to organise the transport to outsourced entities, third party logistic service providers (3PLs). A distinction between these two parties is important since the characteristics of these two shippers could affect their decision-making. For instance, the 3PLs could provide shipments consolidation possibilities between different sender-receiver combinations, which would affect the transport and distribution-related choices.

3.2.1 Markets and agents in MASS-GT

There are four markets observed in the MASS-GT framework. First, the commodity market in which the sourcing process - interaction between the producers (senders) and consumers (receivers) - are observed.

Second, the logistic services market. In this market, the organisation of distribution structures and warehousing takes place. Typically, 3PLs serve this market, however, it could also be served by the own account carriers, especially for large companies. The logistic decision that takes place in this market is the network design, distribution centres location and selection, warehousing, and storage, and determining the packaging/shipment size.

The third is the transport market where the transportation of goods is organised. This market is typically served by both shippers (3PLs and own account carriers). The logistic decisions in this market are the selection of carrier, mode choice, vehicle type choice, and routing and scheduling choices.

The last market is the infrastructure market, which defines the supply side of the transportation market. The infrastructure networks and traffic flows defined in this market will affect the transport times and route choices of the shipments. Other transport cost-related factors such as reliability, or parking facilities on the loading/unloading activities are also defined within this market. The decision making in this market is handled by the policy market, which includes pricing measures, infrastructure investments, environmental zones, subsidies, and zoning schemes. Their behaviour is defined as the input to the model and not simulated explicitly.

Within those aforementioned markets, agents interact and make decisions on their problems. Figure 3 pictures the conceptual model of MASS-GT. We can distinguish several agents that are considered in this model. Generally, some agents are active in one or more markets, including producers, receivers, shippers, carriers, own account carriers, and 3PLs. Furthermore, as was mentioned in the previous paragraph, policy makers are also considered as an agent in this conceptual model. It can be observed that the agents could be one and the same person, for instance, shippers can be both the producer and consumer of goods. The same duality could also be observed in carriers: the transport could be handled by themself (own account carriers) or by 3PLs. This duality needs to be distinguished and defined correctly so that the model could translate the agent behaviour precisely. summarizes the agents, markets, and logistics choices in the conceptual model for MASS-GT.

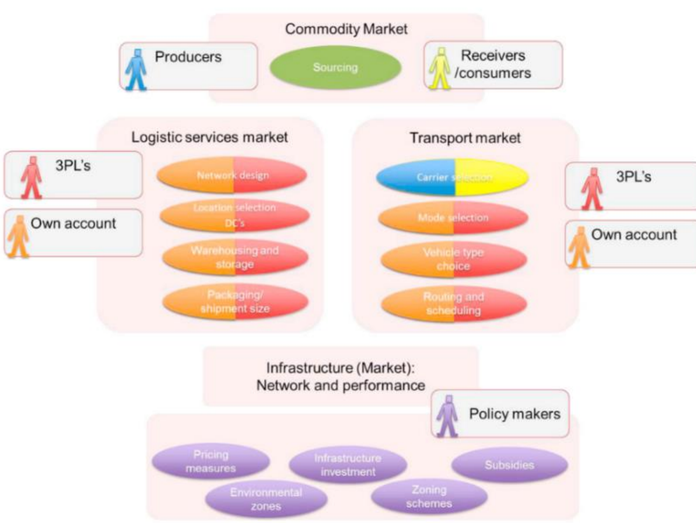


Figure 3 Agents, markets, and logistics choices in the conceptual model for MASS-GT (de Bok &

3.2.2 Shipment modules

Shipment modules of MASS-GT have a modular structure, consisting of three models: Shipment synthesizer, Tourformation, and Network module. The main outcome from this modular structure is the freight tour patterns that can be assigned to the urban network. These three modules will be explained in this subsection.

In this thesis, the shipment module of MASS-GT is not used because this study focuses more on the last-mile delivery, which is represented by parcels. However, the network module of MASS-GT is used for distributing the parcel demand and will be explained further in Chapter 4.

Shipment synthesizer

The shipment synthesizer module simulates the logistic processes at the strategic level, including sourcing, choosing distribution channels and shipment size (de Bok et al., 2020). The main objective of this module is to build a dataset of individual firm-to-firm shipments from an aggregate commodity flow matrix and disaggregate firm data from the bottom-up approach. MASS-GT uses an aggregate freight transport demand matrix, derived from a strategic freight transport demand model as input to simulate shipments between producing and consuming firms. This module will use the data as an input to simulate the shipment demand between the producer and consumers. The aggregated data are dissected into individual shipments in this module and allocated to the individual firms. Then, the make/use probability will be used for the respective producing and consuming firms, depending on the commodity type. The output of this module is a dataset with firm-to-firm shipments, consisting of the commodity type in the shipments and the firms' attributes, both the producing and the consuming parties.

Tourformation module

This module will include the logistical choices at the tactical level and assign the shipments to tours and vehicles (de Bok et al., 2020). The objective of this module is to build tour patterns from the shipments generated in the previous model, combined with observed tour statistics. The output of this module will be a dataset with urban freight tours, containing the commodity type, number of discrete shipments to be delivered, and the location and industry sector of sending and receiving firms for each shipment. This module uses the output from the shipment synthesizer module and combines it with the observed data. The logistics decision-making process of the corresponding agents will be simulated in this module, for instance, the tour start time and the decision in making extra stops in the tour.

Network module

In the second prototype of MASS-GT (de Bok et al., 2020), a new module of the network model was introduced. This module simulates the route choice of the logistics vehicles on a congested network, representing the choices at the operational level. The tour patterns simulated in tourformation module are translated into vehicle trip matrices, assigned into a congested network to determine the shortest path in the predefined generalised transportation costs. The network assignment approach used in this module is all-or-nothing assignment method. By assigning the simulated tour pattern to the network, the load of freight transportation on a link in the network could be observed.

3.2.3 LEAD Parcel modules

In recent years, the team from LEAD project (Kourounioti and Tapia, 2021) is developing a new market in MASS-GT, the parcel market. The parcel market is simulated using the LEAD Parcel Modules. The LEAD parcel modules are being used in this study to simulate the parcel-side of the model, before being implemented in MATSim.

Generally, the parcel delivery is modelled by two modules: **parcel demand module** and **parcel scheduling module**. The main output of these modelling processes are matrices consisting of the tours and trips of parcel deliveries. The process of how the parcel module works in detail is presented in Figure A.1 and Figure A.2 in Appendix A. For this thesis, a special module extension for crowdshipping assignment is also used. This subsection provides the concepts and description of each module used in this thesis. How these modules are adjusted and being used in this thesis are discussed in Chapter 4. The following Figure 4 visualises the process in the LEAD parcel module.

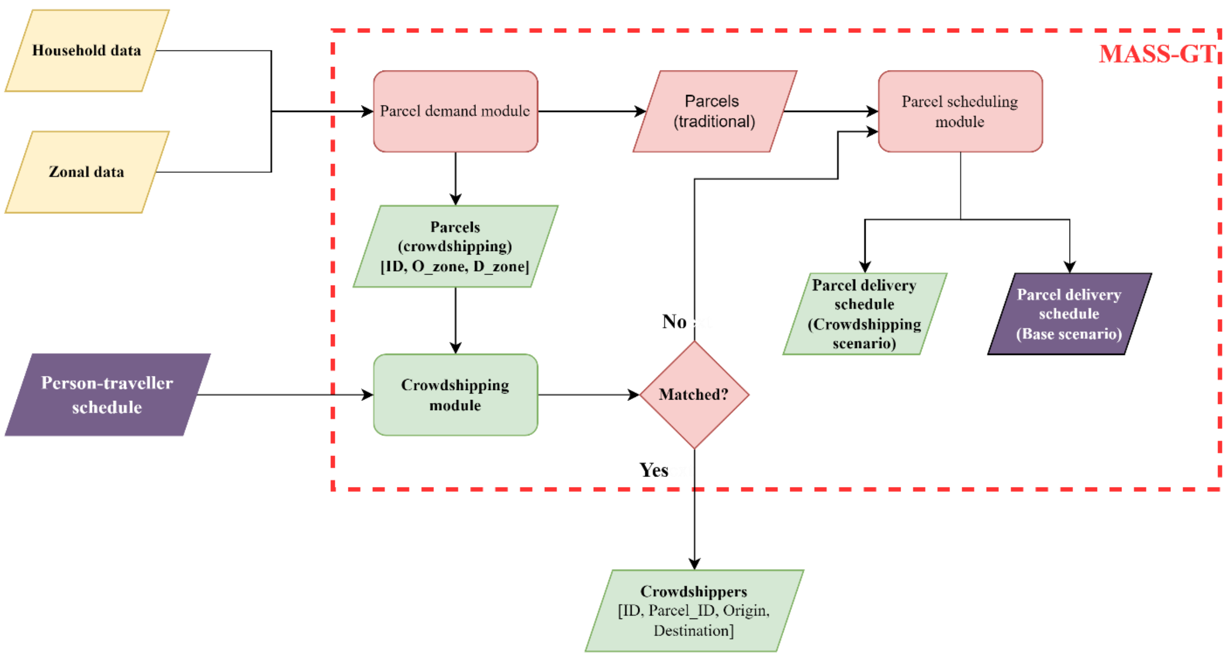


Figure 4 LEAD parcel modules (adapted from Kourounioti and Tapia, 2021)

Parcel demand module

This module uses the household data to generate the synthetic parcel demand. The parcel demand generated in this module is assumed for business to consumer (B2C) and business to business (B2B) purposes, with an average number of 0.288 parcels per household per day, derived from statistical market monitor data. The parcels will be distributed by companies of express and parcels (CEPs) in this module. The parcel demand generated and considered in this module and this study is assumed to be uniform in type and size.

This module will generate the number of parcels in the study area based on the number of households. Then, the generated parcel is assigned to the CEPs based on the market share. Afterwards, the assigned parcels will be assigned to a traffic analysis zone (TAZ), in which the CEPs will choose the nearest depot as the parcel origin. The output of this module is the parcels data, including its ID as well as its origin and destination zones. This parcel data then will be used as an input for the parcel scheduling module to simulate the distribution tours for parcel delivery. In the case of the crowdshipping scenario, a certain percentage of the demand generated are assigned to the person-traveller, representing occasional couriers delivering parcels in a crowdshipping scheme.

Crowdshipping module

The crowdshipping module provides a "hybrid" platform, in which a certain percentage of the parcels are assigned to a person traveller, obtained from the person-agents' activity schedule data. Generally, this module consisted of two steps: generating the crowdshipper supply and assigning the parcels to the available crowdshipper. In the first step, the person agent activity schedule is used as an input to the module. The activity schedule consists of trips of each agent throughout the day. The crowdshipping module then set the status of "CS_willingness" and "CS_eligible" which means willing to be a crowdshipper and eligible to be a crowdshipper, respectively. Then, the module calculates the travel time and distance between the origin and destination of each trip of the potential crowdshippers. Then, these trips are assigned to a crowdshipable parcel demand, generated in the parcel demand module, based on the minimum detour of the couriers. The output of this module is a matrix containing the matched parcel ID with a trip ID, and another matrix containing the data of the unmatched parcels. If a parcel is assigned to a crowdshipper, that particular parcel is removed from the parcel demand file so that it won't be assigned to the traditional van delivery schedule. On the other hand, if a parcel is unassigned to a crowdshipper, the data of the unmatched parcel is brought back to the parcel demand file, so that a delivery van will handle its delivery.

Parcel scheduling module

The generated demand from the previous module will be consolidated to create the delivery tour in this module. The parcels that are ready to be delivered are assigned to a specific depot, depending on proximity to the respective destination. Thereby each depot will have the list of parcels that it is storing. Then, more parcels will be added to the tour, based on the delivery location until it reaches the maximum number of parcels in a tour (180 parcels/vehicle). In case there are no more parcels that can be added to the tour, additional parcels will be searched from the other depots available. After parcels are already assigned to a tour, then they are assigned to an available vehicle with the start time of the tour derived from time-of-day distribution. The zone with the smallest proximity then is found using the travel time skim matrices between zones. If the number of parcels exceeds the vehicle capacity, the van will return to the depot and store the parcels in the depot. Then, the remaining parcels will be updated and assigned as new parcels that are ready to be delivered. After all parcels are already scheduled for delivery, then the tours and trips matrices will be formulated. In case of the crowdshipping scenario, the unmatched crowdshipping trips which were produced by the crowdshipping module are picked up by the traditional van in this module as well.

3.3 MATSim

In simulating transportation problems, especially in urban areas, the real world must be realistically represented in the virtual reality, incorporating the dynamics of the demand, traffic flow, and the fleets (Maciejewski & Nagel, 2013). Furthermore, incorporating an additional dimension of urban freight transport to the system will bring more complexity and conflicting objectives will emerge, such as balancing the logistics costs of an operation, environmental impact, and the traffic flow of the city (Maciejewski & Nagel, 2012). Multi-agent approach is a suitable method to solve those problems because of its capability to include all actors and components, along with their interaction and behaviours in such complex system, and these actors' decisions can be observed individually (Maciejewski & Nagel, 2012).

One of the most popular microscopic traffic simulations platforms is MATSim (Multi-Agent Transportation Simulation), due to its high computing speed and excels in modelling the behaviour in the trip planning (Maciejewski & Nagel, 2013). MATSim is an open-source disaggregate activity-based multi-agent transport simulation software, designed to handle large-scale scenarios (Horni et al., 2016). Horni et al. (2016), the developers of MATSim, described the software in their paper, elaborately. MATSim enables a single-day modelling of an activity-based transportation.

MATSim is built based on co-evolutionary principle, in which the agents' objective is to optimise their daily activity while competing for space-time slots amongst others in the transport infrastructure. While being relatively similar to the route assignment cycle, MATSim also incorporates time choice, mode choice, or destination choice into the iterative cycle, along with the route assignment.

3.3.1 MATSim iterative loops

MATSim iterative loop is consisted of several modules, namely: initial demand, mobsim, scoring, replanning, and analyses. A typical loop is presented on Figure 5.

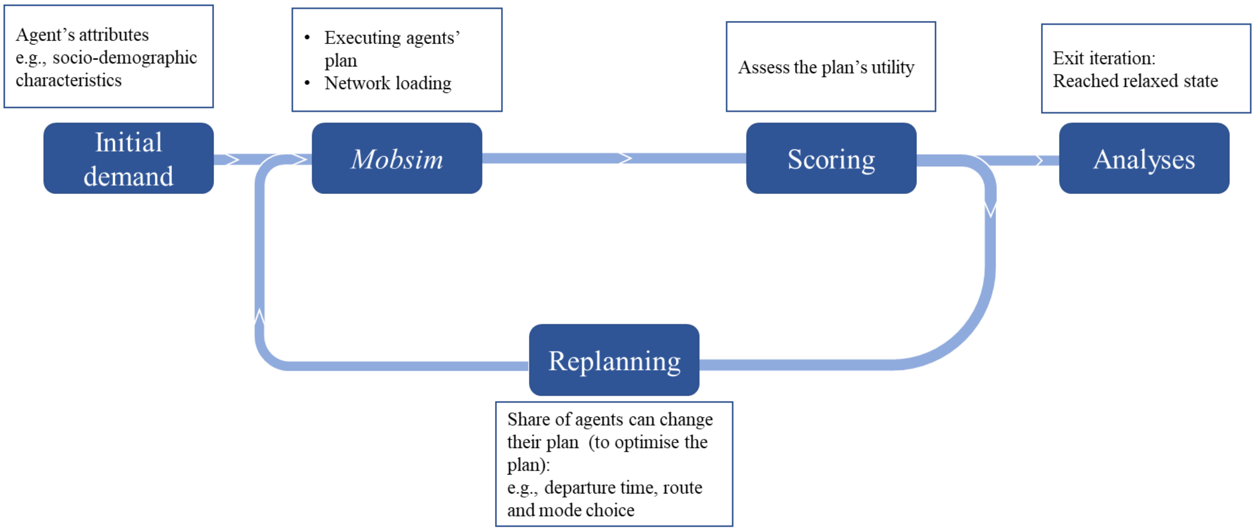


Figure 5 MATSim iterative cycle (adapted from Horni et al., 2016)

Initial demand will be formulated from the observation area populations' daily activities. The populations are consisted of agents, representing a person in real life. Each agent has the socio-demographic characteristics, representing that of real person, for instance, age, gender, occupation, home location, and private vehicle ownerships (Ciari et al., 2016). These agents have a memory, consisted of fixed number of day plans, and each plan is constructed of a daily activity chain (locations, times, and the activities agents will conduct) along with its respective score. The activity chains are derived from empirical data, obtained using sampling or discrete choice modelling. The locations of agents' activities are connected with legs, and within each leg, the agents will travel using a specified transport modal choice (Zilske et al., 2012).

The second step is *mobsim* or mobility simulation. Prior to this step, each agent will select a plan form its memory, depends on the score of the plan, computed after each *mobsim* run, considering the executed plans' performances. The selected plan then will be executed using queue-based traffic flow simulator (Maciejewski & Nagel, 2013). The queue-based model is based on the principle that a vehicle will spend time on a link that is equal to time moving end-to-end of the link and added with waiting time in a queue (Zilske et al., 2012). The links are represented in first-in-first-out (FIFO) manners with sets of parameters, for instance, the length of the link, free-flow speed, flow capacity, and storage capacity. Having the network loaded, this module will give a documentation of changes in the state of any object in the system.

Few agents (often 10%) can clone the chosen plan and modify the clone in replanning modules. The factors that are considered in this step are departure time (and activity duration), route, mode, and destination. This step is done in order for the agents to achieve a more optimal plan with higher utility score. The changes that can be made are among others, change their departure time, mode choice, and their routes (Ciari et al., 2016). There are several approaches to do the replanning, from random mutation to approximate suggestions to achieve the optimal choice. If an agent ends up with too many plans, then the plan with the least score will be removed from its memory.

The iteration then will be completed by assessing the agents' experiences within the selected day plans. This step is called scoring. The solutions that generate a high score will be selected by the agents and won't be removed during the replanning step. The iteration between plan generation and *mobsim* is repeated until the system achieve a relaxed equilibrium state (Ciari et al., 2016). The simulation in MATSim is generated stochastically, which means that the convergence criteria are not suitable in this case.

3.3.2 MATSim: Input

MATSim needs several necessary files to be used as the input. While the number of the input files needed depends on how the model scenario was designed, at the very least, MATSim needs 3 files to run a model, namely: **config file, population/plan file,** and **network file**. The config file keeps all of the configurations to run the model. The plan file of MATSim defines the agent's daily activity plan, structured hierarchically in an XML file. The plan file needs to contain at least the ID of each agent, activity purpose and the location coordinates of each activity, as well as the end time of each activity, and the transport mode used by each agent in each leg (Rieser et al., 2016). The network file defines the spatial boundary of the simulation and needs to be constructed in XML format as well. The three files that are constructed for this study is explained further in Chapter 4.

3.3.3 Previous applications of MATSim in transport studies

MATSim has been applied to numerous transport studies previously. Hörl (2016) explored the impact of a scenario in which shared autonomous taxis are deployed in a city could bring in urban traffic. He simulated the scenario in MATSim, while also adding an extension to the MATSim's Sioux Falls traffic network and introduced AgentLock framework to simulate dynamic agents to reduce the computational time. His study found that it could lead to an increase in overall milage, mainly caused by PT users switching mode to autonomous taxis. While it is beneficial from the environmental sustainability perspective, the traffic network is burdened even more compared to the base scenario.

Ciari et al. (2016) modelled carsharing strategies using MATSim. In their developed simulation framework, it was argued that the model is rather very detailed, enabling for the insights on how different operation strategies of carsharing would work and how the demand would be modified to be captured. The substitution effect within different modes and competition for the infrastructure among travel participants are explicitly modelled and captured. However, since MATSim models based on single-day time scope, the long-term effect of such innovation can't be captured, and therefore, out of the study's scope.

Jahn et al. (2020) explored the potential of using electric vehicles as a transportation mode to deliver freight in urban area of Berlin by determining possible charging strategies for the vehicles. In their model, each vehicle is observed individually, focusing on their state of charge (SOC) and the remaining tour lengths along their delivery route. The model showed the necessary number of charging stations to be opened in order for the electric vehicles to be used in urban freight delivery, particularly in food trade sector, and showed that implementing such vehicles in urban areas is technically feasible.

Zilske et al. (2012) added the freight traffic layer to the MATSim in their study. They introduced a new layer in the model, composed of *carrier agents* that represent a firm with fleets of vehicle, depots, and contracts. These agents represent a group, contrast to those of the person-agents that represent individuals. In the contract, the packages' quantity and type are defined, along with their respective origins and destinations. While the plan of a person-agent is composed of their daily activity chains, the firm-agent's plan is composed of the delivery tour schedule of each vehicle in the fleet, containing pick-up and delivery times and the route they will take throughout the network. Similar to the person-agent, the *carrier agents* also went through the MATSim's iterative cycle, executing and evaluating their plan in order to achieve a better utility. The distance travelled by the vehicles and the experienced pick-up and delivery times are being keep tracked of so that the evaluation could be done by the *carrier agents*. A modification to the model on the speed of the vehicles were also done, since the roads are being shared with vehicles with different speeds (e.g., trucks and cars).

In conclusion, MATSim offers a detailed and expendable agent-based model. It means that there is an opportunity to integrate a freight transport model (e.g., MASS-GT) to MATSim. By doing so, the dynamics of an urban area, affected by passenger and urban freight transport could be potentially captured. Moreover, carsharing or carpooling are based on "sharing economy" concept (Ciari et al., 2016), the same as crowdshipping. Since both share the same principles, there is a potential of implementing crowdshipping in the model. This could be useful to observe the impact if such innovation to be implemented in a city from a simulation perspective.

3.4. ALBATROSS Synthetic Population

In order for MATSim to work, the activity schedule of the agents is needed. While there are numerous ways of generating the population, this research is using the synthetic population generated by ALBATROSS (A Learning-Based Transportation-Oriented Simulation System), developed by Arentze et al. (2000). This simulation system generated the synthetic population of The Hague, based on the data that were available in 2014.

ALBATROSS is derived from activity-diary data as the system's input. Since the activity-diary data are often incomplete and inconsistent, the systems in ALBATROSS are capable of test the consistency these data, and consequently, correcting the data. In addition to the activity-diary data, other data such as the physical environment, the transportation infrastructure, institutional context, and a set of derived choice heuristics are also needed.

The synthetic population from ALBATROSS consists of households, which consisted of at least one person and a maximum of two-person per household. Each household has its own attributes, namely household income, car ownership, and their home location. Similarly, each (synthetic) person also has its own attributes such as their work status, age, gender, etc.

The data structure of the ALBATROSS data almost fulfils the MATSim's plan file requirement as were mentioned in section 3.3.2, although, adjustments are needed since the data's location variables are on the zonal level. Hence, the data from ALBATROSS can be converted as an input for MATSim as the synthetic population. The data from ALBATROSS are processed and used in this study as the MATSim input, explained and discussed on chapter 4**.**

3.5 Chapter overview

MATSim offers an ABM framework with high level of detail, and it is expendable, possessing opportunity for it to be integrated with ABM framework for urban freight transport such as MASS-GT. While urban freight and passenger transport are using the same infrastructures, they differ in numerous aspects, such as different transport systems, policies, planning, and research, especially in urban areas (Arvidsson et al., 2016). The planning problem of actors in the freight transport are different to that of the passenger transport, they are aiming to optimise the commercial success by satisfying the customers' demand and they need to optimise the usage of multiple vehicles that they are using, including rescheduling the deliveries and moving parcels from a vehicle to another (Zilske et al., 2012). Hence, the agents used in both urban freight transport and passenger transport ABM are also different, as can be seen in MASS-GT for urban freight transport (de Bok & Tavasszy, 2018) and MATSim for urban passenger transport (Horni et al., 2016).

In order to run the simulation, MATSim needs the synthetic population data. The data for the parcel delivery transport is obtained from the MASS-GT's LEAD Parcel Module (Kourounioti and Tapia, 2021) and the passenger transport activity and attributes data are derived from ALBATROSS (Arentze and Timmermans, 2004).

4 – Model Integration

In the previous chapter, it is found that the MASS-GT's extension that is being developed by LEAD offers an ABM simulation of parcel delivery and MATSim offers a microscopic agent-based simulation of transport activities. There is a potential to implement the results of MASS-GT, which are on zonal level, combined with the passenger transport demand produced by ALBATROSS, which are also on zonal level, in MATSim to model both transport spectrum in a microscopic level.

Since both models share the same transport infrastructure with result in the same level, the transportation network assigned with the transported goods/people, an integration of both models will be helpful for the future of sustainable urban mobility. With respect to this research's objective, several adjustments will need to be done to integrate both models. The agents in both transportation demand should be clearly distinguished. In MASS-GT – LEAD Parcel Module, the agents are the parcels and the delivery vans (Kourounioti and Tapia, 2021) while in ALBATROSS data, the agents are the individual travellers (Arentze and Timmermans, 2004). MATSim could provide a platform to model both kind of agents in the same environment and load them into the network to perform ABM in a more detailed scope, and hence, an integration process is needed. This chapter aims to explains the formulation of the conceptual integrated model framework, and the process to realise it.

One of the main aim of this study is to integrate the usage of MASS-GT and MATSim. It is important to note that the term *"integration"* could be ambiguous. One way to do integration is to bridge the output of both models. The integration that is done on this study is to convert the output of MASS-GT and ALBATROSS so that they are compatible to be used as the input for MATSim. While the integration is one of the most valuable outcomes of this study, the data collection and processing phase are equally challenging and fundamental for this study. This section describes the integration steps and the preparation stage for MATSim's input in detail.

4.1 Defining the study area

As was mentioned previously, this study will focus on the city centre of The Hague. Since the term "city centre" has no specific boundary, a study area is introduced to set the spatial limit of the simulation. Furthermore, the data needed, and computational time of the simulation can be significantly cut down. The study area that is being used in this thesis consists of eight 4-digits Dutch postcode zones that are located in the heart of The Hague, The Netherlands. The study area defined in this study is shown in Figure 6 and Table 3.

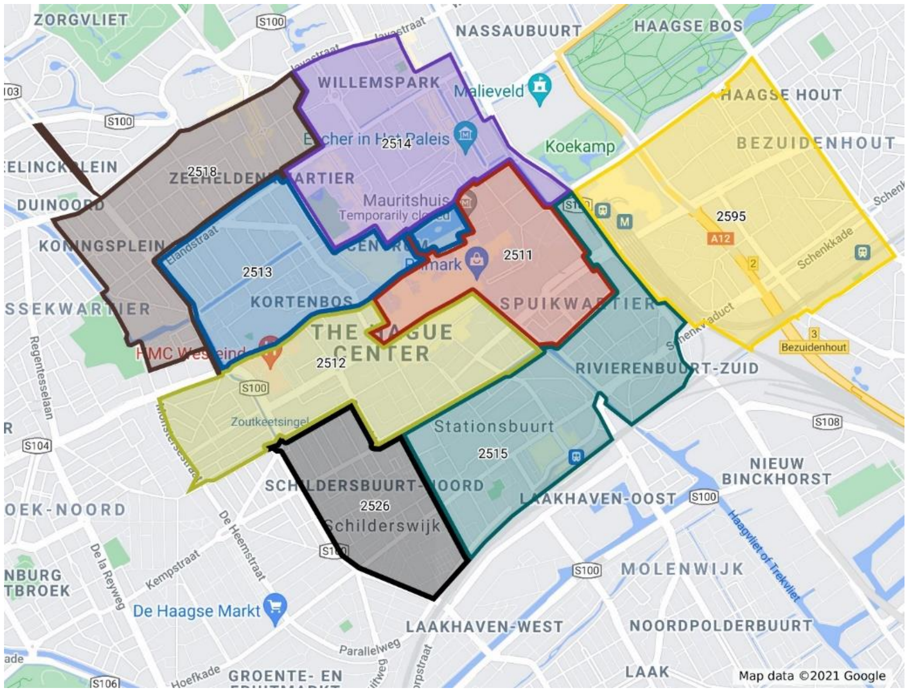


Figure 6 Study area, taken from Google Maps

Table 3 Postcode number and name of the study area

2511	Spui-Grotemarkt
2595	Den Haag central station area
2515	Den Haag HS area
2513	Den Haag Centrum area
2526	Schilderswijk
2512	Chinatown + Western centre area
2514	Northerm Centrum
2518	Koningsplein

Although the study area is defined in postcode format, each ABM framework in this study applies a different format to define the location variables such as origin and destination in the schedule file. MASS-GT and ALBATROSS defines their location format on a zonal level, on V-MRDH (*Verkeersmodel Metropoolregio Rotterdam Den Haag*) and postcode number, respectively. The V-MRDH zones have a smaller zonal scale compared to the postcode number. The example of V-MRDH zones with a postcode area is shown on Figure 7. On the other hand, MATSim provides agent-based modelling in a more microscopic level, which needs the coordinates of every activity location. Thus, adjustments while processing a different kind of location format in each data needs to be done.

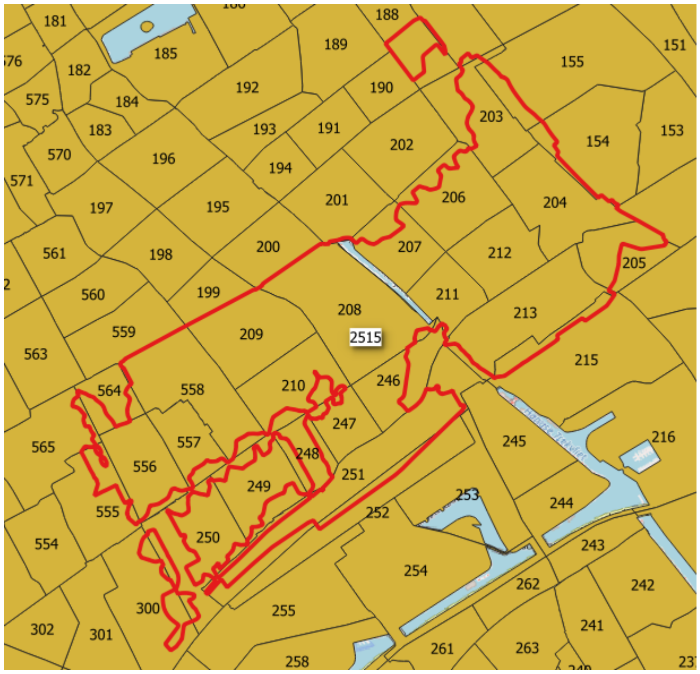


Figure 7 example of V-MRDH zones (yellow) and Postcode zone 2515 (red line)

In this study, only the trips which have at least one end (origin or destination) within the study area is considered. Therefore, the study focuses on the trips **to, from, and within** these zones are observed and analysed. By doing so, the activities in the schedule data have been filtered from 1,048,575 activities to 153,320 relevant activities and significantly reduce the run-time of the processing and simulation steps in this study.

4.2 Integration framework

The conceptual integration framework of MASS-GT and MATSim is shown in Figure 8. The microscopic simulations will be run in MATSim, and in order to do so, the passengers' and parcel deliveries' schedule data are needed first. The synthetic population activity schedule data and their respective attributes are obtained from ALBATROSS, consisting of the synthetic population of The Hague, based on the data obtained in 2014. On the other hand, the schedule data produced by the output of parcel modules of MASS-GT are being used as the data for parcel demand and parcel delivery schedule. The parcel data consisted of the parcel demand and schedule in the Province of Zuid-Holland, the Netherlands. Both of these data then are converted and combined into a plan file for running MATSim as the initial demand.

To model the interaction between the passenger and freight transport, the crowdshipping module of LEAD Parcel Module is used. This module plays one of the most important roles in the integration since it processes the data of parcel and the person-agents activity schedule to match the parcels with the occasional courier. More details about this module is explained on section 4.3.2**.**

The network file that is used as a spatial boundary of the simulation is obtained from OpenStreetMap. Together with the network and config file, MATSim will run the simulation and perform network loading in *mobsim* module. The simulation will be run for multiple iterations, and over iterations, the agents will assess and reassess their plan. A few percentages of the total population can choose to perform replanning, by changing their routes within the network to reach their destination. After the Stochastic User Equilibrium

(SUE) condition (or relaxed state) has been reached, the results of the simulation will be analysed in terms of the defined KPIs: vehicle.km driven to assess the mileage impact and the carbon emission produced to assess the environmental impact.

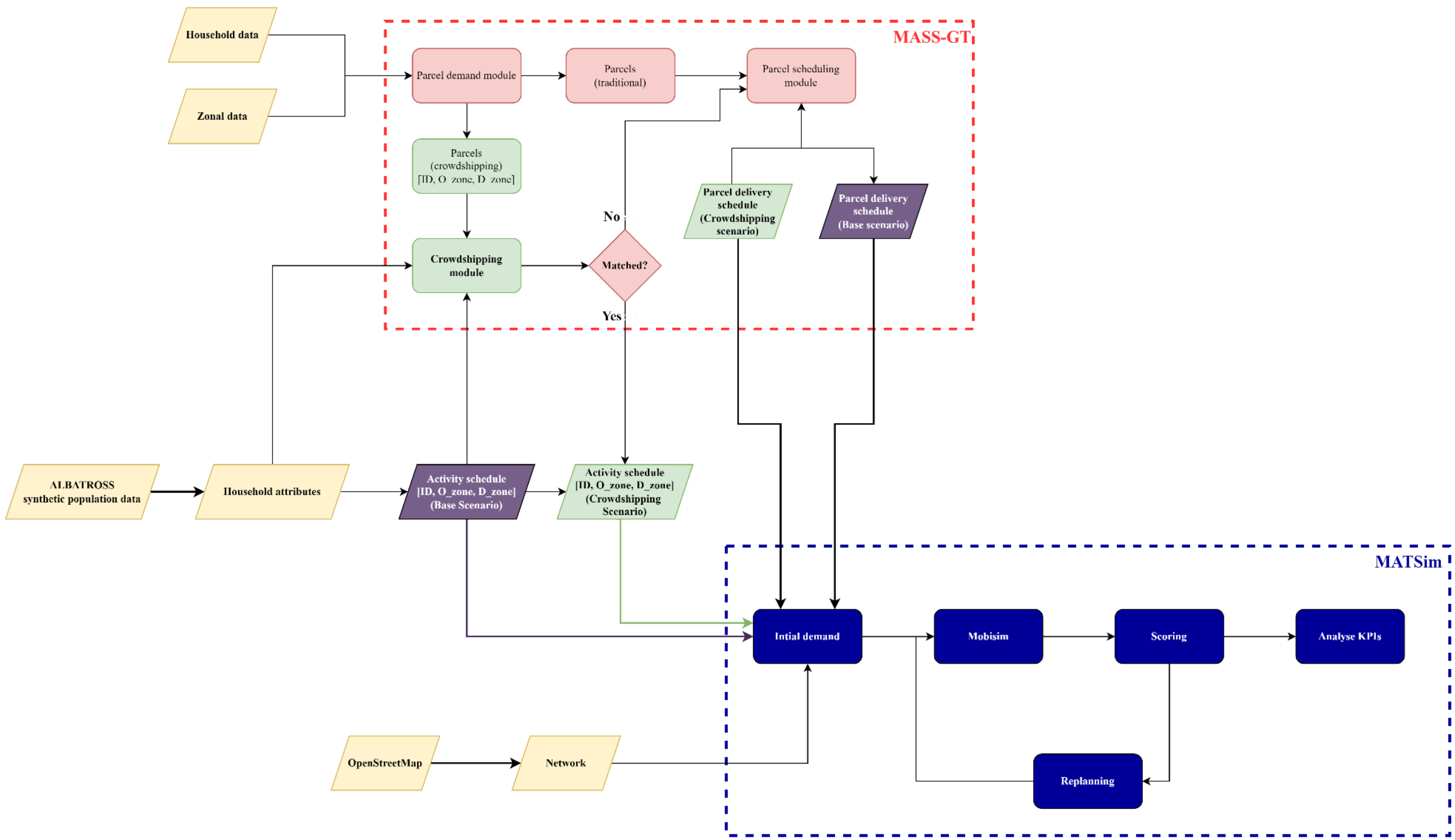


Figure 8 Integration plan of MASS-GT and MATSim (adapted from Kourounioti and Tapia, 2021 and Horni et al., 2016)

4.3 LEAD Parcel Module – MASS-GT

The first part of the integrated model is the parcel-side demand simulation. Three modules of LEAD Parcel Module is used: the parcel demand module, crowdshipping module, and parcel scheduling module. In addition, the MASS-GT network module is also used to simulate the parcel demand distribution in constructing the parcel delivery schedule. How the three modules are implemented in the integrated model is described in this section.

4.3.1 LEAD Parcel Demand Module

As was explained in the previous chapter, the parcel demand module of LEAD generates the synthetic parcel demand from the zonal and household data of the study area, by assuming that average number of 0.288 parcels per household per day are generate (Kourounioti and Tapia, 2021). The zonal data of the whole The Hague area is being used as an input to this module in this thesis. The module then process the input to generate synthetic parcel demand and assign them to the CEP available. A percentage of parcels generated are set to be eligible for crowdshipping, in this case, a value of 10% of the total parcels is used. 4% of parcels generated are also set as local-to-local, which means that it is originated and needs to be delivered within the municipality of The Hague.

Initially, the parcel demand module of MASS-GT generates the parcel demand, and assign them to the CEP, then select the nearest depot as the origin. If a parcel is local to local or eligible for crowdshipping, an origin zone inside The Hague is randomly assigned, following the distribution of houses inside each zones in The Hague and they are categorised as *"parcels hyperconnected"*. The rest of the generated parcels are categorised as *"parcels hubspoke"* which are not eligible to be crowdshipped and will be assigned for traditional delivery service. The parcels in *"hubspoke"* category are also assigned to be originated from retails within the province of Zuid-Holland, following the distribution of jobs in the zones across Zuid-Holland.

After they are processed, each parcel demand is assigned to some routes over the network generated in the network module of LEAD modules. In MASS-GT network module, parcels are assigned to the existing transportation network, depends on their category. Generally, there are two different network: the *hubspoke* network and crowdshipping network. The *hubspoke* network represents the traditional delivery services, consisted of multiple CEPs' network. On the other hand, crowdshipping network represents crowdshipping and only accessible for the parcel that are set for crowdshipping. Then, both networks are connected in a *hyperconnected* network. Through the network module, the distance between the origin and destination of parcels can be calculated and used as a variable to be considered in assigning the parcels with the person traveller in the crowdshipping module.

4.3.2 LEAD Crowdshipping Module

In this module, the CS-eligible parcels are assigned to a CS-eligible person-agent. The main input of this module are the *"parcels hyperconnected"* demand data and the activity schedule data of the person-agents, generated from ALBATROSS which has been processed (explained in section 4.4.1.1). This module works by matching the origin and destination of the parcels in the crowdshipable parcels demand data with the travelling person-agents that are eligible to be crowdshippers. There are two crowdshipping matching procedures that can be used in this module: least detour distance and minimum compensation. This study uses the former, the least detour distance method to match the crowdshipper with the parcels. This matching process takes the detour distance that the person-agents have to take to deliver the parcels into consideration, then choose a traveller with the least detour to be the crowdshipper of one specific parcel.

To calculate the detour distance, the location variables in the person-agents' schedule file need to be adjusted so that it is on the same level as the location variables in the parcel data generated from LEAD's parcel demand module. This is done by converting the coordinates in the person-agents' schedule file into V-MRDH zones, which are being used in the parcels data. The travel time is calculated by zone-to-zone travel time and distance skim matrix which are available from the LEAD module. The crowdshipping module then matches the parcels with the travellers, based on the least detour distance for traveller. Then, the module generates an output in a form of a *DataFrame* table, which includes the parcel ID, the traveller ID responsible for delivering the parcel, origin and destination of the parcels, and the (zonal) detour distance and compensation for the crowdshipper.

The compensation scheme implemented in LEAD crowdshipping module is calculated using natural logarithm of distance, following the equation 1 below. However, the compensation for the crowdshipper is not considered in any matching procedure in this study.

$$compensation = \ln(distance + 2) \qquad \text{(Eq. 1)}$$

The distance considered in the equation is the distance between parcel origin and parcel destination. This distance is also calculated using the same skim matrix as was explained in the previous paragraph. The crowdshippers' data then are processed further to formulate the person's activity schedule in the crowdshipping scenario. If a parcel couldn't be matched with a crowdshipper, the parcel data then are being called back by the scheduling module to be included in the traditional delivery van schedule.

It can be concluded that the LEAD crowdshipping module plays a very important role in the integration of the two software. It connects the schedule of the person agent from ALBATROSS, with the parcels generated from the parcel demand module of MASS-GT and provides output which could be used to process the data further so that it could be used for MATSim input. It is important to note that this module is only activated in crowdshipping scenario.

4.3.3 LEAD Parcel Scheduling Module

The parcel demand generated are consolidated in this module to create the delivery tours. In case of unmatched crowdshipping, that particular parcel is also included into the conventional delivery vans' schedule in this module. The main output of this module is the parcel delivery schedule. In each trip, the origin and destination zones, departure time, travel time, and arrival time, number of parcels need to be delivered at the destination, and the CEP involves are stated. This schedule data is translated to an XML format so that can be used to run in MATSim, as is explained in the next section.

4.4 MATSim Input

The main input data needed by MATSim are the plan file, network file, and config file. These three inputs then will be used to run the MATSim simulation. This section describes the formation of the three input files in the detail.

4.4.1 Plan file

The MATSim plan file defines the activity of the synthetic population throughout the day (Horni et al., 2016). Within this file, the agents with their respective attributes and activities throughout the day are defined. The plan file needs to have all necessary information of the agents, including the time of their activity, mode used in each leg, the coordinates of the origin and destination, the activity type, and the agents' respective attributes. Since this study will observe the interaction between the passenger (population) transport and the urban freight (parcel delivery vans) transport, the plan file needs to contain all necessary information of both spectrums. Therefore, the plan file was constructed by using the data from ALBATROSS and MASS-GT and will be discussed in the following sections, respectively.

4.4.1.1 Passenger transportation: from ALBATROSS data to MATSim plan file

The data that are used in this study are the schedule and household data of Den Haag, The Netherlands in 2014, obtained from ALBATROSS. These synthetic populations are generated in ALBATROSS, and consisted of households, which are consisted of at least one agent per household. They have their activities throughout a day listed in their schedule file, including the origin, destination, begin time, end time, leave time, travel time, arrival time, and transport mode.

The example of an ALBATROSS schedule data is shown in Figure 9. The column HHID stands for the household ID of the agents, with MemID is the member ID of each household, and each EpisodeID represents the activity number of each agent. OrigLoc and DestLoc are the origin location and destination location of each episode (or trip) and they are stated in the postcode number format of the Netherlands. The ActivityType column describes the activity each agent wants to do in each episode's destination location. Each agent starts its activity at its home and ends the day at home. Along the day, they travel to their designated destination, using a certain mode in each leg, with different activity types or trip purposes. Each activity has its own time variables, such as the begin time and end time, followed by the time variables of each leg: leave time and travel time.

index	HHID	Home	MemID	EpisodeID	OrigLoc	DestLoc	LeaveTime	TravelTime	BeginTime	EndTime	ActivityType	Mode
0	1	2515	0	0	2515	2515	03:00+0	0	03:00+0	08:49+0	Home	Missing
1	1	2515	0	1	2515	7547	08:49+0	130	10:59+0	11:23+0	Business	Car as Passenger
2	1	2515	0	2	7547	2515	11:23+0	130	13:33+0	03:00+1	Home	Car as Passenger
3	2	2515	0	0	2515	2515	03:00+0	0	03:00+0	03:00+1	Home	Missing
4	3	2515	0	0	2515	2515	03:00+0	0	03:00+0	09:53+0	Home	Missing

Figure 9 Example of ALBATROSS schedule data

Since the location variables (origins, destinations, homes) in the ALBATROSS data are stated in postcodes number format, the data needs to be adjusted so that it could be used as a MATSim input. MATSim simulates the agent's activities in disaggregate, microscopic level, meaning it needs the exact location of each agent in coordinates, instead of the zonal level. Therefore, several processing steps needs to be done and are described in this section. The processing steps that were performed in this study are:

1. Data filtering
   The schedule data of the agents provided by ALBATROSS consisted of hundred-thousands of agents and their schedule throughout the day. To narrow down the data, only the data that fit the study scopes were chosen. First, only trips that use car as mode of transport, either as a driver or passenger, were chosen for this study, this was done by filtering the transportation mode data in each trip to only contains car and carPassenger. Then, only the trips that have at least one location (origin or destination) located inside the 8 postcodes study area are chosen and processed further.

2. Reverse geocoding: finding the address – postcode
   The ALBATROSS data only stated the origin and destination in 4-digit Dutch postcodes. On the other hand, MATSim needs the coordinates of each activity in the MATSim plan file. Therefore, each activity's location are assigned to a random building inside the postcode area if the location is located within the 8 postcodes study area. If it is located outside of the study area, the centroid's coordinate of the postcode is used instead. The postcodes zoning boundaries used in this study are obtained from The Dutch Postcode information, compiled in a *shapefile (.shp)* format (CBS, 2021).

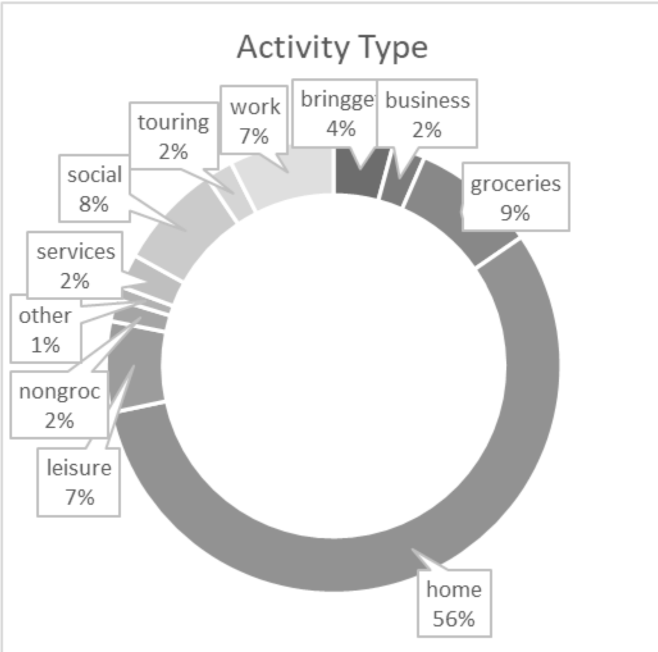


Figure 10 Activity types of the agents

The data of the building located inside the study area is obtained from OpenStreetMap, accessed in QGIS. However, these data are missing details of numerous locations, including the address of the building. That said, the coordinates that are provided in this dataset are intact and can be used to be processed further. The next step is to find the address information of all coordinates in the dataset, usually referred as reverse geocoding. The reverse geocoding process is performed in *Python*, using *Geopy* module. The coordinates data then is processed using this module, and the addresses of each coordinate point can be obtained. The coordinates reference system (CRS) that are used in this study are all in EPSG:28992 – Amersfoort, which suits the projection of the Netherlands' landscape.

After the address of each point is found, the activities' location performed by the agents are assigned randomly to a random location within the same 4-digits postcode. This step was done in *Python* using several data processing libraries. Because the locations were assigned randomly, the home locations of all agents were not consistent, for instance, agent A could start his/her activity in a certain location, but in *ActivityType: Home*, he/she are not returning to its initial point. Therefore, the dataset were adjusted to behave accordingly.

The transport modes that are considered in this study are cars. Therefore, the schedule files are filtered one more time, to only get the trips that were performed using car and carPassenger. In total, there are 10 different activity types in the population file, namely: *home*, *work*, *leisure*, *bringget*, *groceries*, *social*, *business*, *services*, *nongroc*, and *other*. Figure 10 shows the activity types of the agents. Since all agents start their day with the activity "home", logically, the "home" activity is the data with the most occurrence. If the agent's home is outside of the study area, the "home" activity should not be captured. However, in a typical MATSim's plan file, all agents starts their activity from home. Therefore, the home activity is set as the initial activity of all agents in the plan file. In some cases, there are also several agents that don't have any activities. In these cases, these agents will just stay at home, and won't travel throughout the network.

In several cases, because this study only considers the local transportation activities that have at least one leg inside the study area, not all agent's trips are accounted. For instance, we could consider most of an agent α's activities throughout the day, say, agent α's first, second, and fourth trip, while the third trip is not considered because both of the legs are outside of the study area. This example is visualised in Figure 11**.** Assuming agent A's destination in the second trip is location X, while the origin of the fourth trip is location Y, and both locations are outside of the study area, the movement from location X to location Y should not be considered in the KPI calculation of this thesis. However, it has to be made sure in plan file that agent A made the trip from location X to location Y. The agent's activity of moving from location X to location Y is set as "outside" activity type, and the transport mode used in this leg is set as "outside" mode. Since both locations are outside of the study area, which also means outside of the available network, the “outside” trips are set as “teleported” mode, which are explained in MATSim’s book as one of the possible way to simulate a transport activities (Horni et al., 2016). A teleported mode means the travelling distance of these kind of trips are the Euclidean distance between the two points and the travel time is as if the agent moves between the two point almost instantly by fixing the mode speed with a very large number in the config file.

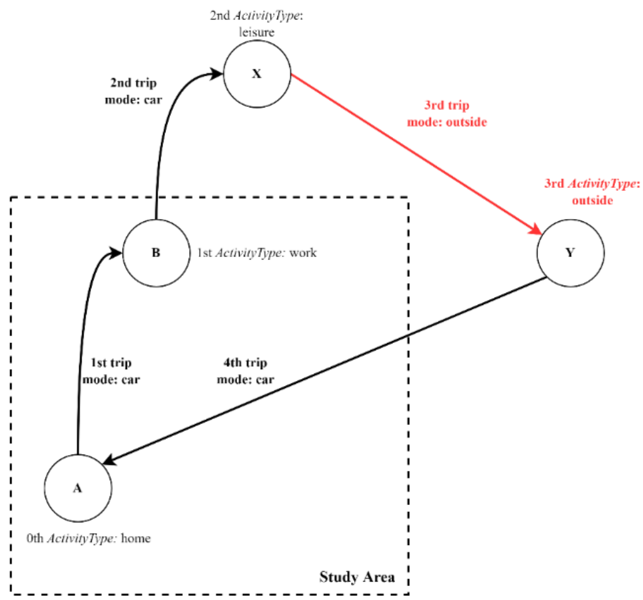


Figure 11 Agent α’s activity schedule: inside and outside of the study area

Agent’s attributes

As was mentioned previously in the previous chapter, each agent has their own attributes, including their age, gender, work status, car ownership status, and their household income. These attributes are generated by ALBATROSS. A household is consisted of at least one agent, and 2 agents at most. Each agent have their own attributes, including gender, age range, and work status. One attribute is on the household level, the household income. If two agents came from the same household, they will have the same household income attribute as well. The pie charts in Figure 12 below visualises the attributes of the agents in the datasets.

The agent’s attributes, in addition of giving extra information about the agent and the socio-demographic landscape of the agents, plays a role in determining whether an agent is eligible to be a crowdshipper or not. This will be explained further in Chapter 5.3 on the crowdshipping scenarios.

Figure 12 Overview of the agents' attributes

4.4.1.2 Parcels

The parcel schedule produced by MASS-GT is being used in this study as the parcel delivery vans' schedule. The dataset contains the ID of the tours and trips, the logistics service provider company, origin, destination, travel time, tour departure time, trip departure time, trip end time, and the number of parcels in a vehicle on the trip.

The origin and destination in the schedule file are written in numbers, representing the zone number in V-MRDH traffic model. These zones are then translated into postcodes, then into coordinates, using the same method as how the population's schedule was processed. Similar to what was done previously, only trips from, to, and within the observation area are considered.

For MATSim's plan file, it is important to have the begin time and end time of the activities. In this case, the activities of the parcel delivery are assumed to be loading/unloading. Since the initial data don't have these time variables, it was appended into the data. The begin time of the activity is the same as the trip end time, which is the summation of the trip begin time and travel time. The end time of an activity is set to be the same as the next trip departure time. If an activity is the last leg of delivery of an agent observed in the dataset, the end time of an activity is set to be the same as the begin time of the activity. In this way, the dataset will match the MATSim's requirement.

The parcels schedule are then written in the plan.xml format, following the MATSim's input requirement. The *ActivityType* of the parcel delivery schedules are set as "delivery", with van stated as the transport mode in the plan file. These delivery schedules then are merged with the population's activity schedule into one file. In total, there are 569 traditional parcel delivery trips that are done and considered in this research. The parcel data are summarised in Figure 9 below. Out of 1228 parcels that are considered, it is observed that the majority are handled by PostNL (54.8%), followed by DHL (29.3%) in the second place, as can be seen on Figure 13 (left). This parcel market share based on the volume found in the data generated by MASS-GT represents that of the real life situation, with PostNL handles 55-60% and DHL handles 30-35% (Autoriteit Consument & Markt, 2020). However, amongst the trips considered in this study, PostNL and DHL have a similar share, with 38% and 37% out of the total trips considered, respectively, as can be seen in Figure 13 (right).

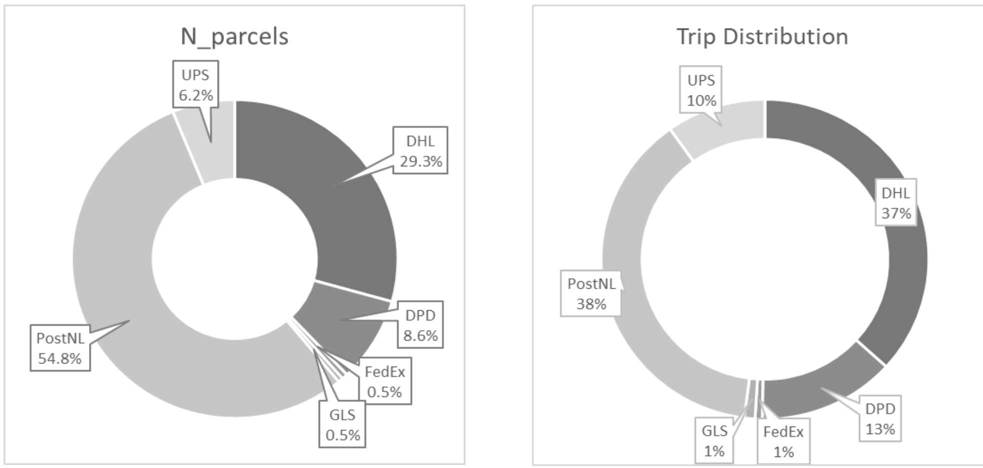


Figure 13 Number of parcels delivered per CEP (left) and Trip distribution among all CEP (right)

4.4.2 Network file

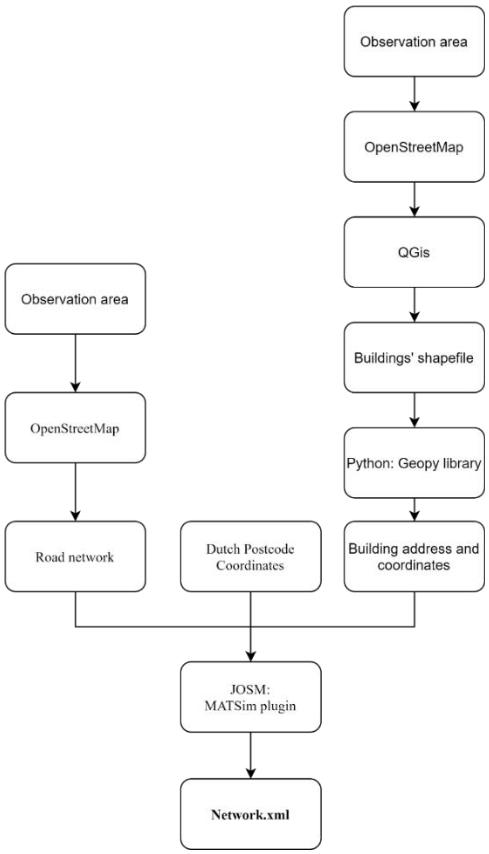


Figure 14 Process of creating the network file

The network used for this study is on the city central of The Hague, focusing on the 8 postcodes area that have been determined as the study area, as was explained on 4.1. By doing so, the geographical boundary of this study has been set. The process of generating the network file for MATSim is summarised on Figure 14.

The observation area that was set before is used as the main boundaries of the network. Inside the observation area, the building coordinates are captured from OpenStreetMap (OSM), processed with QGis. Afterwards, since not all building data from OSM have the postcode, all of them are reverse geocoded using *python*'s *geopy* library. When all necessary data are obtained, they are put into QGis again to get the building address and coordinates in comma separated value (.csv) format. This dataset is also being used to assign the coordinates into the schedule file for population and parcels, along with the Dutch postcodes coordinates to capture the leg from/to the external zones.

The road network of the observation area is captured with the similar way. All roads within the observation area that are able to be accessed using cars are filtered from OSM. All these roads then are defined as the links in the network. Along with the other datasets that were processed previously, the road network is processed in JOSM's MATSim plugin to get the network.xml file. Afterwards, all links in the network.xml file are set to be accessible by car, carPassenger, and van, the three transport modes in the schedule file. Figure 15 presents the network in this study in OSM format and in MATSim's format.

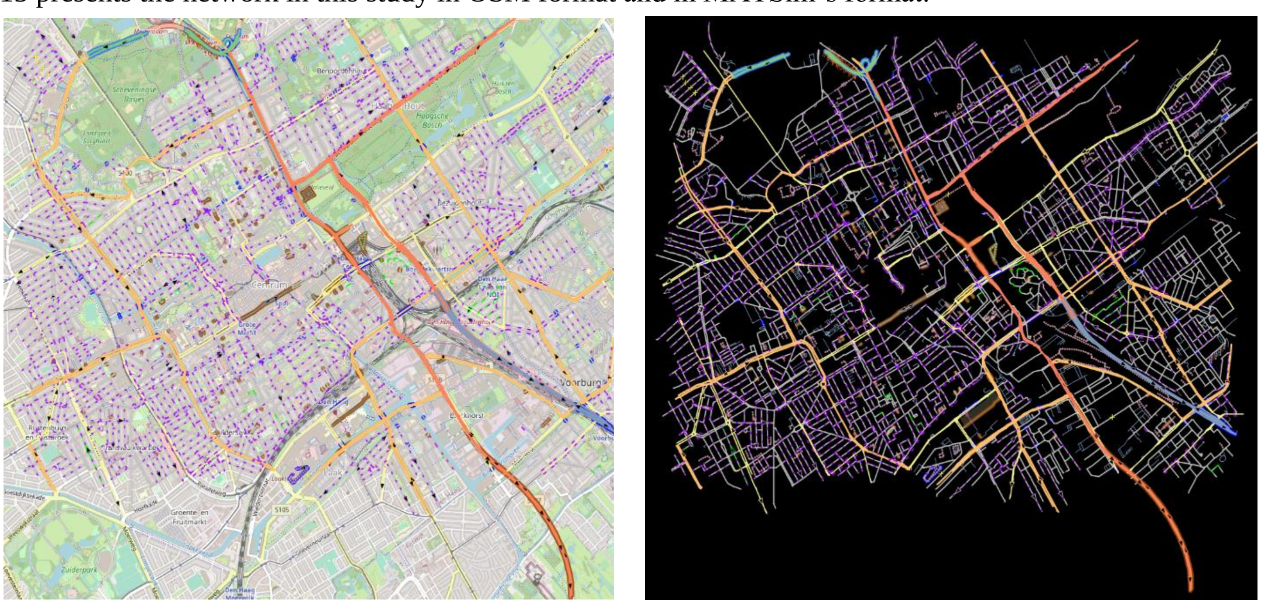


Figure 15 The transport network in OSM (left) and MATSim (right)

4.4.3 Config file

The config file contains all configurations used to run the MATSim simulation. Besides the directory details, this file also controls the simulation, for instance, the number of iterations, which mobsim module is going to be used, etc. The weights and utility function used in the logit model that influence agents' behaviour is also defined in this file.

The mobsim module that is used in this research is QSim, a queue-based and time-step based MATSim's default mobsim (Dobler & Axhausen, 2011). The agents are set to stick with their own mode, since there are no public transport in this case, thus, the replanning strategy "ChangeLegMode" is not used. The replanning strategy that is used in this model is only the "ReRoute" strategy, in which the agents are allowed to find the new shortest-path route for themselves given the mean travel times based on the information from the previous iteration. 5% of the total agents are allowed to use the "ReRoute" strategy. The rest 95% of the agents are using the "ChangeExpBeta" strategy. This strategy would allow the agents to select different plan within their memory with a probability of the exponential value of the difference between the scores of the current and new plan.

meaning the agents can change their route throughout the network, to find the shortest and the most efficient route possible for their trips over iterations. 5% of the total agents are allowed use the "ReRoute" replanning strategy. The rest of the agents (95%) are using the "ChangeExpBeta" strategy.

Initially, MATSim use "SelectExpBeta" strategy which allows the agent to perform Multinomial Logit Model (MNL) between their plans, to select the best one. This is based on the following equation 2, based on MNL, as was proposed by Horni et al. (2016):

$$P(i) = \frac{e^{\mu S_i}}{\sum_j e^{\mu S_j}} \quad \text{(Eq. 2)}$$

where $P(i)$ is the probability for plan i to be selected among j number of plans, S_i is the score of plan i, and μ is an empirical constant. Since the agents have a limited memory for storing a plan, set to 5 plans per agent, the worst scoring plan will be deleted and replaced with a new plan. This feedback loops are repeated for numbers of iteration, until the system reaches the relaxed state, the Stochastic User Equilibrium (SUE) condition.

However, it was argued by Horni et al. (2016) that the replanning strategy "ChangeExpBeta" might be a better approach compared to the "SelectExpBeta". It is because the "ChangeExpBeta" replanning strategy have several advantages compared to the basic MNL model, by allowing the agents to switch between plan so that it converges into equation 2, instead of using that equation directly. "ChangeExpBeta" strategy is based on equation 3.

$$T(i \rightarrow j) = \gamma e^{\beta (S_j - S_i)/2} \quad \text{(Eq. 3)}$$

where i represents the previous plan, j is a randomly selected plan from the same agent and γ is a constant that is small enough so that the expression won't be larger than 1. This equation will bring more consistency and made sure that the chosen plan is indeed better and the improvement it brings is above a certain threshold.

The summary of the configurations used in this thesis to run MATSim are presented in Table 4 while the full configurations are presented in Appendix B.

Table 4 Summary of the config file

Configuration	**Value**
coordinateSystem	EPSG:28992
mobsim	qsim
routingAlgorithmType	Dijkstra
flowCapacityFactor	1.7
storageCapacityFactor	2.0
linkDynamics	FIFO
mainMode	car, carPassenger, van
BrainExpBeta	1.0
maxAgentPlanMemorySize	5.0
ChangeExpBeta	0.95
ReRoute	0.05

4.5 Chapter Overview

In this chapter, the integrated model is developed. The integrated model works by connecting the workflow of LEAD Parcel Module and the passenger transportation data from ALBATROSS, then load them both into a microscopic simulation in MATSim. The main challenge in integrating both model is the fact that LEAD Parcel Module and ALBATROSS data are provided in zonal level, while MATSim needs information on microscopic level. In order to put all models in the same level, processing steps are done. All data from LEAD Parcel Module and ALBATROSS are processed, then converted into MATSim plan file.

The network file is developed from OpenStreetMap and processed with a processing software, JOSM, to convert it into XML format that is compatible with MATSim. The network used in this study case is the study area defined, 8 postcodes area in the city centre of The Hague.

Config file consists of the configuration for every MATSim run. This file governs and set the rule for the simulation. Several configuration parameters are to be highlighted: replanning strategies that consists of *ChangeExpBeta* and *ReRoute*, as well as the network capacity factors: *flowCapacityFactor* and *storageCapacityFactor*. The latter two factors are also used for calibrating the model, discussed in Chapter 6.

The modules that connect all frameworks; MASS-GT, MATSim, and ALBATROSS, are the crowdshipping module which connects the passenger transport data and the parcel delivery data, and MATSim's initial demand module. The model then is implemented and simulates the scenarios that are formulated in the following Chapter 5.

5 – Scenarios

The scenarios are needed to run and analyse the output of MATSim. Two kind of scenarios is formulated in this study: the base scenario and crowdshipping scenarios. Base scenario represents the existing condition, without the existence of crowdshipping. On the other hand, crowdshipping scenarios represents the condition in which crowdshipping exists in the simulation. In order to construct the scenario, the study area is defined first, and several assumptions are made to simplify the model. The scenario formulation is discussed in this chapter.

5.1 General Assumptions

Several assumptions were made in this study. This simulation study aims to analyse the externalities impact of car-based crowdshipping, which means the movement of the vehicles are more interesting compared to the static vehicles, such as parking problem. Thus, every time the agent arrived at their destination; the model doesn't consider the time it takes for the agent to find parking space in the building. Both passenger's transportation mode, car and carPassenger, have the same parameters defined in the config file. The only difference is that the agents that are using carPassenger as the transport mode can't be a crowdshipper. Furthermore, this study will focus on the value of VKT, which is based on the number of vehicles instead of passenger. For the van mode, it is also assumed that a van is consisted of one driver.

While assigning the agents to buildings inside the study area, no distinctions between the buildings were made. This means that the function of the building is not considered in this study, for instance, this study doesn't consider which building is school, office, home, etc. That said, the plan file used have been checked and made sure that the coordinates of agents' origin and destinations are consistent. The households with 2 agents also depart from the same coordinates on their initial episode in a plan, assuming that is their home. The same assumption is also applied to the delivery van agents. Although no distinctions between the buildings were made, the coordinate location of the depot are set to be consistent throughout the schedule file.

The simulation is run for one day period, however, some activity data from ALBATROSS ends at 3 in the morning, which is the latest time of the simulation. Therefore, the end-time of the simulation is 30:00:01, or a second after 3 in the morning.

5.2 Base Scenario

The base scenario was formulated based on the data from ALBATROSS and MASS-GT. The base scenario is the (synthetic) existing condition of the population in The Hague, without the existence of crowdshipping. In this scenario, all parcels are distributed by the parcel vans and person-agents execute their activities throughout the day. After the data have been processed, they could be run in MATSim to set the base of comparison, to be compared with the crowdshipping scenario.

In this scenario, the parcel vans' activities are independent of the passengers' activities. The number of parcels delivered are not considered in the base scenario, since there will be no exchange between the parcel vans and the person-agents. The interaction between the two is only that they are sharing the very same transport infrastructure.

5.3 Crowdshipping Scenario

In the crowdshipping scenario, the parcels in the network are delivered by the person-agents that use car in addition to the one that are being delivered by parcel vans. The available crowdshipable parcels are matched with the available potential couriers in the crowdshipping module, developed by LEAD (Kourounioti and Tapia, 2021). In this module, a percentage of the parcels that are crowdshipable are defined, then the status of crowdshipable parcels are assigned randomly to the generated parcels from the parcel demand module. These crowdshipable parcels then will be matched with a person-agent.

5.3.1 Crowdshipper's eligibility

The eligibility of a person-agent to be a crowdshipper is bounded to several constraints. First, assumptions on the criteria of crowdshippers are defined based on the attributes of the agents. Based on the literature review, the older a person gets, the more reluctant they are to be a crowdshipper. Departing from that finding, the person-agents that are eligible to perform as the crowdshippers are only those with age attribute of "35less" or younger than 35 years old and "35-55", resembling the age range of working age category (OECD, 2021). The crowdshipper set in this study are agents that have "low", "average", or "aboveAverage" household income attribute. Furthermore, only agents that use car as the driver, mode car, are allowed to be crowdshipper. Using these sets of attributes as constraints, the number of potential crowdshipper agents are reduced from 64,688 agents to 18,378 agents that fulfil the criteria, with 55,726 trips that are performed by these agents. Since the detour caused by doing crowdshipping will potentially cause delay for the potential courier to reach their original destination, the trips of person-agent that ends with "work" activity type are not eligible to be selected as a crowdshipping trips as well. This constraint followed the findings of Miller et al. (2017), stating that travellers that are on a trip with a more flexible schedule are more likely to be a crowdshipper. Using this assumption, the trips' schedule is filtered from 55,726 to 38,974 trips. Out of the remaining trips, the willingness to be a crowdshipper status, "CS_willingness", are assigned randomly. The maximum number of willing crowdshipper is bounded by the defined "CS_willingnessness" value, which defines the percentage of the total passenger trips that are allowed to be a crowdshipper. The value of the aforementioned two parameters in several different crowdshipping scenarios are presented in Table 13 in Chapter 7.

Table 5 Crowdshipper's eligibility criteria

Criteria	**Findings**	**Sources**	**Implementation**
Age	22 to 55 years old	*Galkin et al., 2021; OECD, 2021*	"<35" and "35-55"
Trip purpose	More flexible activity	*Miller et al., 2017*	Not **Work**
Compensation	Lower than traditional van, 1.5 – 3.35 euros	*Autoriteit Consument & Markt, 2020; Berendschot et al., 2021*	$compensation = \ln(distance + 2)$ (Implemented in LEAD modules)
Acceptable detour	2 to 2.5 kilometres	*Marcucci et al., 2017; Neudoerfer et al., 2021*	Considered
Mode	Car, bicycle, PT, walk	*Binetti et al., 2019; Gatta et al., 2019; Wicaksono et al., 2021*	Car
Household Income	-	*Assumed*	"low", "average", "aboveAverage"

5.3.2 Crowdshipping matching procedure

The remaining trips are still in the processed ALBATROSS format, which means that it doesn't use the V-MRDH zonal system as the MASS-GT does. Instead, the person schedule file have the coordinates of each agent's origin and destination. These coordinates are assigned to V-MRDH zones, then, the travel time between the origin and destination zones are calculated based on the information from the skim matrix of travel time.

Crowdshipping module's algorithm then match the available parcels with the remaining travellers' trips based on the information that are previously obtained. The parcels are matched with the potential crowdshipper's trip that cause the least detour. However, the detour measured are on zonal level. The more detail value of detour while also considering the traffic condition are obtained from the output of MATSim. The crowdshipping module then generates a table, including the ID of the parcel and the traveller's unique ID (person ID + trip ID) responsible to deliver the parcel.

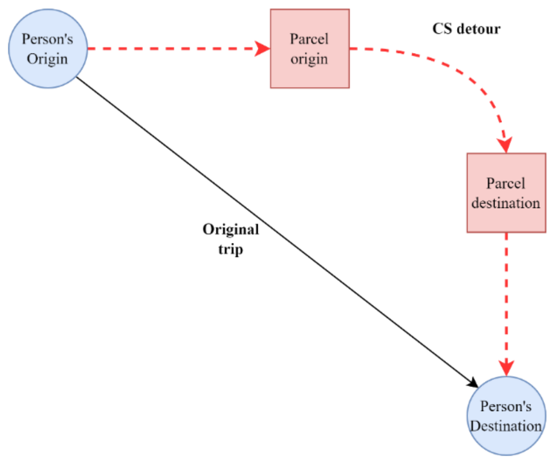


Figure 16 Illustration of crowdshipping trip

Crowdshipping considered in this simulation is the customer to customer (C2C) crowdshipping, which means that if a parcel is assigned for crowdshipping, the crowdshipper will take the parcel from its origin and deliver it to its destination. Every matched crowdshipper will make 2 extra trips, to pick up the parcel at the parcel's origin and to deliver the parcel to the parcel's destination. These two trips take place directly after the person-agent's original origin, but before the person-agent's original destination, as shown in Figure 16. This means that the parcels in crowdshipping are delivered directly after picked up by the crowdshipper. In reality, a crowdshipper might want to take the parcel first, then goes on with his/her activities throughout the day, before finally delivering the parcel to its destination. However, that is not the case considered in this thesis. Using the same logic, the schedule of the person-agents then are expanded, so that the crowdshipping trips are included, as shown in an example provided in Figure 17 . The agent's activity in base scenario only consists of *home* → *leisure* → *home*. After running the crowdshipping module, the agent's last trip (unique ID: 811_0_3) is chosen to be a crowdshipping trip. Therefore, the trip "811_0_3", which is a trip from *leisure* location to *home* location, is expanded into 3 trips, consisting of *leisure* →*pickupCS* (pick-up crowdshipping), *pickupCS* →*delivCS* (delivery crowdshipping), *and delivCS* → *home*. In this case, the location in which *pickupCS* takes place is the parcel's origin, and *delivCS* takes place in the parcel's destination location. Furthermore, the activity duration of *pickupCS* and *delivCS* is set as 2 minutes, assuming that is enough time for the courier to wait for the sender/receiver of the parcel to give/take the parcel.

Base scenario

person_id	unique_id	origin_x	origin_y	estination_	estination_	eparture_tin	mode	preceding_purpose	following_purpose	begin_time	end_time
811_0	811_0_0	81814	454475	81814	454475	3:00:00	missing	home	home	3:00:00	11:17:00
811_0	811_0_1	81814	454475	79500.7	456016	11:17:00	car	home	leisure	11:27:00	11:40:00
811_0	811_0_3	79500.7	456016	81814	454475	13:55:00	car	leisure	home	14:05:00	27:00:01

Crowdshipping scenario

person_id	unique_id	origin_x	origin_y	estination_	estination_	eparture_tin	mode	preceding_purpose	following_purpose	beginTime	endTime
811_0	811_0_0	81814	454475	81814	454475	3:00:00	missing	home	home	3:00:00	11:17:00
811_0	811_0_1	81814	454475	79500.7	456016	11:17:00	car	home	leisure	11:27:00	11:40:00
811_0	811_0_3a	79500.7	456016	80123.5	455963	13:55:00	car	leisure	pickupCS	13:59:00	14:01:00
811_0	811_0_3b	80123.5	455963	80633.8	456422	14:01:00	car	pickupCS	delivCS	14:03:00	14:05:00
811_0	811_0_3c	80633.8	456422	81814	454475	14:05:00	car	delivCS	home	14:12:00	27:00:01

Figure 17 Example of schedule expansion (agent person_id: 811_0)

If there are any parcels that were assigned for crowdshipping but were not matched with a person-agent, the data of these parcels are then brought back to the pool of available parcels available to be picked up by the traditional delivery vans. Finally, the two most important output from this process, the person schedule file and parcel schedule file, are converted into XML files as MATSim's plan file.

This study focuses more on the impact of crowdshipping's existence in a city by observing the VKTs and CO2 emission produced, and therefore, it is considered that the pricing strategy used by the crowdshipping company in the simulation is acceptable and agreed by the potential couriers. The time window for the person-agent to pick-up the parcel is not set because the time window constraints are assumed to be neglectable hence are not applied in this study. Further assumption that was made is that all logistics companies in this study is assumed to be willing to collaborate with the crowdshipping service, allowing them to take parcels that the logistics companies are responsible for.

5.4 Chapter overview

The scenarios formulated to run the integrated model introduced in the previous chapter are explained in this chapter. In total, 4 scenarios are formulated: a base scenario without the existence of crowdshipping that represents the current situation, and 3 crowdshipping scenarios with different adoption rate. These scenarios are then simulated using the integrated model formulated in Chapter 4. The results of the simulation and the analysis is provided in the following Chapter 6.

6 – Simulation and Results analysis

On Chapter 4, the integration framework to bridge the two models is constructed. The scenarios formulated in Chapter 5 is then simulated in the integrated model. This chapter aims to explain the implementation of the integrated model in an actual simulation environment, including the process of the model calibration, verification, and validation. Then, the result of the simulation is presented on the last section of this chapter.

6.1 Model calibration

After the framework is constructed, first, the base scenario is simulated using the model. In MATSim's config file, there are two parameters that influence the traffic condition of the simulation, namely, the *flowCapacityFactor* and *storageCapacityFactor*. If the value of these two parameters are too low, then extreme congestion might happen, resulting in numerous agents stuck on the network even when the simulation time has ended. Initially, the model is run for 1000 iterations and the network's *flowCapacityFactor* and *storageCapacityFactor* are set as 0.7 and 1.0, respectively. The pkm travelled per mode that is generated from the initial run is showed in Figure 18.

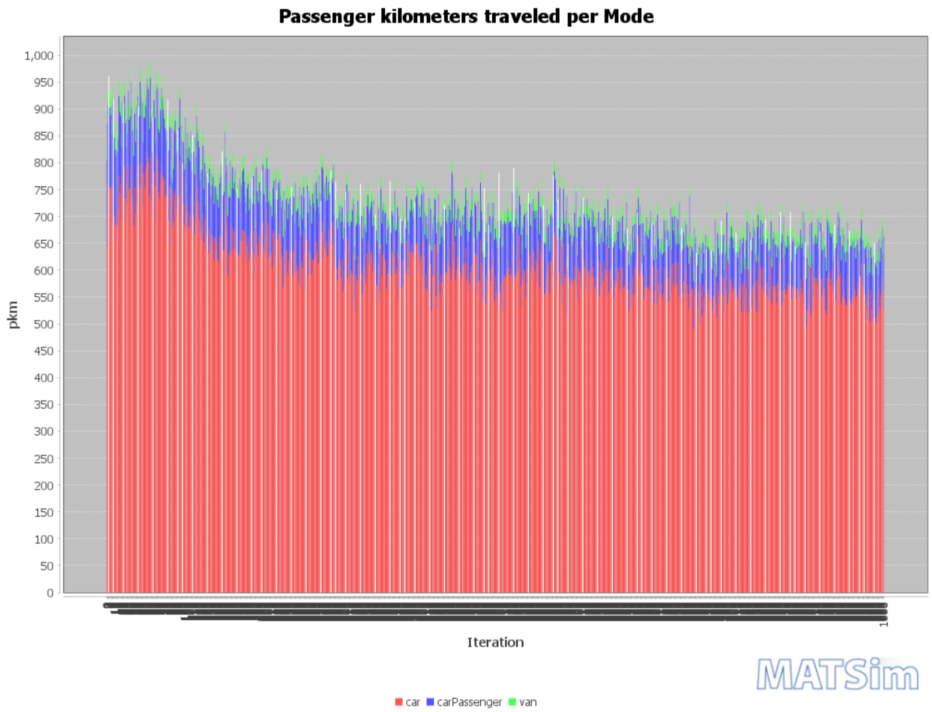


Figure 18 Initial run trial

It can be observed from the chart that even though 1000 iterations has been run, the resulting pkm value per mode still fluctuates over iterations, which indicates that the relaxed state cannot be reached with the network configuration. It can be seen in even more detail from the result of the leg histogram of all mode in the last iteration, as pictured in Figure 19. There are numerous agents that are still en-route by the time the simulation ends as shown by the green line. This doesn't represent the plan file that has been derived from ALBATROSS because all agents should have been arrived at their destination by the end of the iteration. This indicates that the value of network capacity factor, *flowCapacityFactor* and *storageCapacityFactor*, are not suitable and needs to be calibrated.

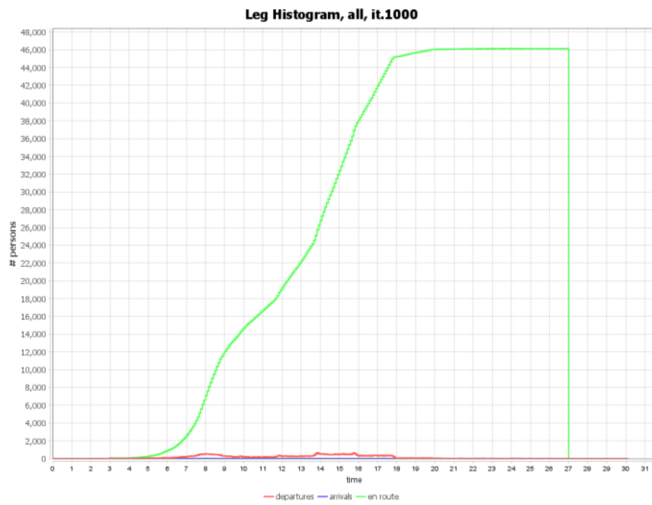


Figure 19 Leg histogram - initial run (last iteration)

To ensure that the model is implemented correctly, it is checked whether the cause of the error really came from the network factor. To do the calibration process, the model was run using an infinite capacity of the network. The result showed in Figure 20 indicates that by running the model using an infinite network capacity, the model works properly, there are no agents still en-route at the end of iteration and the resulting pkm travelled is consistent. This shows that the model behaves accordingly, however, the capacity factors that were used previously are too small, resulting in extreme congestions everywhere on the network

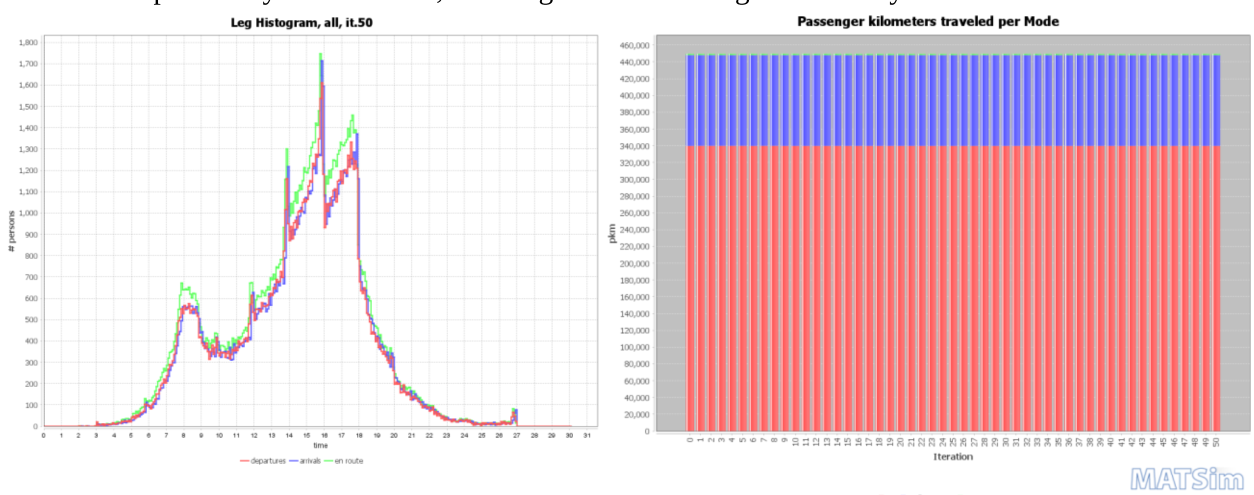


Figure 20 Model calibration - running with infinite network capacity

In the calibration process, the model is run with multiple different values of *flowCapacityFactor* and *storageCapacityFactor*. This trial and error process is repeated until the values that results in all agents departed and returned to their destination by the end of the simulation without leaving some agents stucked in the network. The final value of these two parameters used in the simulation is presented in Table 6.

Table 6 Network capacity factor used

Parameters	**Value**
flowCapacityFactor	1.7
storageCapacityFactor	2.0

6.2 Model Verification and Validation

A simulation model is made with the aim to represent the dynamic of real-life situation. However, it is impossible to make a "perfect" simulation model which considers all of the real-life details and characteristics. Therefore, assumptions are made to simplify the system and introduce abstraction to the system. While simplifying the model, assumptions and abstractions also bring inaccuracies to the simulation system. Verification and validation of the model needs to be done to ensure the model developed contributes to achieve the research goals that has been defined. The model verification and validation process are described in this section.

Generally, the model verification and validation are performed in three steps as was introduced by a study done by Robinson (1997). These three steps are the conceptual model's validation, model verification, and the model validation. The former step's purpose is to assess the validity of the conceptual model that was formulated in this research. On the second step, the implementation of the conceptual model in the simulation model is verified. Lastly, on the latter step, the simulation model's validity is checked to assess whether it contributes to achieve the research goal in a correct way.

6.2.1 Conceptual Validation

Since assumptions are made to formulate the conceptual model framework, it has to be checked whether the conceptual model is valid and contributes to achieve the research objective. The limitations and assumptions that are introduced to develop the model is presented in Chapter 5**.** The conceptual validation process follows the process introduced by Liu et al. (2011), about the conceptual model and its validation. In their literature, the conceptual model should consist of three components: simulation context, simulation concept, and simulation elements. The integrated model framework was developed and categorised by the concept introduced in the literatures and should be validated by the expert in its domain. The conceptual model in this study is validated by expert interview with Dr. Frederik Schulte, an expert in system analysis and simulation from TU Delft. It was concluded that the conceptual model is valid, however, the actual simulation and its results should be validated further using some kind of a reality check, to assess whether the model's behaviour will be logical or resembles the reality, if a parameter is changed. Therefore, behaviour prediction test is performed and is explained further in subsection 6.2.3 on model validation.

6.2.2 Model Verification

After the conceptual model is validated, it is implemented in actual simulation environment. Afterwards, the model needs to be verified to check whether the implementation of the conceptual model is correctly done. Stochastic model such as MATSim simulates an environment while also incorporating the uncertainty factor in the system (Flötteröd, 2016). The uncertainty factor is incorporated in the model by the defined random seeds value. To check the consistency of the model, a random seed test is done by running the exact same model with the variation in random seed. An additional run of the simulation using an exact configuration, but different number of iteration is also done. The verification test is then done by comparing the resulting pkm per transport mode on the 100th iteration. The result of the test is presented on Table 7.

Table 7 Model verification - random seed test

Random Seed	N iterations	Car pkm	carPassenger pkm	Outside pkm	Van pkm
373	100	350619	111749	92426	932
373	150	350619	111749	92426	932
1234	100	350485	111801	92426	933

From the result, it can be seen that the model showed a relatively consistent result. The differences in random seed causes variation to the resulting pkm per mode, however, the deviation of the results are relatively small.

6.2.3 Model Validation

A simulation model needs to be validated to check whether it behaves as it was designed. Often, a traffic count comparison between the model's network with the real world is used as the validation method (Chu et al., 2003). However, such method could not be performed in this study because of two reasons, first, the agents are randomly assigned to an address inside the study area and no distinctions between buildings are made, and second, the unavailability of the open-access traffic count data of the study area. Therefore, this study use another way to validate the model.

To assess whether the model in a way resembles the real world condition, a comparison with the real system is done, as were introduced by Robinson (1997). The relationships between the model input and output is compared to the real world situation. In this case, the model is run with different adoption rate of crowdshipping, and it is checked whether the model behaves accordingly. To do so, multiple hypotheses are formulated and to be tested with the model's result.

- **An increase in the crowdshipping adoption rate will leads to higher number of trips made by cars and a smaller number of trips made by van compared to the reference crowdshipping scenario**
- **A decrease in the crowdshipping adoption rate will leads to a lower number of trips made by cars and a higher number of trips made by van compared to the reference crowdshipping scenario**

These formulated hypotheses are then compared with the results experiment presented in Section 6.6

6.3 Key Performance Indicators (KPIs)

Two KPIs are used for analysing the results of the simulation in this study: the vehicle kilometres travelled, and the carbon emission produced. These two KPIs are used to assess the externalities impact of car-based crowdshipping in the study area, based on the simulation results. This section discusses the definition of these two KPIs.

6.3.1 Vehicle kilometres travelled

By default, MATSim produces the data of passenger-kilometres (pkm) travelled per iteration. Pkm is a unit of measurement, used in transportation sector, that measures the transportation of a passenger over one kilometre (Eurostat, ITF, & UNECE, 2004). It means that 1 pkm is defined as 1 passenger, travelling 1 kilometre. The value of pkm then needs to be translated into vehicle kilometres travelled (VKT), one of the KPIs used in this study. By definition, VKT is the unit of measurement that describes the total kilometres travelled by motorised vehicles on a certain road network, over a period of time (Rudman, 1979; OECD, 2002). VKT can be calculated by multiplying the number of vehicles on a given road network with the average length of the trips that were made. Based on these definitions and assumptions that were made, it can be concluded that the value of VKT in this study is equal to the value of pkm. Based on the assumptions made in this study, it can be concluded that 1 pkm is equal to 1 VKT, and these value then can be used as the base value for calculating the Carbon Dioxide (CO_2) emission factor.

6.3.2 Carbon Dioxide Emission

The value of VKT then can be used to calculate the carbon emission produced by the travelling activity in the simulation. The emission of a transport activity can be calculated by multiplying the transport activity (VKT) with the CO_2 emission factor per transport activity (gCO_2/km). By doing so, the carbon dioxide emission can be calculated.

The passenger cars and the parcel delivery vans are two different kind of vehicles with different vehicle size and fuel consumptions, and consequently, different CO2 emission factor. It is assumed that all cars are using petrol fuel. According to the European Environment Agency (2021), average CO2 emission produced by the new cars with petrol fuel in 2019 is around 127.6 gram carbon dioxide per kilometres (gCO2/km). The parcel truck's CO2 emission factor is based on PostNL's environmental value performance indicators annual report (2020), reaching the value of 245 gCO2/km. Therefore, the value of CO2 emission produced by each mode can be calculated using these three equations

$$CO2_{car} = VKT_{car} \times \alpha_{car} \quad \text{(Eq. 4)}$$

$$CO2_{van} = VKT_{van} \times \alpha_{van} \quad \text{(Eq. 6)}$$

where $CO2_{mode}$ is the CO2 emission produced by specific mode, measured in $gCO2$(gram CO2), and α_{mode} is the CO2 emission factor per each mode measured in $gCO2/km$. The value of VKT_{mode} is measured in kilometres (km). The value of both CO2 emission factors that are used in this study are presented in Table 8.

Table 8 CO2 emission factor per mode

Mode	α_{mode} $(gCO2/km)$	**Source**
Passenger cars	127.6	European Environment Agency, 2021
Parcel vans	245	PostNL, 2020

6.4 Model Results

All the necessary files that have been developed are simulated in MATSim environment. The simulation was run for 100 iterations, and it took 6 hours of run time using a computer with Intel i7 and 8GB of RAM.

6.4.1 Base scenario

The passenger kilometres traveled per mode based on the run of base scenario is presented on Figure 21. In each iteration, due to the co-evolutionary algorithm of MATSim, the agents are set to generate a new plan and compare it to the plans that they already stored in their memory. The total distance that the agents went through in the simulation are summed per mode to calculate the passenger kilometres traveled (pkm) per mode. It can be observed from the charts that the value of pkm starts to converge and stabilized after the 50th iteration. This indicates that the agents in the simulation couldn't generate a better new plan compared to the one that they already stored in their memory, hence, the total pkm couldn't be optimized further. This results imply that the “relaxed state” or stochastic user equilibrium (SUE) condition have been reached in the simulation of base scenario.

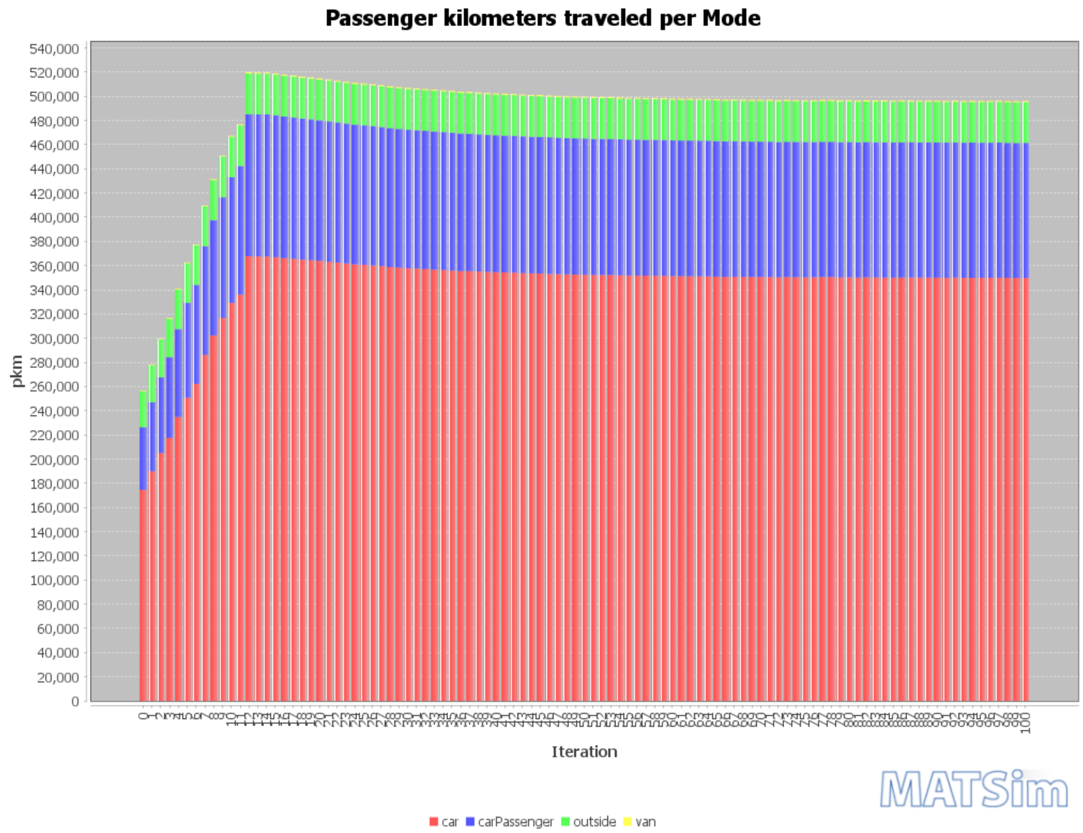


Figure 21 pkm per mode (base scenario)

The value of pkm per mode in the very last iteration (100th iteration) is presented in Table 9**.** The van truck has the least trips in the plan file, even significantly less than the person-agents, therefore, it is logical that the resulting pkm is significantly smaller compared to the other mode. As was explained in Section 4.4.1.1, the mode “outside” is not considered in this study, instead, it is only used to make sure if an agent leaves the study area, it will come back from the right direction.

Table 9 Simulation result pkm per mode (base scenario)

Mode	pkm
car	349846
carPassenger	111692
van	951
outside	33657

6.4.2 Crowdshipping scenario - reference

The total pkm per mode in the reference crowdshipping scenario is shown in Figure 22. As can be observed from the chart, the SUE condition is also reached in this scenario. The pkm value per mode in the last iteration is shown in Table 10. This reference crowdshipping scenario is simulated assuming 20% of the travellers are willing to become a crowdshipper and 10% of the customers are willing to use the crowdshipping service.

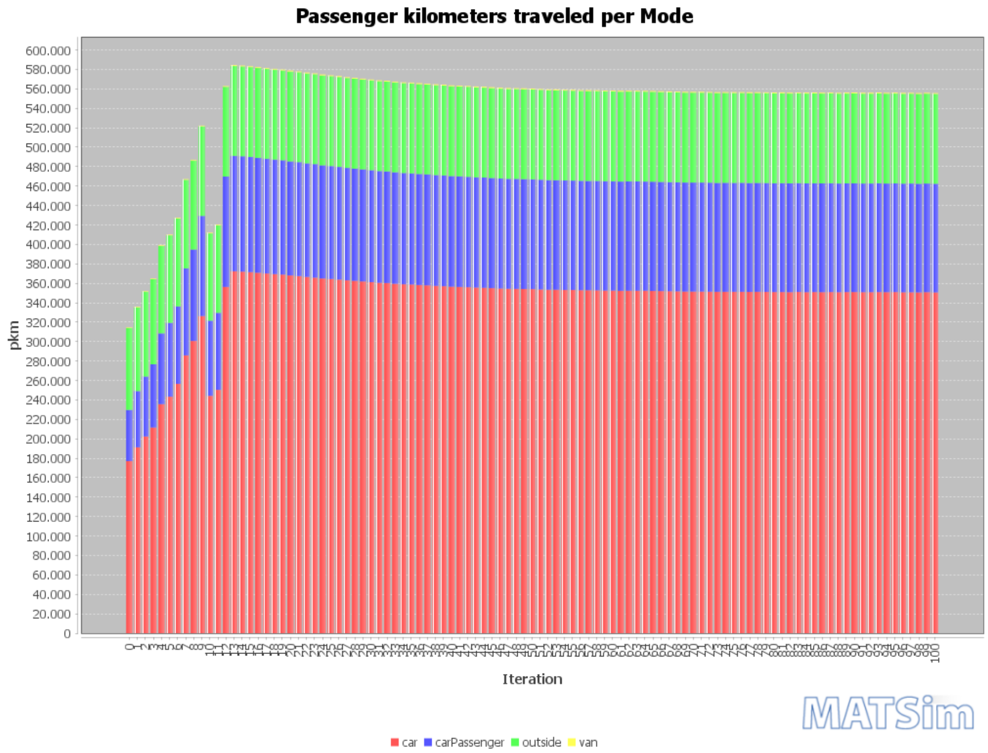


Figure 22 pkm per mode (crowdshipping scenario)

It can be observed that the total pkm value of car and carPassenger escalates slightly compared to the base scenario, while the total pkm value of van lessen slightly. A more in-depth comparison between the two scenarios is presented on the following section.

Table 10 pkm per mode (crowdshipping scenario)

Mode	**pkm**
car	350619
carPassenger	111749
van	932
outside	92426

6.5 Scenario comparison

The results of both scenarios are presented in the previous two sections. In this section, the comparison between the two is analysed.

6.5.1 Vehicle mileage and CO2 emission

Table 11 Run result comparison

Mode	Pkm – base (km)	CO2 emission – base (gCO2)	Pkm – CS (km)	CO2 emission – CS (gCO2)
car	349,846	44,640,350	350,619	44,738,984
van	951	232,995	932	228,340
Total	**350,797**	**44,873,345**	**351,551**	**44,967,324**

As expected, it can be seen that the total pkm produced by car increased slightly in the crowdshipping scenario, while the total pkm of van is decreased slightly compared to the base scenario. This represents the crowdshipping activity, in which the passenger's cars are being used to deliver the parcels, resulting in extra trips for cars. On the other hand, less parcels to handle by the delivery vans also means that the total pkm of the van are reduced slightly. This shows that the existence of crowdshipping by car would affect the pkm travelled by both transportation activities, although, the numbers are relatively small.

Because of the added trips in car mode to perform crowdshipping, and the less trips in van mode due to the existence of crowdshipping, the result of the total pkm and corresponding CO2 emission is presented on Table 11 above. The calculation of the CO2 emission produced is based on Equation 3 and Equation 4 that were presented in subsection 6.3.2. The mode "outside" is not considered in this calculation, since they indicate the trips that occurred outside of the study area and configured using "teleported" mode parameters. The carPassenger mode is also not considered since they are not included in crowdshipping activity, however, they are still deployed in to the network as background traffic.

Based on the simulation result and emission calculation, it is observed that there is a slight increase of 0.21% in carbon emission produced by all transport mode in the crowdshipping scenario. This is due to the increase in car mode's mileage, by 773 pkm, exceeds the mileage profit caused by the reduced the delivery van's trips mileage. Based on the simulation results, the total mileage saved by crowdshipping in van mode is only 19 pkm, accounted for 1.998 % reduction in both the total pkm and CO2 emission produced KPIs.

It is important to note, however, MATSim is a stochastic model, not deterministic. Stochasticity nature of MATSim is implemented in plan selection of the agents, among others, to include the uncertainty element in the modelling, because unlike deterministic model, a stochastic model's output represents the prediction of a future condition, including the uncertainties that might happen (Flötteröd, 2016).

6.5.2 Detour

All crowdshipping trips involve a detour from the agent's original route. The detour is calculated by finding the differences in total driven distance of car mode in the base scenario and crowdshipping scenario. Most of the crowdshipping trips results in detour for the crowdshipper, however, a few crowdshipping trips indicate that by doing crowdshipping, it could even save distance for the corresponding agents. This could be caused by the stochastic assignment of MATSim, in which the agents can choose a new route or plan, depends on the information obtained from the iteration before. From the comparison between the two scenario, it is found that the average detour distance caused by crowdshipping is **2.523 km per parcel**. This value is similar to the output of LEAD crowdshipping module that is used as input for MATSim, with an average detour distance of 2.45 km per parcel. This result is also in-line with the findings from literatures that state the maximum detour for crowdshipper is around 2 – 2.5 kilometres (Marcucci et al., 2017; Neudoerfer et al., 2021).

In crowdshipping scenario, there are less van trips compared to the base scenario. 220 person-agent's trips are expanded because of the crowdshipping task. This results in 440 additional trips made by the person-agent, half of them are to pick-up the crowdshipping parcels, and the other half are to deliver the crowdshipping parcels to its destination. This means that for every parcel that is crowdshipped, there will be two additional trips made in the car trips and not necessarily mean one less trip for van. This is because compared to the traditional delivery van, car-based crowdshipping is less efficient. In traditional van deliveries, multiple parcels can be carried in a single trip, meanwhile, the assumption set for the crowdshipper in this study is that they can only bring one parcel at a time. However, more trips doesn't necessarily mean more vehicle mileage, since the distance taken in each trip might differs from one to another. To compare the efficiency of delivering a parcel, the distance through per parcel is calculated. This is calculated dividing the total pkm for van with the number of parcels delivered. In the base scenario, the traditional delivery service on average travels for 0.77 km/parcel, with 1228 parcels handled per day in the study area. In crowdshipping scenario, the efficiency value increased to 0.79 km/parcel, with 1175 of parcels handled. Meanwhile, the crowdshipper spend 2.523 km of travelling per parcel, as was mentioned in the previous paragraph. This is in line with the findings of Rai et al. (2019) that indicates the parcel delivery service have the more efficient delivery system due to its capability of consolidating the parcel demand.

The results showed in the previous paragraph can be used to calculate the CO2 emission produced for delivering a parcel by multiplying the distance through per parcel with the CO2 emission factor. Using the emission factors that were presented in section 6.3.2**,** on average, delivering a single parcel using a traditional delivery service emits 195.75 gCO2/parcel, while the crowdshipping service emits 321.93 gCO2/parcel. The result from this section is summarised and presented on Table 12.

Table 12 Parcel delivery efficiency (car vs van) – CS scenario reference

Distance travelled per parcel	Car	2.523 km/parcel
	Van	0.799 km/parcel
CO2 emission per parcel	Car	321.93 gCO2/parcel
	Van	195.75 gCO2/parcel

6.6 Experiment

Two more crowdshipping scenarios are also run in this research. From this point, the crowdshipping scenario that previously has been discussed will be referred as the reference crowdshipping scenario. The two other scenarios have a different value of crowdshipping adoption rate in the study area. The parameters used in the experiment are provided in Table 13.

Table 13 Parameters used in each scenario

Parameter	Crowdshipping scenario - reference	Crowdshipping scenario B - increased	Crowdshipping scenario C – reduced
CS_willingness	0.2	0.3	0,1
CS_cust_willingness	0.1	0.2	0.05

The parameter "CS_willing" represents the willingness of the person-traveller to become a crowdshipper and it limits the number of CS-eligible person-traveller. On the other hand, "CS_cust_willingness" is the parameter of the customers' willingness to use the crowdshipping service and it limits the number of CS-eligible parcels. All parameters' value are the percentage of the subject out of the whole population (of parcels or traveller). The two experiment scenarios are simulated to see the relation between the crowdshipping adoption rate to the local vehicle mileage and the resulting CO2 emission produced. It is important to note, however, no references on the adoption rate of car-based crowdshipping were found from the literatures. Rather, the adoption rates used in this study are assumed.

This section discuss the result of two scenarios, compared to the base scenario and the reference crowdshipping scenario.

6.6.1 Crowdshipping scenario B – increased adoption rate

In crowdshipping scenario – increased, the adoption rate of crowdshipping is increased slightly. The parameter "CS_cust_willingness is increased to 0.2 and "CS_willingness" is increased to the value of 0.3.

By increasing the adoption rate, the chosen crowdshipping trips are increased from 220 in the reference crowdshipping scenario to 442 trips. For every chosen trip, two additional trips are made, resulting in extra 884 trips made by cars for crowdshipping purposes. The resulting pkm value and the CO2 emission, compared to the base and the original crowdshipping scenario is shown on Table 14.

Table 14 CS scenario B vs base and reference CS scenario

Mode	Base		CS-Reference		CS-B	
	pkm (km)	CO2 (gCO2)	pkm (km)	CO2 (gCO2)	pkm (km)	CO2 (gCO2)
car	349,846	44,640,350	350,619	44,738,984	351,074	44,797,042
van	951	232,995	932	228,340	823	201,635
Total	350,797	44,873,345	351,551	44,967,324	351,897	44,998,677

Since there are more crowdshipping trips, the mileage of the van mode in the study area is decreased by 13.5% (128 km) compared to the base scenario, and 11.7% (109 km) compared to the reference crowdshipping scenario. On the other hand, the total mileage of cars increased by 0.35% (1,228 km) compared to the base scenario and 0.13% (455 km) relative to the reference crowdshipping scenario. The same goes for the CO2 emission produced per mode. In total, increasing the crowdshipping adoption rate increased the total local CO2 emission produced by the transport activities in the study area by 0.25%, equals to 146,26 kgCO2.

The resulting average detour distance, or the distance travelled per parcel, for the crowdshipper is 2.76 km/parcel in this scenario, with 442 parcels delivered by the crowdshippers. Meanwhile, in base scenario, the distance travelled per parcel for the traditional delivery van is 0.77 km/parcel, and in crowdshipping scenario B the value is 0.84 km/parcel with 979 parcels handled by the traditional delivery vans. This means that 352.18 gCO2 is produced for each parcel delivered by crowdshipping and 205.8 gCO2 is produced for each parcel delivered by traditional van delivery service, on average.

6.6.2 Crowdshipping scenario C – reduced adoption rate

In this scenario, the adoption rate of crowdshipping is reduced from the reference crowdshipping scenario. The value of the parameters used in this scenario are half of the crowdshipping reference scenario, with the value of "CS_willingness" and "CS_cust_willingness" are set as 0.1 and 0.05, respectively.

The reduction of the adoption rate results in less chosen crowdshipping trips compared to the CS reference scenario. In total, there are 111 person-agents' trips that are chosen to perform crowdshipping, which means that there are 222 extra trips made by the car mode. The simulation results of this scenario is presented on Table 15.

Table 15 CS scenario C vs base and reference CS scenario

Mode`	**Base**		**CS**		**CS-C**	
	pkm (km)	**CO2 (gCO2)**	**pkm (km)**	**CO2 (gCO2)**	**pkm (km)**	**CO2 (gCO2)**
car	349,846	44,640,350	350,619	44,738,984	350,120	44,675,312
van	951	232,995	932	228,340	941	230,300
Total	350,797	44,873,345	351,551	44,967,324	351,061	44,905,612

It can be observed that the increase in car mode's pkm is now 274 km compared to the base scenario, accounted for 0.08% increase. On the other hand, the parcel delivery trips' mileage is decreased by 10 km (1.05%) relative to the base scenario. In total, the increase in local CO2 emission produced by the transport activities is 0.075% or 32.3 kgCO2 more compared to the base scenario.

In this scenario, the resulting average detour distance per parcel for the crowdshipper is 2.28 km/parcels, with 111 parcels delivered. On the other hand, the distance travelled per parcel for the van is 0.79 km/parcels with 1163 parcels delivered by the vans. In delivering a parcel with car-based crowdshipping in this scenario, on average, 290.93 gram of CO2 emission is produced per parcel. The van delivery emits 193.73 gCO2/parcel on average, on the other hand.

6.6.3 Results implication

The results of all scenarios imply that the adoption of car-based crowdshipping will not have a significant impact to the total vehicle mileage and CO2 emission produced by the transport activities in the study area. Although the simulation results show that all crowdshipping scenarios will lead to increase in both KPIs, the differences are very small, ranging from 0.07% to 0.28% increase. However, a pattern on the correlation between car-based crowdshipping with the total mileage and CO2 emission can be discerned. With the increasing value of crowdshipping adoption rate, the total CO2 emission produced will also increase. This could be explained by the better efficiency of traditional van in delivering parcels due to its capability of delivering multiple parcels in a single trip and the ability of consolidating parcels before dispatching delivery fleets from the depot. The crowdshipper, on the other hand, have to dedicate two extra trips, detouring from their initial route to pick-up and deliver one parcel. Consequently, the increase in car mode due to crowdshipping activity exceeds the savings in the traditional van in every scenario.

The simulation shows that even 5% of crowdshipping adoption rate will increase the CO2 emission and vehicle mileage, although the addition in both KPIs are very small. However, if the car-based crowdshipping adoption become more successful, the increase in both KPIs will potentially increase. To prevent further increase in CO2 emission, crowdshipping would be better performed using a more sustainable transport mode such as bicycle or public transport. Electric car could also be a sustainable option to perform car-based crowdshipping, as the emission produced by its entire life cycle are approximately 17-30% less than the emission produced by the traditional cars and it emits zero gas emission on the operational level (EEA, 2018). However, electric cars operates in the same transport network as the regular cars, hence, the impact on vehicle mileage will still be similar with that of the regular cars. It is also interesting to execute an experiment with even lower value of market adoption rate than crowdshipping scenario C to find the threshold in which car-based crowdshipping exists while also reducing the CO2 emission and mileage.

To even reduce the detour distance, innovations in last-mile deliveries such as pick-up points or parcel lockers could be combined with crowdshipping. If pick-up points exist across the city in a frequently busy area such as metro or train stations, supermarkets, and business area, the detour of the crowdshipper could be potentially decreased. Furthermore, if public transport mode is also considered in the simulation, this should be more environmentally beneficial. However, it would possess its own challenges for the crowdshipping service providers since they have to formulate a more comprehensive matching algorithm.

6.7 Policy Recommendations

Given the results of the simulations, several policy recommendations for various stakeholders could be formulated. These recommendations are derived from the simulation results, however, it is important to note that there are a lot of limitations and assumptions in this study that might hinder the results of the simulation, presented in Chapter 8.

- Conduct further study on car-based crowdshipping on larger scale, involving intercity deliveries
- Focus on crowdshipping performed by sustainable transport modes (bicycle, walk, public transportation)
- Give more opportunities to electric vehicles as the mode for car-based crowdshipping as it could potentially offer a more environmental benefits
- Implement crowdshipping with pick-up points across the city such as parcel lockers in various spots to potentially reduce further detour
- Conduct feasibility study on crowdshipping performed with multiple modes (e.g., car and public transport combination)

6.8 Added value of the integrated model

The integrated model developed in this study offers a microscopic simulation of both transport spectrum, the passenger and parcel delivery transport, in an activity-based agent-based modelling framework. The added value that the integrated model could provide are presented in Table 16. The input to the integrated model is simulated in zonal level, and MATSim simulates them in a more microscopical way, on the coordinate level. This offers a higher level of detail in modelling a scenario.

Table 16 MASS-GT vs integrated model

	MASS-GT	**Integrated MATSim**
Passenger transport simulation	No	Yes
Parcel transport simulation	Yes	Yes
Travel time and distance calculation	Zonal level	Coordinate level
Network congestion and background traffic	No	Yes

Route choice	Static network assignment	Stochastic, based on the initial demand and replanning module
Input data	Zonal data, household data, network	Activity schedule, network
Contribs and extension modules	Do not exist yet	Yes

MASS-GT can simulate parcels with an ABM framework, as was explained in Chapter 3.2. The parcels are simulated thoroughly, from the parcel demand generation process, the parcel distribution among the firms, parcel distribution along the network, until it reached a parcel schedule, consisted of tours and trips. The MASS-GT parcel modules also has the potential to be expanded, for instance, the inclusion of other methods in last-mile delivery such as parcel lockers, pick-up points, etc.

The integrated model provides a framework to convert the output of MASS-GT's parcel module to be simulated in MATSim. Since MASS-GT by itself offers an in-depth simulation for freight transport, by simulating the model in MATSim, the output provided would be in even more detailed. Moreover, simulating in MATSim allows the inclusion of congestions and background traffic because it can simulate all transport mode that are configured, including public transport, passenger cars, etc. MATSim simulates the route choice stochastically, meaning, it captures the uncertainties that might occur in the environment. Moreover, MATSim has numerous modules that could be used to expand the model and it could help in solving future research. For instance, the MATSim's emission module could be used to measure the hot and cold emission produced by the agents in the simulation.

6.9 Chapter Overview

In this chapter, the result of MATSim simulation is presented. The simulation is run using 4 scenarios that were formulated in the previous chapter. The results by the MATSim simulation showed that car-based crowdshipping causes more CO2 to be emitted by the cars and carPassenger mode while reducing the one produced by the traditional delivery service. Although the overall increase is relatively small, ranging from 0.066% to 0.24%, this is contradicting with the goal of achieving the European Green Deal to reduce 90% of carbon emission produced from transportation sector by 2050. The results showed that the increase in the externalities impact of cars and carPassenger exceeds the savings in the traditional parcel delivery vans by significantly more. The results presented in this chapter then consequently answers the final sub-question and hereby answering the main research question. The answers to all sub-questions and main research question are presented in the following Chapter 7.

7 – Conclusion

In this research, a study is conducted to find the impact of car-based crowdshipping as a form of interaction between urban freight and passenger transport on the externalities in last-mile delivery, particularly on the vehicle mileage and CO2 emission produced. Numerous studies on crowdshipping is found while conducting this study, most of them focused on the study of crowdshipping acceptance in society, challenges in implementation, and the supply and demand side of crowdshipping. Moreover, most prior studies focused on crowdshipping performed using either public transport or bicycle. Therefore, a research gap is identified: **the possible effect of car-based crowdshipping on the local vehicle mileage and its resulting impact on the environment**. This study aims to fill the research gap by conducting a microscopic agent-based simulation study of car-based crowdshipping in the city centre of The Hague, The Netherlands and analyse the implications of what such a last-mile delivery method would bring to the existing condition.

7.1 Answers to sub research questions

A set of sub-research questions is formulated in order to answer the main research question in a structured and sequential way. The answer to each sub-question is presented in this section.

SQ1. What are the factors that influence the implementation of crowdshipping?

The first sub-question is answered by conducting a literature review on crowdshipping. First, the literatures on the definition of crowdshipping and its implementation are explored. From the literatures, it is found that crowdshipping is a means of delivering parcels by utilising travelling crowd, with an expectation to reduce the carbon emission emitted by the logistics sector by reducing the number of trips dispatched by traditional parcel delivery companies, and giving the responsibilities to the travelling crowd, whom already have an origin and destination. The crowd chosen to be the courier is referred to as crowdshipper, and they will take a detour from their original route to perform the courier's task: picking up and delivering the parcels. The crowdshipper then will receive monetary compensation in return for their service of performing the courier's task. The concept of crowdshipping is often deemed to be attractive since it has the potential to offer a cheaper same-day delivery method compared to the traditional delivery service.

The potential impact of crowdshipping itself has been studied in multiple studies. It is found from the literature that the impact of crowdshipping is heavily dependent on the modal choice of the courier while delivering the parcels. However, most of the studies conducted focused on a more sustainable transport mode. On the other hand, private cars can be accounted for a significant modal share in the traffic (Ministerie van Infrastuctuur en Waterstaat, 2019). It seems attractive to implement car-based crowdshipping because of the enormous amount of crowd supply. However, the externalities impact of the car-based crowdshipping is yet to be explored thoroughly, as was emphasised by Pourrahmani and Jaller (2021).

Crowdshipping's adoption itself can be affected by two sides in general, the supply-side, which are the occasional couriers and the parcels to be delivered, and the demand-side, which are the actual customers that use the service. The success of crowdshipping implementation is dependent on these two sides, which are affected by multiple factors. The willingness-to-work (WTW) is one of the most important factors that affect the couriers in supply-side of crowdshipping. Unless the remuneration paid to the courier is attractive and fit the courier's demand and the detour distance is acceptable, working as a crowdshipper won't be as attractive. Furthermore, it is also found that a person's attributes such as age, trip purpose, and income could affect the willingness of a person to be a crowdshipper. As for the demand side, it depends on the quality of delivery that the crowdshipping platform offers and the price that has to be paid for using the service.

The factors that affect crowdshipping found from the literature review are then used as one of the inputs to develop the scenarios to run the model, presented previously in Chapter 5 and is presented in Table 2. These findings presented in Chapter 2 provides the answer to the first sub-question of this study.

SQ2. How could crowdshipping as the interaction between urban freight and passenger transport be simulated?

This research aims to answer the main research question by conducting a simulation study on crowdshipping implementation. The agent-based modelling approach is used in this study because of its capability to simulate the entities in real life as autonomous agents in the simulation and can interact with each other. Since the main focus of this study is to analyse the impact of the interaction between the two categories of transportation demand, ABM is considered suitable for this research.

The parcel side of the transportation is modelled using LEAD's parcel modules, an extension of MASS-GT that focuses on the parcel's last-mile delivery. This framework is suitable because MASS-GT is an ABM framework that models the individual parcels as autonomous agents, then, they are assigned to delivery vehicles, which are the agents in delivering the parcels. Moreover, LEAD's parcel modules also have the crowdshipping module that can match the generated parcel demand with the travelling person-agents or crowd.

The person agent's data are needed to simulate the passenger transport demand. In this study, the data are derived from ALBATROSS, an activity schedule simulator that models a synthetic populations' daily activity from the activity diary collected through a survey in The Netherlands. Each traveller in the data also has its own attributes, such as age, gender, income, etc., representing those of the real-life person. The data from ALBATROSS, with adjustments, can be used as an input to model passenger transport.

MATSim offers a stochastic microscopic agent-based simulation of transport activity. By microscopic, it means that the choices made by the agents in the system are performed at an operational level. Furthermore, MATSim's co-evolutionary algorithm allows the agents to adjust their plan over iterations, which will be repeated until the SUE condition is reached by the end of the simulation.

In order to simulate in MATSim, three forms of input are needed: the **config file, network file,** and **plan file.** The plan file consists of the activity schedule of the agents that will be simulated. The output of MASS-GT and the ALBATROSS data fulfils the requirement to be used as MATSim input, in this case. However, adjustments are needed since MATsim needs the data to be stated on the coordinate level, while MASS-GT and ALBATROSS data are mostly on the zonal level. Therefore, to use MATSim, adjustments to the aforementioned two data sources are needed, therefore, integration needs to be performed.

In Chapter 3, the method for simulating the interaction between the two transport sectors are defined, including the details needed to run each simulation. This chapter consequently answers the second sub-question. Furthermore, an integration between the models is needed to run the microscopic simulation of MATSim. Since the term "integration" could be misleading, the definition of "integration" that is used in this study means using the output of each input model (MASS-GT and ALBATROSS) to obtain the final output from the microscopic modelling framework (MATSim). The method to integrate the model is identified by connecting the frameworks of each model.

The parcel-side of the model is simulated through MASS-GT's LEAD Parcel Modules, which consisted of parcel demand module, crowdshipping module, and parcel scheduling module. This module works by using the household and zonal data as the input to generate the synthetic parcel demand, which then are distributed amongst the courier agents, either delivery van agents or person agents. The person-side, on the other hand, is derived from ALBATROSS data, which consists of the schedule data and the attributes data. The activity schedule data of the person-agents are included in the schedule file of ALBATROSS is used as an input to MATSim and the crowdshipping module. However, adjustments to these data are needed to convert them into the same level as MATSim, on an operational (or coordinate) level. These processes are done by converting the zonal information of the agents (origin, destination, home locations) to coordinate level, assigned randomly in the study area. After being converted into the coordinate level, these data are then converted into XML format to fulfil the MATSim's input requirement.

It is found that the **LEAD Crowdshipping Module** have the potential to connect the frameworks. This module could connect the person's activity schedule data with the parcel demand data to generate a list of crowdshippers and their designated origin and destination, similar to a crowdshipping matching platform to some extent. This module matches the parcel with the potential couriers with the least detour from their original routes, calculated by the zonal skim matrix provided by the module.

The data generated are then loaded into the **Initial Demand Module** of MATSim, which provides the entry gateway for all models mentioned. A network file of the study area is then loaded into the initial demand to provide the spatial boundary of the simulation. In the config file of MATSim, the strategy of the agents are defined with 5% of the whole populations are given the ability to change their route (*ReRoute* strategy) over iterations, while the rest are given the capability to change their plan over iterations to ensure the best plan is always selected (*ChangeExpBeta* strategy).

The study case is then simulated using MATSim over iterations to obtain the results provided in Chapter 6. In order to assess the implications of crowdshipping, scenarios are built so that the condition of before and after crowdshipping adoption can be compared.

This sub-question is further answered by defining the integration framework of the models. The integration process is done through data processing in Python and Microsoft Excel before finally the simulation is run in MATSim which was written in Java. Chapter 4 of this thesis provides the answer to the integration of the model.

SQ3. What are the possible scenarios of crowdshipping implementation in an urban area?

Scenarios are built to compare the results between the condition of before and after crowdshipping adoption in the study area. No model can be built to represent the whole situation of real-life conditions; it needs to be simplified. To simplify the model, assumptions are set in this study. These assumptions include:

- No distinction between the building/address in the study area are made, meaning, it is not defined which address/coordinate is a school, office, grocery store, etc.
- The parking problem is ignored
- Assuming one car is occupied by one person
- Only run a one-day simulation period from 00:00:00 to 27:00:01 or 3:00:01 in the morning of the next day
- Only considers the trips that are made **to, from,** and **within** the study area

Two categories of scenarios are formulated and presented in Chapter 5. The first is the base scenario which represents the existing condition, without the adoption of crowdshipping. The second category is the crowdshipping scenarios, with the adoption of crowdshipping exists in the study area. Three crowdshipping scenarios with different market adoption rates are formulated. The market adoption rate will affect the number of crowdshippers and crowdshipable parcels, which results in a different number of delivery trips performed by either crowdshippers or delivery vans.

A chosen crowdshipper's trip is expanded to represent the detour in delivering the parcel. The expansion is done by putting the crowdshipping activities in between the original origin and destination. This means for every crowdshipper's trip, two additional trips are made, each to pick-up and deliver the crowdshipping parcel. This also means that if a crowdshipper's trip is chosen to perform a crowdshipping activity, the parcel is picked up and delivered directly, and this is also one of the assumptions used in this study.

The crowdshipper is chosen based on the least detour they have to take to deliver a parcel. However, before a person is chosen to be a crowdshipper, it has to fulfil the crowdshipper's criteria. The criteria is obtained from the literature review chapter, implemented in the data filtering process. These criteria are summarised in the following Table 17. The mode considered is only the trips that are made with cars, since this study is focused on the car-based crowdshipping. The household income of the eligible crowdshipper is also assumed in this study because no information on this criteria is found in the literatures.

Table 17 Crowdshippers' criteria

Criteria	Model	Reference	Source
Age	"less35", "35-55"	25-55 years old	Galkin et al., 2021; OECD, 2021
Household income	"low", "average", "aboveAverage"	Assumed	Assumed
Trip purpose	Other than **work**	Flexible schedule	Miller et al., 2017
Mode used	car	Justified	Justified

Another assumption used is that the crowdshipper can only carry one parcel on each trip. Furthermore, the maximum number of willing crowdshipper is limited by a variable "CS_willingness" in the LEAD crowdshipping module, which represents the percentage of travellers that are willing to be crowdshipper. Each eligible agent can be a crowdshipper once in each trip, however, they can be a crowdshipper more than once a day.

The formulated scenarios are used to run the simulation in MATSim to assess the impact of crowdshipping existence in the study area.

SQ4. How to measure the local vehicle mileage and the resulting carbon dioxide emission from the simulation results?

By simulating the scenarios generated in the previous sub-questions in the formulated integration framework, this sub-question is answered. To measure the impact, two KPIs are generated: the vehicle-kilometres travelled (in km) and CO2 emissions (in gCO2). Three crowdshipping scenarios, each with a different adoption rate of crowdshipping, are simulated and compared to the base scenario. However, no references on the adoption rate of car-based crowdshipping were found in the literatures, therefore, the values are assumed in this study.

The vehicle-kilometres travelled in this study are considered equal to the value of passenger-kilometres travelled, because it is assumed that each car is occupied by only one traveller. It is measured by MATSim by calculating the total distance travelled by each vehicle of each transport mode, then summed up to obtain the total pkm value. This KPI represents the total daily vehicle mileage in the simulation. CO_2 emissions are measured by multiplying the VKT value with the CO_2 emission factors obtained from various sources. The CO_2 emission factors themselves are measured in gram CO_2 emitted per kilometres. The results are the total gram CO_2 emitted per transport mode per simulation period, in this case, 30 hours (from 00:00:00 to 30:00:00). This simulation period is chosen to adjust with the schedule file produced by ALBATROSS

7.2 Answer to the Main Research Question

To recall, the main research question is represented below.

"What are the impacts of car-based crowdshipping on the local vehicle mileage and its results on the local carbon emission production caused by the transportation activities?"

To answer the main research question, four scenarios are simulated using the integrated simulation framework that was built in this study. By comparing the results of each scenario with a base scenario the local vehicle mileage and the environmental impact is measured. The presented results indicate that **car-based crowdshipping would not have a significant impact on vehicle mileage and carbon dioxide emission**. The increase in the local vehicle mileage and CO_2 emission are insignificant, ranging from 0.07% to 0.28% increase. This slight increase is due to the distance savings in traditional delivery vans being greatly exceeded by the increased travel distance covered by the private cars in the simulation.

The model's results showed that with 20% of travellers willing to be crowdshipper, 10% of the total customers are willing to use the crowdshipping service, and 10% of the total parcels are eligible to be crowdshipped, there is a slight increase of 0.17% in carbon emission produced by all transport mode. Although the VKT of van mode is reduced by 19 pkm (1.998%), the increased mileage of cars is more significant (773 pkm). On average, 2.523 km are travelled to deliver one parcel for the crowdshipper, while for the traditional delivery service, it requires 0.79 km/parcel in the first crowdshipping scenario and even 0.77 km/parcel in the base scenario. As a consequence, on average, 321.93 grams of CO_2 is emitted to deliver one parcel by crowdshipper and 188.65 gCO_2 per parcel by the traditional van delivery.

Two more crowdshipping scenarios are simulated, each with a higher and lower crowdshipping adoption rate compared to the reference crowdshipping scenario. By increasing the adoption rate by almost two times of the reference crowdshipping scenario, it is found that even higher CO_2 emissions are produced. 1228 more kilometres are travelled by cars (0.35% increase from base scenario), which results in more CO_2 emission, while the reduction in the van's mileage is 128 kilometres. As a result, with 442 parcels being delivered by the crowdshippers, the average distance to deliver a parcel by crowdshipping is 2.76 km/parcel (352.18 gCO_2/parcel) and 0.84 km/parcel (205.8 gCO_2/parcel) by the traditional delivery.

Even if the adoption rate is reduced by half of the reference crowdshipping scenario, the total resulting CO_2 emission is still increased by 0.07% (32 kgCO_2). This results in 2.28 km/parcel travelled by the crowdshippers, emitting 290.93 gCO_2/parcels. Meanwhile, the traditional delivery vans travels for 0.79 km/parcels, which results in 193.73 gCO_2/parcel on average.

In all crowdshipping scenarios, the average detour distance of the courier ranges from 2.52 km to 2.8 km per parcel, which are in line with the findings of Marcucci et al. (2017) and Neudoerfer et al. (2021) that found the average maximum detour distance accepted by the crowdshippers ranges from 2 to 2.5 km. The more successful a car-based crowdshipping, indicated by the increasing adoption rate of crowdshipping, could lead to more CO_2 emissions produced by the transport activities. However, no business was made to be unsuccessful, therefore, this study could be an evidence that if car-based crowdshipping succeeds heavily, it could lead to more CO_2 emission in last-mile delivery. This is in-line with the findings of

Pourrahmani and Jaller (2021) which found that crowdshipping will be environmentally beneficial if performed mainly by sustainable transport modes.

The inefficiency of car-based crowdshipping simulated in this study is mainly underlined by two factors: the (still) inefficient parcel delivery system in crowdshipping and the mode choice to deliver a parcel on crowdshipper. For each crowdshipper, two extra trips are made, which means that it would require more trips to deliver parcel demand compared to the van delivery service, which can consolidate the parcels in an urban consolidation centre (UCC) before dispatching the vans. These extra trips will slightly increase the CO2 emission produced and the total mileage, as long as they are performed using regular private cars.

A more sustainable transport mode could be a better option to perform crowdshipping, on the other hand. This is because of the difference in the CO2 emission produced per distance travelled of the other mode. For instance, electric vehicles and bicycles emit less or even no (local) CO2 emission while travelling. This is in-line with the finding of Rouges and Montreuil (2014) and Rai et al. (2019) that discussed if crowdshipping is performed using a sustainable transport mode, the CO2 emission could be reduced.

In all cases, the existence of crowdshipping reduces the number of trips made by traditional vans. By performing fewer trips and travelling less distance, a logistics company would indeed make a lot of savings. These savings could come from the less fuel they have to consume, and the less compensation for the CO2 produced. Although this is beneficial for the logistics company, it is emphasised once more that by handling the parcels to car-based crowdshipping, the CO2 emission produced will increase. It is just as if the CEP would pass the baton of CO2 production to the others instead of trying to contribute to achieving the European Green Deal that aims for a 90% reduction in emission from the transport sector.

The result of this study affirms the findings presented in the study of Rai et al. (2017) that suspects crowdshipping could increase or reduce the traffic congestions and CO2 emissions produced by the transportation activities. Furthermore, the integrated model framework developed in this study could help in modelling the future condition of crowdshipping implications in a certain area.

8 – Discussion

The findings and results of this study are provided in the previous chapter. The main research question and the related sub-questions are answered thoroughly. In this chapter, the discussion on to what extent the research objective is achieved, the contribution and the limitation of this study, and recommendations for future research is discussed.

8.1 Limitations

The model and study conducted in this research are done by formulating a set of assumptions and simplifications that generalises the model, which might to causes some imperfection to the result of the model. The MATSim simulation is usually run for a large area over many iterations, often 1000 iterations. However, due to the limitation in computational power and time availability, this research simulated a small area of The Hague for 100 iterations. Furthermore, the assumptions that made no distinctions between the address in the study area could make the model rather unrealistic, not representing the real world transportation pattern in the study area. Because the study area is relatively small, the ratio between the number of parcels and the travellers might be inaccurate.

Another assumption that might hinder the result is that the agents are not allowed to change mode throughout their plan. In reality, often, people travel using multiple modes in a day. By not considering the public transport in this study, it assumes if a person travels by car from home, he/she will use the car for all trips made in a day.

The differences in the number of trips performed between the private cars and the traditional delivery van are very enormous in this study, resulting in the unresponsiveness of the model in this study to the changes in both KPIs. This is caused by the data availability of the passenger trips and parcel delivery trips that are used in this study. It can be seen by the total pkm travelled by each mode, with parcel delivery van trips produced around 800-950 kilometres depending on the scenario. This value is relatively very small if compared to the total pkm travelled by cars which are around 350,000 kilometres. These huge differences made the results of this study somewhat predictable since any changes in van trips would be relatively insignificant compared to the car trips. Although, this reflects the study performed in Vienna that found parcel delivery's transportation activities could only be accounted for 0.6% of the total urban traffic while passenger cars are accounted for 86.5% (Herold, 2019). That said, the value of vans' pkm found in this study could be accounted for 0.3% of the total pkm, which means it is still smaller compared to the other study that was conducted previously. A better dataset of the van trips could potentially lead to better results.

The realistic crowdshipping adoption rate value was not found in the literatures, and therefore, it is assumed in this study. The assumption could make the result less realistic, because the exact value of this parameter is assumed, meaning, the simulated crowdshipper's supply could be way less or more compared to the real-life condition. It also could affect the validity of the simulation and its results since the exact car-based crowdshipping adoption rate could not be found. Furthermore, a crowdshipper in real life can choose to reject the request to deliver a parcel if he/she feels the planned detour are way unacceptable. The agents in this simulation are not given such freedom, hence, the matching process of crowdshipping is very simplified. Moreover, it is assumed that all CEPs are willing to collaborate with the crowdshipping platform by giving up their share of parcels. While in reality, not all companies are willing to do so. This could reduce the supply of crowdshipable parcels.

Delivering parcels directly in crowdshipping is not always the case in real life as well. A crowdshipper could, for instance, take a parcel along the way to a grocery store, keep the parcel for several more activities, say, leisure and business, before finally delivering the parcel to its destination while on the way to a social activity's location, as long as it is delivered in the same day period. This is not represented in this model, as the simplification made the courier deliver the parcel directly after it is received. Therefore, the detour might exceed the ones that are generated in the real world situation.

The assumption on travellers could only carry one parcel at a time might hinder the result as well. Picking up multiple parcels in one route could potentially save even more detours and will result in less CO2 emission per parcel calculated for the crowdshipper. Behrend et al. (2019) conducted a research on this domain, and the findings indicate that a significant improvement could be brought to the system.

The demand-side of crowdshipping in this study is represented in rather a minimal way by only considering the number of crowdshipable parcels. Although the parcels are delivered by a person-agent, the sending and receiving-end of the parcel are not assigned to a specific person agent. Creating a more coherent schedule between the parcels and person could lead to a better realistic representation of crowdshipping in the analysis.

Regarding the emission calculation in this study, it is only calculated using a simple multiplication of the travelled distance with the emission factor. This is mainly because this study only considers the emission produced by the transportation activities in the network, disregarding the parking activities. On the other hand, the CO2 emitted by a vehicle could vary depending on various factors, for instance, the road's inclination angle, the driving speed, and the passive CO2 emission while the vehicle is parking. A more comprehensive method to calculate the emission exists and is recommended to be used to get a more detailed result.

8.2 Recommendation for future research

Utilising MATSim more

It is recommended to simulate the crowdshipping case in a larger scale, for example, for the whole city or province, if such a computational requirement can be achieved. MATSim excels in simulating a large-scale scenario in microscopic way. Furthermore, the emission module of MATSim can be used to calculate the emission produced by the transport sector, including the hot and cold emissions. While this module is not used in this study due to the time limitation, this module is a good approach in calculating the emission since it is more realistic. Incorporating public transport could also be an improvement to this study since MATSim can model public transport decently. If public transport exists in the analysis, a more realistic case of crowdshipping could be achieved. It is interesting to see the efficiency of crowdshipping performed with different modes.

Holistic integration of the models

The model integration performed in this study is merely an initial small step to reach a more comprehensive urban freight and passenger transport model. The integration process took place mostly in Python using Pandas library and Microsoft Excel. The next step recommended in integrating the model is to make the integration more seamlessly and fluid. This could be achieved by creating a module that connects all the framework and could be used as a "single-door" platform that processes everything. For instance, a "MASS-GT" extension module in MATSim could be developed. The integration process done in this study takes a significant amount of time, going back and forth between platforms.

Incorporating the sender and receiver agents

In this study, the crowdshipper takes the parcel directly from the sender. On the other hand, the sender and receiver end of the parcels are not represented by a person-agent in this study. By defining a more detailed approach in connecting the parcels with the person-agent, a more sophisticated result in analysing crowdshipping could be achieved. For instance, the dynamics between the person-agent, the parcels, and their interaction could be achieved by allowing a scenario in which a sender-agent could bring the parcel to a certain pick-up point of their choice, then the crowdshipper takes the parcel from the pick-up point and deliver it to the designated destination. By conducting such a study, the crowdshipping is better represented both from the supply and demand side.

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APPENDIX A – LEAD Parcel Module

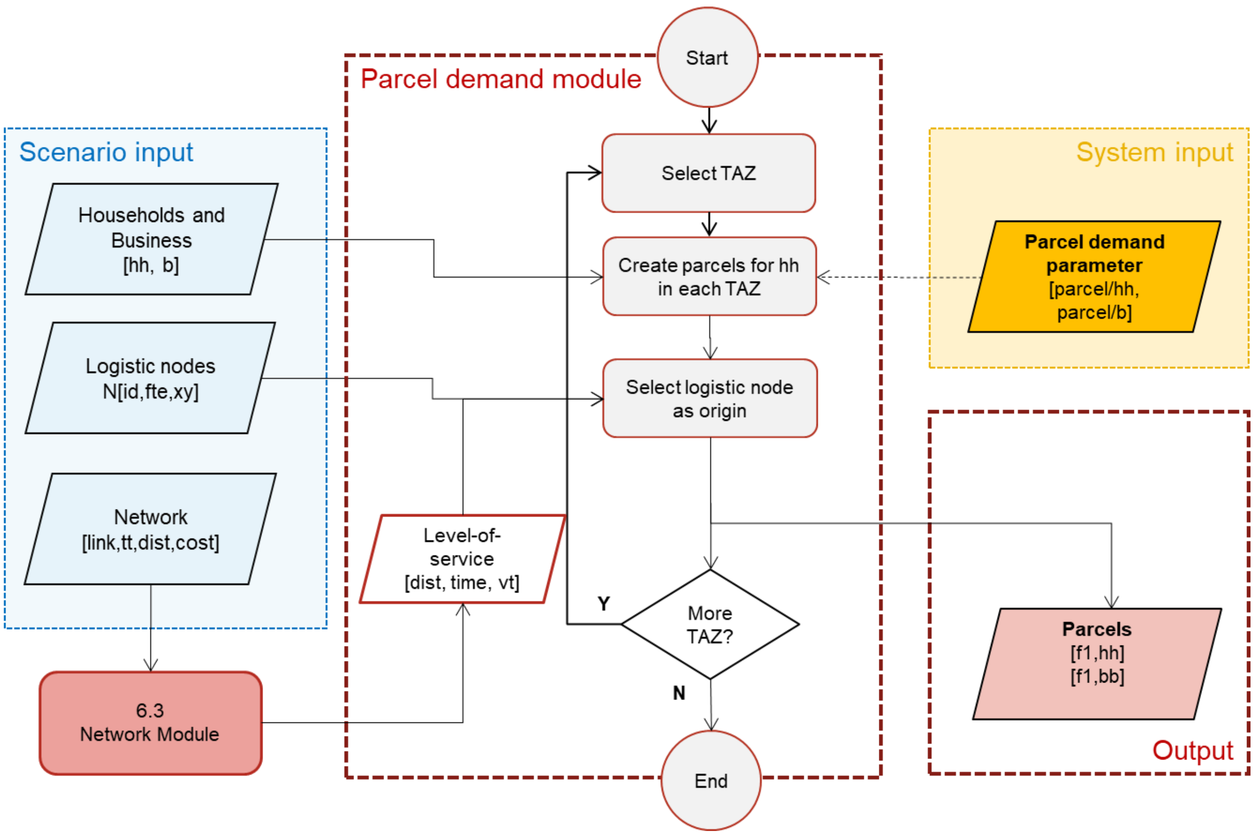

Figure A. 1 Parcel Demand Simulator (Kourounioti and Tapia, 2021)

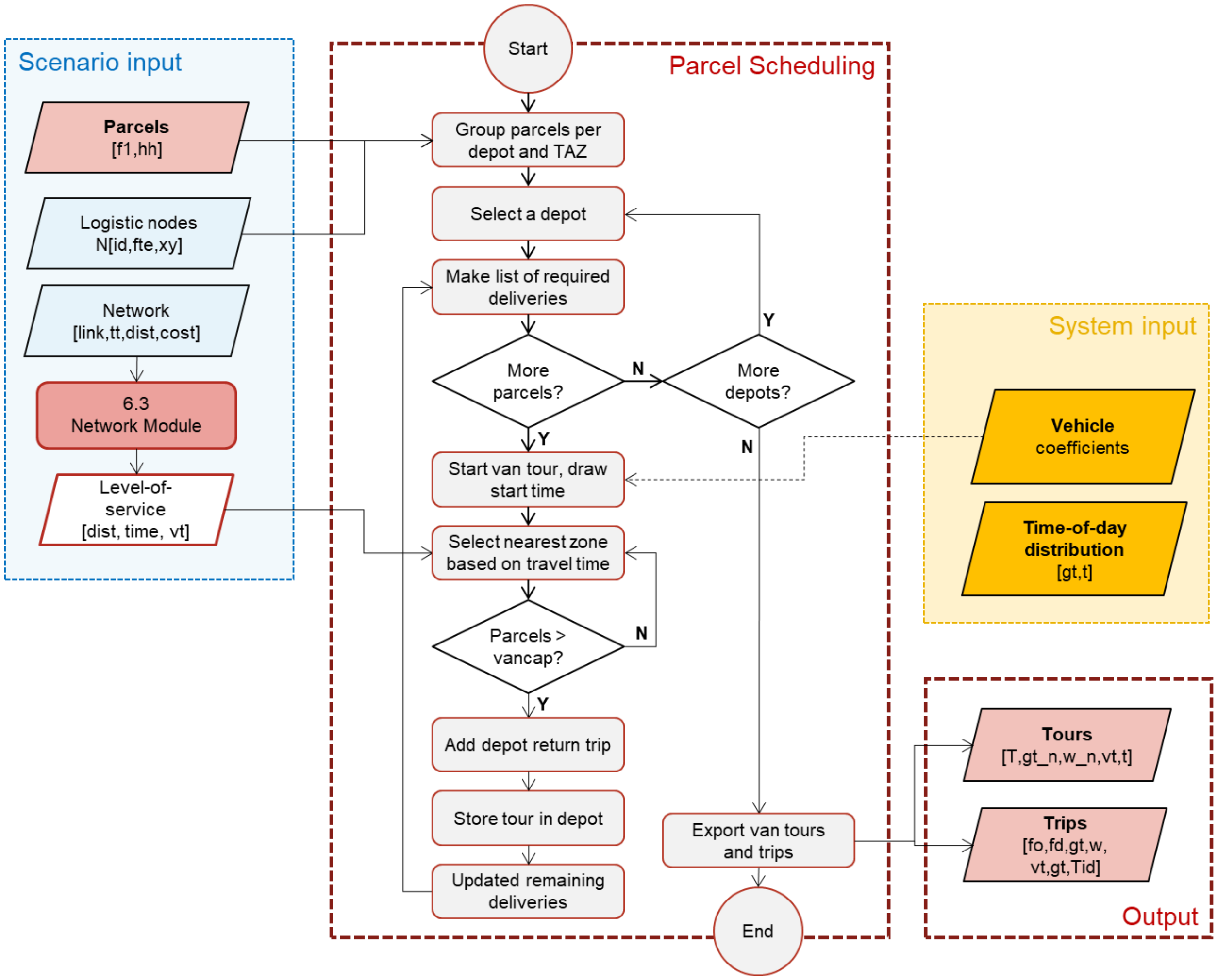

Figure A. 2 Parcel Scheduling Simulator (Kourounioti and Tapia, 2021)

APPENDIX B – Config File

```xml
<?xml version="1.0" ?>
<!DOCTYPE config SYSTEM "http://www.matsim.org/files/dtd/config_v2.dtd">
<config>

  <module name="global">
    <param name="randomSeed" value="1234"/>
    <param name="numberOfThreads" value="8"/>
    <param name="coordinateSystem" value="EPSG:28992"/>
  </module>

  <module name="network">
    <param name="inputNetworkFile" value="network_check_withVan.xml" />
<!--    <param name="inputCRS" value="EPSG:28992"/> -->
  </module>

  <module name="plans">
    <param name="inputPlansFile" value="base_scenario_teleport.xml" />
  </module>

  <module name="controler">
    <param name="mobsim" value="qsim"/> <!--  Defines which mobility simulation will be used. Currently supported: qsim JDEQSim
    Depending on the chosen mobsim, you'll have to add additional config modules to configure the corresponding mobsim.
    For 'qsim', add a module 'qsim' to the config.  -->
    <param name="compressionType" value="gzip"/>  <!--  Compression algorithm to use when writing out data to files. Possible values: [none, gzip, lz4, zst]  -->
    <param name="firstIteration" value="0"/>     <!--  Default=0. First Iteration of a simulation.  -->
    <param name="lastIteration" value="100"/> <!--  Default=1000. Last Iteration of a simulation.  -->
    <param name="outputDirectory" value="D:\\MATSim Thesis\\RunOutput-run100-Dijkstra-16-20-utility-baseteleport-2211"/> <!-- path to the output file -->
    <param name="overwriteFiles" value="deleteDirectoryIfExists"/> <!--  Possible values: failIfDirectoryExists, overwriteExistingFiles, deleteDirectoryIfExists  -->
    <param name="routingAlgorithmType" value="Dijkstra"/> <!-- what to fill???  The type of routing (least cost path) algorithm used, may have the values: Dijkstra, FastDijkstra, AStarLandmarks or FastAStarLandmarks  -
    <param name="runId" value="null"/>     <!--  An identifier for the current run which is used as prefix for output files and mentioned in output xml files etc.  -->
    <param name="snapshotFormat" value=""/> <!--  Comma-separated list of visualizer output file formats. `transims', `googleearth', and `otfvis'.  -->
    <param name="writeEventsInterval" value="1"/> <!--  iterationNumber % writeEventsInterval == 0 defines in which iterations events are written to a file. `0' disables events writing completely.  -->
    <param name="writePlansInterval" value="1"/>  <!--  iterationNumber % writePlansInterval == 0 defines (hopefully) in which iterations plans are written to a file. `0' disables plans writing completely.  Some plans
    <param name="writeSnapshotsInterval" value="1"/> <!--  iterationNumber % writeSnapshotsInterval == 0 defines in which iterations snapshots are written to a file. `0' disables snapshots writing completely  -->
    <param name="writeTripsInterval" value="1"/> <!--  iterationNumber % writeEventsInterval == 0 defines in which iterations trips CSV are written to a file. `0' disables trips writing completely.  -->
  </module>



  <module name="qsim">
    <param name="startTime" value="00:00:00" />
    <param name="endTime" value="40:00:01" /> <!-- latest activity time = 27:00:01. use 27:00:01? -->
    <param name="simStarttimeInterpretation" value="onlyUseStarttime"/>
    <param name="insertingWaitingVehiclesBeforeDrivingVehicles" value="true" /> <!--  decides if waiting vehicles enter the network after or before the already driving vehicles were moved. Default: false  -->
    <param name="flowCapacityFactor" value="1.6" />
    <param name="storageCapacityFactor" value="2.0" />
    <param name="numberOfThreads" value="1" /> <!--  Number of threads used for the QSim.  Note that this setting is independent from the "global" threads setting.  In contrast to earlier versions, the non-parallel spec
    <param name="mainMode" value="carPassenger,car,van"/>
    <param name="snapshotperiod" value="00:00:00"/>
    <param name="linkDynamics" value="FIFO"/> <!--  default: FIFO; options: FIFO PassingQ SeepageQ  -->
    <!-- Boolean. `true': stuck vehicles are removed, aborting the plan; `false': stuck vehicles are forced into the next link. `false' is probably the better choice. -->
    <param name="removeStuckVehicles" value="false" />

    <!-- time in seconds.  Time after which the frontmost vehicle on a link is called `stuck' if it does not move. -->
    <param name="stuckTime" value="3600.0" />
    <param name="timeStepSize" value="00:00:01" />
    <!-- `queue' for the standard queue model, `withHolesExperimental' (experimental!!) for the queue model with holes -->
    <param name="trafficDynamics" value="queue" />
  </module>

  <module name="planCalcScore">
    <param name="learningRate" value="1.0"/>
    <param name="BrainExpBeta" value="1.0"/>

<!--    <param name="fractionOfIterationsToStartScoreMSA" value="0.8"/> --> <!-- fraction of iterations at which MSA score averaging is started. The matsim theory department suggests to use this together with switching
    <param name="marginalUtilityOfMoney" value="0.0" />

    <param name="lateArrival" value="-18.0" /> <!-- 3x value for performing, from configAms -->
    <param name="performing" value="6.0" /> <!-- Amsterdam average salary 33800 euro, for 260 workdays: hourly wage 16.25 euro/h  -->
    <param name="earlyDeparture" value="-0.0" />

    <!--<param name="traveling" value="6.0" /> -->
    <param name="utilityOfLineSwitch" value="-0.5" />

    <parameterset type="modeParams" >
    <!-- [utils] alternative-specific constant.  no guarantee that this is used anywhere. default=0 to be backwards compatible for the time being -->
      <param name="constant" value="0" />
    <!-- [utils/m] utility of walking per m, normally negative.  this is on top of the time (dis)utility. -->
      <param name="marginalUtilityOfDistance_util_m" value="0.0" />
    <!-- [utils/hr] additional marginal utility of traveling.  normally negative.  this comes on top of the opportunity cost of time -->
      <param name="marginalUtilityOfTraveling_util_hr" value="-1" />
      <param name="mode" value="car" />
    <!-- [unit_of_money/m] conversion of distance into money. Normally negative. -->
      <param name="monetaryDistanceRate" value="0.0" />
    </parameterset>
```

```xml
    <parameterset type="modeParams" >
      <!-- [utils] alternative-specific constant.  no guarantee that this is used anywhere. default=0 to be backwards compatible for the time being -->
      <param name="constant" value="0" />
      <!-- [utils/m] utility of walking per m, normally negative.  this is on top of the time (dis)utility. -->
      <param name="marginalUtilityOfDistance_util_m" value="0.0" />
      <!-- [utils/hr] additional marginal utility of traveling.  normally negative.  this comes on top of the opportunity cost of time -->
      <param name="marginalUtilityOfTraveling_util_hr" value="-1" />
      <param name="mode" value="carPassenger" />
      <!-- [unit_of_money/m] conversion of distance into money. Normally negative. -->
      <!--param name="monetaryDistanceRate" value="0.000154" /-->
      <param name="monetaryDistanceRate" value="0.0" />
    </parameterset>

<!-- Parcel Vans -->
    <parameterset type="modeParams" >
      <!-- [utils] alternative-specific constant.  no guarantee that this is used anywhere. default=0 to be backwards compatible for the time being -->
      <param name="constant" value="0" />
      <!-- [utils/m] utility of walking per m, normally negative.  this is on top of the time (dis)utility. -->
      <param name="marginalUtilityOfDistance_util_m" value="0.0" />
      <!-- [utils/hr] additional marginal utility of traveling.  normally negative.  this comes on top of the opportunity cost of time -->
      <param name="marginalUtilityOfTraveling_util_hr" value="-1" />
      <param name="mode" value="van" />
      <!-- [unit_of_money/m] conversion of distance into money. Normally negative. -->
      <!--param name="monetaryDistanceRate" value="0.000154" /-->
      <param name="monetaryDistanceRate" value="0.0" />
    </parameterset>

    <parameterset type="modeParams" >
      <param name="constant" value="0.0" />
      <param name="marginalUtilityOfDistance_util_m" value="0.0" />
      <param name="marginalUtilityOfTraveling_util_hr" value="-1.0" />
      <param name="mode" value="outside" />
      <param name="monetaryDistanceRate" value="0.0" />
    </parameterset>
```

```xml
<!-- all activityType, typicalDuration-->
    <parameterset type="activityParams" >
      <param name="activityType" value="dummy" />
      <param name="closingTime" value="undefined" />
      <param name="earliestEndTime" value="undefined" />
      <param name="latestStartTime" value="undefined" />
      <param name="minimalDuration" value="undefined" />
      <param name="openingTime" value="undefined" />
      <param name="priority" value="1.0" />
      <param name="scoringThisActivityAtAll" value="true" />
      <!-- typical duration of activity.  needs to be defined and non-zero.  in sec. -->
      <param name="typicalDuration" value="02:00:00" />
      <!-- method to compute score at typical duration.  Options: | uniform | relative | Use uniform for backwards compatibility (all activities same score; higher proba to drop long acts). -->
      <param name="typicalDurationScoreComputation" value="relative" />
    </parameterset>

    <parameterset type="activityParams">
      <param name="activityType" value="work" />
      <param name="typicalDuration" value="06:30:00" />
      <param name="priority" value="1.0" />
    </parameterset>

    <parameterset type="activityParams">
      <param name="activityType" value="home" />
      <param name="priority" value="1.0" />
      <param name="typicalDuration" value="07:40:54" />
    </parameterset>

    <parameterset type="activityParams">
      <param name="activityType" value="leisure" />
      <param name="priority" value="1.0" />
      <param name="typicalDuration" value="01:36:00" />
    </parameterset>

    <parameterset type="activityParams">
      <param name="activityType" value="other" />
      <param name="priority" value="1.0" />
      <param name="typicalDuration" value="01:00:00" />
    </parameterset>

    <parameterset type="activityParams">
      <param name="activityType" value="groceries" />
      <param name="priority" value="1.0" />
      <param name="typicalDuration" value="00:30:00" />
    </parameterset>
```

```xml
    <parameterset type="activityParams">
      <param name="activityType" value="social" />
      <param name="priority" value="1.0" />
      <param name="typicalDuration" value="01:46:22" />
    </parameterset>

    <parameterset type="activityParams">
      <param name="activityType" value="business" />
      <param name="priority" value="1.0" />
      <param name="typicalDuration" value="00:48:28" />
    </parameterset>

    <parameterset type="activityParams">
      <param name="activityType" value="bringget" />
      <param name="priority" value="1.0" />
      <param name="typicalDuration" value="01:00:00" />
    </parameterset>

    <parameterset type="activityParams">
      <param name="activityType" value="services" />
      <param name="priority" value="1.0" />
      <param name="typicalDuration" value="01:00:00" />
    </parameterset>

    <parameterset type="activityParams">
      <param name="activityType" value="nongroc" />
      <param name="priority" value="1.0" />
      <param name="typicalDuration" value="01:00:00" />
    </parameterset>

    <parameterset type="activityParams">
      <param name="activityType" value="touring" />
      <param name="priority" value="1.0" />
      <param name="typicalDuration" value="01:00:00" />
    </parameterset>

    <parameterset type="activityParams">
      <param name="activityType" value="delivery" />
      <param name="priority" value="1.0" />
      <param name="typicalDuration" value="01:00:00" />
    </parameterset>

    <parameterset type="activityParams">
      <param name="activityType" value="pickupCS" />
      <param name="priority" value="1.0" />
      <param name="typicalDuration" value="00:02:00" />
    </parameterset>
```

```xml
    <parameterset type="activityParams">
      <param name="activityType" value="delivCS" />
      <param name="priority" value="1.0" />
      <param name="typicalDuration" value="00:02:00" />
    </parameterset>

    <parameterset type="activityParams">
      <param name="activityType" value="outside" />
      <param name="priority" value="1.0"/>
      <param name="typicalDuration" value="00:00:01" />
    </parameterset>
  </module>
```

```xml
  <module name="planscalcroute">
    <param name="networkModes" value="car,carPassenger,van"/>
    <param name="clearDefaultTeleportedModeParams" value="false" />
    <param name="routingRandomness" value="0.0"/>
    <parameterset type="teleportedModeParameters">
      <param name="beelineDistanceFactor" value="1.3"/>
      <param name="mode" value="walk"/>
      <param name="teleportedModeSpeed" value="1.2"/>
    </parameterset>

    <parameterset type="teleportedModeParameters" >
      <param name="beelineDistanceFactor" value="1.0" />
      <param name="mode" value="outside"/>
      <!-- Free-speed factor for a teleported mode. Travel time = teleportedModeFreespeedFactor * <freespeed car travel time>. Insert a line like this for every such mode. Please do not set teleportedModeFreespeedFactor
      <param name="teleportedModeFreespeedFactor" value="null" />
      <!-- Speed for a teleported mode. Travel time = (<beeline distance> * beelineDistanceFactor) / teleportedModeSpeed. Insert a line like this for every such mode. -->
      <param name="teleportedModeSpeed" value="1000.0" />
    </parameterset>
  </module>

  <module name="travelTimeCalculator">
    <param name="analyzedModes" value="car,carPassenger,van"/>
    <param name="separateModes" value="true"/>
    <param name="travelTimeBinSize" value="900"/> <!--  The size of the time bin (in sec) into which the link travel times are aggregated for the router  -->
    <param name="calculateLinkToLinkTravelTimes" value="false"/>
    <param name="calculateLinkTravelTimes" value="true"/>
  </module>

  <module name="linkStats">
    <param name="averageLinkStatsOverIterations" value="1"/>
    <param name="writeLinkStatsInterval" value="1" />
  </module>

  <module name="strategy">
    <param name="maxAgentPlanMemorySize" value="5"/>
    <parameterset type="strategysettings">
      <param name="strategyName" value="ChangeExpBeta" />
      <param name="weight" value="0.95" />
    </parameterset>

    <parameterset type="strategysettings">
      <param name="strategyName" value="ReRoute" />
      <param name="weight" value="0.05" />
    </parameterset>
  </module>
</config>
```

APPENDIX C – Scientific Paper

Potential Impact of Car-Based Crowdshipping on Vehicle Mileage and Carbon Dioxide Emission:

An Agent-Based Modelling Study Case

Farizky Wijanarko

Abstract

The significant growth in B2C e-commerce in the last decade increased the traffic and volume of parcels in last-mile delivery significantly. To mitigate the impact of the last-mile delivery service such as the increased traffic and carbon dioxide (CO2) emission, crowdshipping emerged as an innovation that utilise the travelling crowd as occasional courier to deliver parcels. The goal of this study is to analyse the potential impact of crowdshipping performed by private cars to the local vehicle mileage and its result to the CO2 emission. This is done by simulating the passenger and parcel delivery transportation activities in agent-based modelling platform using MASS-GT and MATSim. An integration framework to bridge MASS-GT and MATSim was formulated in this study to model the interaction between the passenger and urban freight transport. Several scenarios are formulated to analyse the impact of crowdshipping. The results show that the CO2 and passenger-kilometres savings in parcel delivery vans transportation is exceeded heavily by the increase in passenger transportation performed by cars. This results in a slight increase in passenger-kilometres travelled and CO2 emission caused by car-based crowdshipping, although the value is very small that could be considered insignificant. It was found that car-based crowdshipping won't either improve or worsen the impact of the current last-mile delivery system. It could be concluded that crowdshipping will be better performed using a more sustainable transport mode instead.

Keywords: crowdshipping, agent-based, MASS-GT, MATSim, passenger-kilometres, CO2 emission

Introduction

In the last decade, B2C e-commerce has grown rapidly, with an expected income of 6.54 trillion US dollars by 2022 (Vakulenko et al., 2018; Lin et al., 2020). The COVID-19 pandemic also significantly increase the growth in the e-commerce sector by 10% compared to the expected value (Nyrop et al., 2020). The increasing popularity of the e-commerce market consequently increases the parcel delivery and return traffic in the last-mile delivery (LMD) sector, specifically home delivery service (Schewel & Schipper, 2012; Iwan et al., 2016; Faugere & Monstreuil, 2017; Vakulenko et al., 2018; Nahry & Vilardi, 2019). Therefore, it is urgent to improve the last-mile delivery (LMD) so that it could be faster, cheaper, and more reliable, because it could be accounted for 13-75% of the total logistics costs (Gevaers et al., 2011; Chen & Pan, 2016; Gdowska et al., 2018). This is further strengthened by the fact that cleaner transportation is one of the most important priorities of the European Commission in The European Green Deal to achieve a 90% reduction in emission produced by the transport sector by 2050 (European Commission, 2019).

One of the innovations to improve LMD is crowdshipping (CS). This innovation is based on the emerging sharing economy phenomenon, taking the advantage of the development in the app-based platform technologies and utilising the "crowd" or person-traveller as occasional couriers to deliver parcels (McKinnon, 2016 & Le et al., 2019). These occasional couriers will get the monetary compensation in return for their service (Simoni et al., 2020). This method is expected to promote sustainable urban freight transport by reducing the number of vehicles needed to deliver packages (Arslan et al., 2018).

The traditional urban freight deliveries using parcel vans can be accounted for approximately 0.6% of the local traffic yet their impact on the local emission and traffic could be considered troublesome (Aditjandra et al., 2016; Herold, 2019). Crowdshipping will affect the dynamics between the traditional deliveries with the local passenger transportation since a few of the "crowd" travellers would act as occasional couriers. Furthermore, its impact on the local vehicle mileage and carbon dioxide (CO2) emission hasn't been explored yet in the literatures. Moreover, while many studied crowdshipping using modes such as public transport and walking from various perspectives, car-based crowdshipping is rarely explored. Therefore, this study focuses on analysing the impact of car-based crowdshipping on the local vehicle mileage and CO2 emission.

Agent-based modelling (ABM) could be used as the method to analyse the interaction between the two and their impact to the externalities since it allows a modelling built from the bottom-up, considering the smallest component in the transportation sector, the travellers themselves (Tchervenkov et al., 2020). Two ABM frameworks are used in this study, MASS-GT (de Bok & Tavasszy, 2018), specifically LEAD parcel modules (Kourounioti and Tapia, 2021), to model the parcel delivery transport and MATSim (Horni et al., 2016) to model the passenger and van deliveries in a microscopic environment. The data of synthetic population are obtained from ALBATROSS (Arentze and Timmermans, 2004). Furthermore, there is a potential to use the output of MASS-GT and ALBATROSS as the input for MATSim. Therefore, these frameworks are integrated in this study by bridging the output of aforementioned platforms. The impact of both transport systems on the local vehicle mileage and CO2 emissions are measured based on the output of the simulations.

The remainder of this paper is structured as follows; first, the literature review on crowdshipping is discussed. Afterwards, both ABM frameworks and the integration process is described. Next, the scenarios used in the simulation are described, followed by the simulation results of the scenario. Finally, the conclusion and discussion is presented by the end of this paper.

Crowdshipping: Literature review

Crowdshipping definition

Crowdshipping is built upon the idea of sharing economy and is expected to increase the efficiency and sustainability of urban freight transport (Marcucci et al., 2017). The occasional couriers that participate in crowdshipping are the people (or 'crowd') that already have an initial origin and destination and will take a detour along their route to pick up and drop off the parcel (Punel et al., 2018). Crowdshipping itself can be done using various modes of transport, from private motorized vehicles (i.e., cars, motorcycles), bicycles, public transport, and walking.

Today, most crowdsourced delivery services are exploring the market of food and groceries delivery, with more and more companies starting to explore the potential of this method in other sectors such as retail logistics to offer same-day delivery service (Galkin et al., 2021). This innovative concept attracts the interest of logistics giants such as DHL and FedEx, which explore the possibility of utilising the crowd to deliver goods (Rogués and Montreuil, 2014).

Benefits and challenges

Crowdshipping relies on the travellers as the occasional couriers, hence, the number of trips can be reduced, which consequently would reduce the traffic congestions as well (Mckinnon et al., 2011). The delivery request in the crowdshipping is handled at an individual level, so, it could provide a more personalised delivery method (Punel and Stathopoulos, 2017). This method also has the potential to bring economic benefits for all parties involved, especially for the faster and cheaper same-day deliveries (Arslan et al., 2018). This is because occasional couriers could costs less compared to the professionals (Pakarti & Starita, 2019).

However, crowdshipping might bring negative impact as well, for instance, rebound effect in which the travellers generate more distance per vehicles instead of satisfying the shipping demand and consequently might negate the benefits of crowdshipping itself (Paloheimo et al., 2016; Gatta et al., 2019).

CS acceptance – study case in Rome

Considering the advantages and concerns of the crowdshipping, Marcucci et al. (2017) and Gatta et al. (2019) conducted studies on the potential of using crowdshipping in Rome. Marcucci et al. (2017) surveyed the students in Rome, Italy on the prerequisite requirements for crowdshipping to be successfully adopted in an urban area. It was found that the acceptance of the idea of crowdshipping is relatively high in Rome. 87% of the respondents are willing to act as crowdshippers if the parcel size is small (shoebox size), with monetary incentives of 5-10 euro per delivery, average maximum detour distance of 2.4 km (or 21% of the actual trip distance), and a proof that the crowdshipping is actually a sustainable method. However, this is relatively deviating from the real application of crowdshipping, in which the monetary incentives are averagely 2-4 euro per delivery and average urban crowdshipping distance varies from 8 to 30 km. They also found that 93% of the respondents would be willing to use the crowdshipping service if the crowdshipping company and the crowdshippers could be contacted and if the package tracking service is available. In contrast, the crowdshippers highly value their privacy and are unwilling to be traced (57% of respondents).

Supply and demand

Le et al. (2019) identified the crowdshipping from the supply and demand perspective. The supply means the actor that perform the crowdshipping activities, the crowdshippers. On the other hand, the demand is defined as the people that use the crowdshipping service, hence, the customers.

Since the majority of these couriers are participating in the crowdshipping market voluntarily, their availability and willingness-to-work (WTW) would heavily influence the *supply* side of the crowdshipping. The WTW is heavily dependent on monetary incentives, working environment, and platform operation (Buldeo Rai et al., 2018). Furthermore, the size of parcel, initial trip purpose of the crowdshipper, and and the detour also affects the WTW (Marcucci et al., 2017; Miller et al., 2017; Punel et al., 2018). The crowdshippers' attributes such as the couriers' age also affects the WTW of crowdshipper (Galkin et al., 2021).

The demand-side of crowdshipping is generated by the individuals in the crowd that act as the senders and the receiver of crowdshipped goods (Le et al., 2019). These individuals could be in the form of retailers, logistics businesses, or a person (Buldeo Rai et al., 2017). There are three types of crowdshipping based on the demand-side: business-to-business (B2B), business-to-customer (B2C), and peer-to-peer (person to person). Because the demand-side of crowdshipping is based on the crowd, the network flow of crowdshipping activity depends on the result of the crowdshipping matching procedure between the customer and the courier's planned route (McKinnon, 2016).

Potential market share

As the literatures have shown, crowdshipping will be best used as a complimentary means of delivery, instead of as the replacement to traditional van delivery. A study conducted in the Netherlands by Berendschot et al. (2021) shows that th\ere is a potential for crowdshipping to handle 6% of the total parcel volume in an urban area. Another study from Delft, the Netherlands, shows that bicycle-based crowdshipping could even reach 14-26% of the parcel deliveries market share (Wicaksono et al., 2021). No prior studies on potential market share of car-based crowdshipping is found. Although this study focus on car-based crowdshipping activities, to generalise, the potential number of 10-30% market share for car-based crowdshipping out of total logistics flow will be simulated and analysed in MATSim.

Impact of CS on Externalities

Crowdshipping relies on the road transport system on either side, passenger transport and traditional parcel delivery, and often, it will bring externalities impact. Externalities in road transport includes the traffic congestion and the environmental impact caused by the transport activities itself (Santos et al., 2010). The existence of crowdshipping could be a boomerang to the system itself, depends on the mode used, crowdshipping could either increase or reduce the traffic congestions and CO2 emission produced by transport system (Rai et al., 2017). The evidence from the literatures showed that if performed using a sustainable mode, crowdshipping will potentially reduce the congestion level and consequently, the CO2 emission could be decreases (Rouges and Montreuil, 2014; Rai et al., 2019). However, increasing supply and demand of crowdshipping can lead to an increasing transportation demand, and consequently, increasing the vehicle traffic in a city.

Alho et al. (2020) evaluates the last-mile impact of cargo-hitching, applied to mobility-on-demand (MOD) services, which is similar to crowdshipping, using simulation approach. One of their finding shows that by implementing the "crowdshipping" to the MOD vehicles, the VKT of both transport activities (MOD and freight transport) could be reduced by 2%. In other study conducted by Ballare and Lin (2020), it was found that the combination of crowdshipping with microhubs could significantly reduce the VKT of parcel vans in an urban area.

Integrated Agent-Based Modelling Framework

Agent-based modelling

ABM is characterised by the existence of autonomous agents, computational system that are situated in an environment that are capable of making their individual decision based on the predefined sets of goals (Maes, 1995; Jennings et al., 1998). ABM framework is built from the bottom up, meaning that it is a tool to understand a complex system by considering the behaviour of the smallest entities in the environment, in this case, agents themselves. (Chen, 2012). These agents have two key properties: autonomy and social ability (Chen, 2012). The autonomous characteristic means that the agents can operate, carry out the predefined instructions, and make decisions on their own (Hayes, 1999). The social ability means that the agents are able to interact with other agents in the environment to carry their tasks and involve in helping other agents' tasks (Jennings et al., 1998). With these characteristics, the ABM approach is deemed to be suitable for the application in socio-related studies, including urban transport studies (Chen, 2012).

Integrated model framework

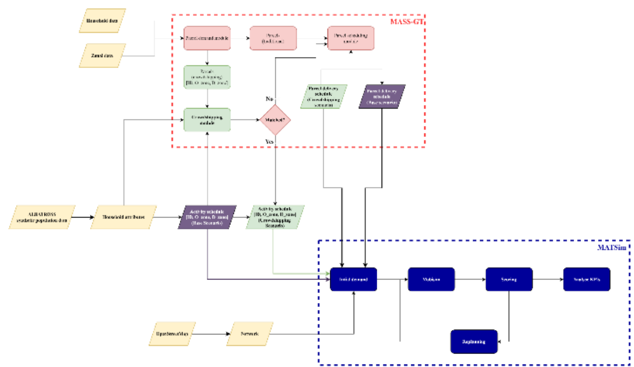

Figure 23Integrated model framework

The integrated model framework is presented in Figure 1. Generally, the integrated model could be distinguished into two parts: MASS-GT side and MATSim side. This section will discuss the integrated model framework.

MASS-GT

MASS GT is an agent-based logistics simulation model for freight transport in the Netherlands as was developed by de Bok and Tavasszy (2018) using large dataset with observed freight transport data in The Netherlands. MASS-GT can model the freight delivery in the shipping module and also parcel delivery in the parcel module. The parcel module of MASS-GT is being developed by LEAD project, a project on the sustainable urban mobility of the future funded by the European Union. This study use the latter module.

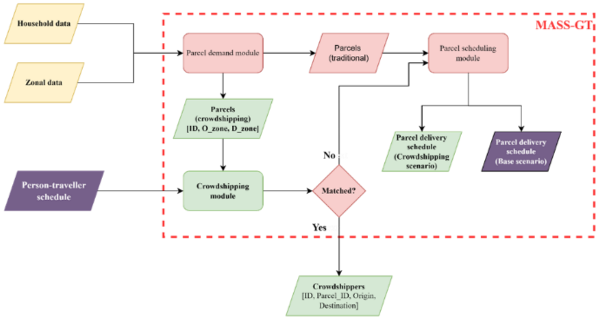

Figure 24 LEAD parcel modules (adapted from Kourounioti and Tapia, 2021)

The LEAD parcel modules are being used in this study to simulate the parcel-side of the model, before being implemented in MATSim. Generally, it consists of **parcel demand module** that generate the parcel demand, and **parcel scheduling module** that assign the synthetic parcel demand to tours and trips of parcel delivery vans. In addition, a special module extension, **crowdshipping module**, is used in this study. The main output of the LEAD parcel modules used in this study are **parcel delivery schedule** and **crowdshippers data.** Figure 1 visualises the workflow of LEAD parcel modules.

Parcel demand module use the household and zonal data to generate synthetic parcel demand. Each parcel generated has their own ID, origin, and destination. The origin and destination variables used in MASS-GT are on the zonal level, specifically, the V-MRDH (*Verkeersmodel Metropoolregio Rotterdam Den Haag)* zones.

The crowdshipping module assigns some percentages of the generated parcels to travelling crowd. The number of crowdshipable parcels and number of travellers allowed to be crowdshipper are bounded by two factors that represents the crowdshipping adoption rate: "CS_eligible" and "CS_willingness", respectively. Then, this module will assign the parcels to the travelling crowds that have their own origin and destination. The matching process is based on the least detour distance, calculated on zonal level using the zonal skim matrix data. The output of this modules is the data of the crowdshipper (traveller ID, origin, destination, parcel origin, and parcel destination).

This data then will be used to create scenarios, discussed on the next section (4. Scenarios). In case there are parcels that were not matched with traveller, the data will be brought back to the demand data and being used as input to parcel scheduling module. This module is the key for integrating MASS-GT with MATSim in this study because it connects all frameworks (MASS-GT, MATSim, and ALBATROSS), along with MATSim's initial demand module.

Finally, parcel scheduling module process the generated synthetic parcel demand that were not assigned for crowdshipping to tours and trips of parcel van deliveries. Each vehicle departs from their own depot, and they have a limit of 180 parcels/vehicle. The main output of this module is the parcel delivery schedule, including the tour ID, trip ID, CEP (parcel and express company), departure and arrival time, and origin and destination of each trips.

MATSim

One of the most popular microscopic traffic simulations platforms is MATSim (Multi-Agent Transportation Simulation), due to its high computing speed and excels in modelling the behaviour in the trip planning (Maciejewski & Nagel, 2013). MATSim is an open-source disaggregate activity-based multi-agent transport simulation software, designed to handle large-scale scenarios (Horni et al., 2016). Horni et al. (2016), the developers of MATSim, described the software in their paper, elaborately. MATSim enables a single-day modelling of an activity-based transportation. MATSim is built based on co-evolutionary principle, in which the agents' objective is to optimise their daily activity while competing for space-time slots amongst others in the transport infrastructure. While being relatively similar to the route assignment cycle, MATSim also incorporates time choice, mode choice, or destination choice into the iterative cycle, along with the route assignment.

MATSim iterative loop consists of several modules, namely: initial demand, mobsim, scoring, replanning, and analyses as presented on Figure 3.

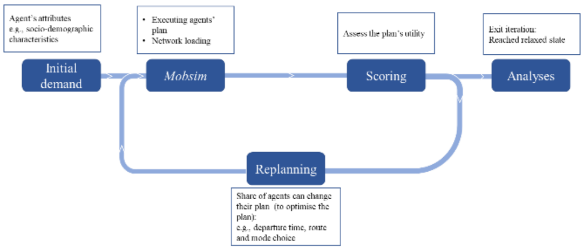

Figure 25 MATSim iterative cycle (adapted from Horni et al., 2016)

Initial demand will be formulated from the observation area populations' daily activities. The populations are consisted of agents, representing a person in real life. Each agent has the socio-demographic characteristics, representing that of real person, for instance, age, gender, occupation, home location, and private vehicle ownerships (Ciari et al., 2016). These agents have a memory, consisted of fixed number of day plans, and each plan is constructed of a daily activity chain (locations, times, and the activities agents will conduct) along with its respective score.

The second step is *mobsim* or mobility simulation. Prior to this step, each agent will select a plan form its memory, depends on the score of the plan, computed after each *mobsim* run, considering the executed plans' performances. The selected plan then will be executed using queue-based traffic flow simulator (Maciejewski & Nagel, 2013). The queue-based model is based on the principle that a vehicle will spend time on a link that is equal to time moving end-to-end of the link and added with waiting time in a queue (Zilske et al., 2012). The links are represented in first-in-first-out (FIFO) manners with sets of parameters, for instance, the length of the link, free-flow speed, flow capacity, and storage capacity. Having the network loaded, this module will give a documentation of changes in the state of any object in the system.

Few agents (often 10%) can clone the chosen plan and modify the clone in replanning modules. The factors that are considered in this step are departure time (and activity duration), route, mode, and destination. This step is done in order for the agents to achieve a more optimal plan with higher utility score. The changes that can be made are among others, change their departure time, mode choice, and their routes (Ciari et al., 2016). In this study, the replanning method that are used are *ChangeExpBeta* and *ReRoute*. *ChangeExpBeta* allows the agent to choose the best plan possible by switching between plans so that it finally converges into the best plan. On the other hand, *ReRoute* strategy allows a few of the agents to change their route based on the information obtained in the previous iteration.

The iteration then will be completed by assessing the agents' experiences within the selected day plans. This step is called scoring. The solutions that generate a high score will be selected by the agents and won't be removed during the replanning step. The iteration between plan generation and *mobsim* is repeated until the system achieve a relaxed equilibrium state (Ciari et al., 2016). The simulation in MATSim is generated stochastically, it means that the convergence criteria is not suitable in this case.

The main input of MATSim are **plan file, network file,** and **config file**. The plan file is the activity schedule of the agents in the simulation. In this study, the plan file of the parcel delivery is obtained from the output of MASS-GT, while the passenger's plan file is obtained from ALBATROSS data. However, MATSim needs the plan file to be set on the operational level, using coordinates to define the location variables. Therefore, pre-processing steps were done to convert the output of MASS-GT (in V-MRDH zones) and ALBATROSS (postcode number) into coordinates. This were done by overlapping both location variables in GIS software, then get all coordinates of buildings inside of it. Afterwards, the agents in the schedule file are assigned randomly to a location if they are located inside of the study area. If a location is outside of the study area, then it will be assigned to the centroid's coordinates of the zone/postcode. The study area is discussed further in the next section (4. Scenarios).

The network file defines the geo-spatial boundary of the simulation and is obtained from OpenStreetMap, processed with JOSM's MATSim module. By doing so, the network file of OSM is converted into XML format that is compatible with MATSim.

The config file contains all configurations used to run the MATSim simulation. Besides the directory details, this file also controls the simulation, for instance, the number of iterations, which mobsim module is going to be used, etc. The weights and utility function used in the logit model that influence agents' behaviour is also defined in this file.

Scenarios

The scenarios are needed to run and analyse the output of MATSim. Two kind of scenarios is formulated in this study: the base scenario and crowdshipping scenarios. Base scenario represents the existing condition, without the existence of crowdshipping. On the other hand, crowdshipping scenarios represents the condition in which crowdshipping exists in the simulation.

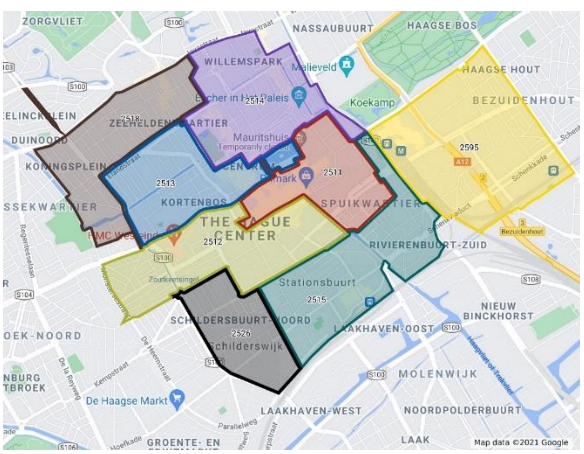

Figure 26 Study area

Study area

This study focuses on the city centre of The Hague. Since the term "city centre" have no specific boundary, a study area is introduced to set the spatial limit of the simulation. Furthermore, the data needed, and computational time of the simulation can be significantly cut down. The study area that is being used in this thesis consists of eight 4-digits Dutch postcode zones that are located in the heart of The Hague, The Netherlands. Figure 4 pictures the study area used in this study. The trips that are considered in this study are only the trips with at least one leg inside of the study area, which means only trips **to, from,** and **within** the study area are considered.

General assumptions

Several assumptions were made in this study. This simulation study aims to analyse the externalities impact of car-based crowdshipping, which means the movement of the vehicles are more interesting compared to the static vehicles, such as parking problem. Both passenger's transportation mode, car and carPassenger, have the same parameters defined in the config file. The only difference is that the agents that are using carPassenger as the transport mode can't be a crowdshipper. Furthermore, this study will focus on the value of VKT, which is based on the number of vehicles instead of passenger. For the van mode, it is also assumed that a van is consisted of one driver.

While assigning the agents to buildings inside the study area, no distinctions between the buildings were made. This means that the function of the building is not considered in this study, for instance, this study doesn't consider which building is school, office, home, etc.

Base scenario

The base scenario was formulated based on the data from ALBATROSS and MASS-GT. The base scenario is the (synthetic) existing condition of the population in The Hague, without the existence of crowdshipping. In this scenario, all parcels are distributed by the parcel vans and person-agents execute their activities throughout the day. After the data have been processed, they could be run in MATSim to set the base of comparison, to be compared with the crowdshipping scenario.

In this scenario, the parcel vans' activities are independent of the passengers' activities. The number of parcels delivered are not considered in the base scenario, since there will be no exchange between the parcel vans and the person-agents. The interaction between the two is only that they are sharing the very same transport infrastructure.

Crowdshipping scenarios

Three crowdshipping scenarios, each with different value of crowdshipping adoption rate are formulated in this study. In this scenario, parcels are partially delivered by crowdshipping activity, in addition to the traditional van delivery.

Not all person-travellers could be chosen as crowdshipper. They have to fulfil the crowdshippers' eligibility criteria that were derived from the literatures. The crowdshippers' criteria used in this study are summarised in Table 1 below.

Table 18 Crowdshippers' eligibility criteria

Criteria	Findings	Sources	Implementation
Age	22 to 55 years old	*Galkin et al., 2021; OECD, 2021*	"<35" and "35-55"
Trip purpose	More flexible activity	*Miller et al., 2017*	Not **Work**
Compensation	Lower than traditional van, 1.5 – 3.35 euros	*Autoriteit Consument & Markt, 2020; Berendschot et al., 2021*	$compensation = \ln(distance + 2)$ (Implemented in LEAD modules)
Acceptable detour	2 to 2.5 kilometres	*Marcucci et al., 2017; Neudoerfer et al., 2021*	Considered
Mode	Car, bicycle, PT, walk	*Binetti et al., 2019; Gatta et al., 2019; Wicaksono et al., 2021*	Car

House hold Income	-	*Assumed*	"low", "average", "aboveAverage"

If a traveller is chosen to be a crowdshipper, they have to deliver the parcels directly. This means their route should be from their origin → parcel origin → parcel destination → their destination, as visualised by Figure 5.

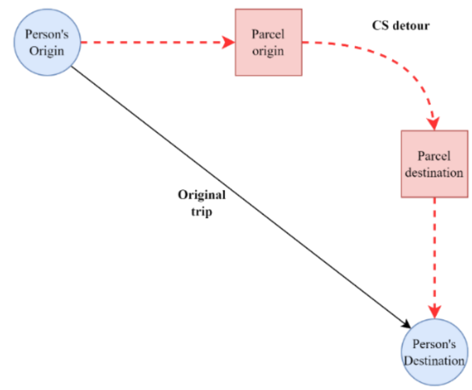

Figure 27 Illustration of crowdshipping trip

Three different crowdshipping adoption rates are used in three different crowdshipping scenarios. The adoption rates used in each scenarios are presented in Table 2.

Table 19 Crowdshipping adoption rate

Parameter	CS - reference	CS B – increased	CS C – reduced
CS_willingness	0.2	0.3	0,1
CS_cust_willingness	0.1	0.2	0.05

Results

The scenarios formulated are simulated using the constructed modelling framework. The results of each scenario run are compared based on the defined KPIs.

Calibration, verification, and validation

To ensure the model is working correctly, the model is calibrated, verified, and validated first. The calibration process is done by fine-tuning the network capacity factor (*flowCapacityFactor* and *storageCapacityFactor*) until the simulation results represents the input schedule file. The integrated model is conceptually validated by doing an expert review. The verification process is done by running the simulation with different random seeds to see if the model shows consistency. Finally, the model is validated by doing a behaviour prediction test. This is done by formulating multiple hypotheses while changing several variables of the model and to see if the model behaves accordingly.

KPIs

Two KPIs are defined to assess the externalities impact of car-based crowdshipping in the study area, based on the simulation results. The first KPI is **Vehicle kilometres travelled (VKT)**. One of the MATSim output is the data of passenger-kilometres (pkm) travelled, which represents the distance through by each passenger. Since in this study each vehicle is assumed to be occupied with one passenger, 1 VKT is considered as 1 pkm.

The other KPI is the carbon dioxide (CO2) emission. This is calculated by multiplying the transport activity (VKT) with the CO2 emission factor per mode, measured in gCO2/km. The passenger cars in this study are assumed to be uniform and are using petrol fuel. The same goes for parcel vans, they are considered as uniform and are using diesel fuel. The value of CO2 emission factor per mode are presented in Table 3.

Table 20 CO2 emission factor

Mode	α_{mode} $(gCO2/km)$	Source
Passenger cars	127.6	*European Environment Agency, 2021*
Parcel vans	245	*PostNL, 2020*

Simulation results

All the necessary files that have been developed are simulated in MATSim environment. The simulation was run for 100 iterations, and it took 6 hours of run time using a computer with Intel i7 and 8GB of RAM.

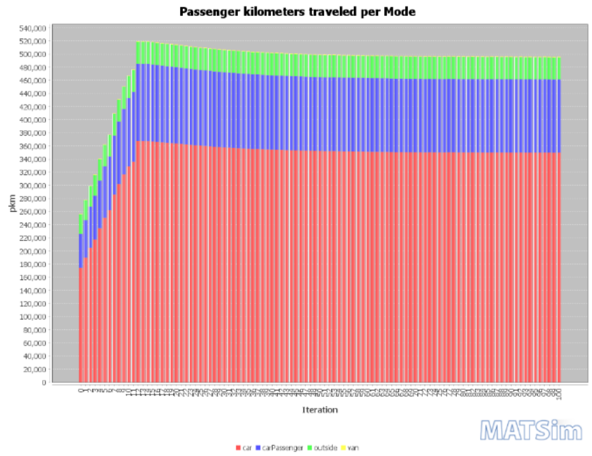

Figure 28 pkm per mode (base scenario)

Figure 6 is the value of pkm travelled per mode in the base scenario over iterations. It can be seen that after number of iterations, the value of pkm stabilises. This implies that the “relaxed state” or the Stochastic User Equilibrium (SUE) condition has been reached by the simulation. The same goes for all scenarios simulated in this study, the SUE condition already has been reached in each scenario.

Scenario comparison

All scenarios simulated are compared based on the KPIs that have been defined: pkm value and the CO2 emission produced. The simulation results of all scenarios are presented in the Table 4. It can be observed that car-based crowdshipping slightly increased the vehicle mileage and CO2 emission. However, the increase in all scenarios are very small, ranging from 0.07% increase (CS-C) to 0.27% increase (CS-B) on both KPIs. This is mainly caused by the fact that the traditional van delivery service offers a more established and efficient method in delivering parcels due to its capabilities of parcels consolidation and delivering multiple parcels on a single trip. Car-based crowdshipping, on the other hand, can only deliver a single parcel on a single trip and it has to take two extra trips to deliver each parcel, one to pick-up the parcel and another to deliver the parcel.

Table 21 Scenario comparison

Mode	Base		CS-C		CS-Reference		CS-B	
	pkm (km)	**CO2 (gCO2)**	**pkm (km)**	**CO2 (gCO2)**	**pkm (km)**	**CO2 (gCO2)**	**pkm (km)**	**CO2 (gCO2)**
car	349,846	44,640,350	350120	44675312	350,619	44,738,984	351,074	44,797,042
van	951	232,995	941	230300	932	228,340	823	201,635
Total	350,797	44,873,345	351,061	44,905,612	351,551	44,967,324	351,897	44,998,677

All crowdshipping activities involve a detour from the agent's original route. The detour is calculated by the differences in total driven distance of car in the base scenario and crowdshipping scenarios. From the comparison between the two scenario, it is found that the average detour distance caused by crowdshipping in all crowdshipping scenarios ranging from **2.28 to 2.76 km per parcel**. This result is in-line with the findings of Marcucci et al. (2017) and Neudoerfer et al. (2021), stating that the maximum detour of crowdshipper is around 2 – 2.5 km. The parcel delivery efficiency comparison between the CS scenario reference with the base scenario is presented in Table 5.

Table 22 Parcel delivery efficiency (CS scenario reference)

	CS-C: reduced		**CS-reference**		**CS-B: increased**	
	van	car	van	car	van	car
Avg. distance/parcel (km/parcel)	0.790	2.28	0.799	2.523	0.84	2.76
Avg. emission/parcel (gCO2/parcel)	193.73	290.93	195.75	321.93	205.8	352.18

Results implication

The results of all scenarios imply that the adoption of car-based crowdshipping will not have a significant impact to the total vehicle mileage and CO2 emission produced by the transport activities in the study area. Although the simulation results show that all crowdshipping scenarios will lead to increase in both KPIs, the differences are very small, ranging from 0.07% to 0.28% increase. However, a pattern on the correlation between car-based crowdshipping with the total mileage and CO2 emission can be discerned. With the increasing value of crowdshipping adoption rate, the total CO2 emission produced will also increase. This could be explained by the better efficiency of traditional van in delivering parcels due to its capability of delivering multiple parcels in a single trip and the ability of consolidating parcels before dispatching delivery fleets from the depot. The crowdshipper, on the other hand, have to dedicate two extra trips, detouring from their initial route to pick-up and deliver one parcel. Consequently, the increase in car mode due to crowdshipping activity exceeds the savings in the traditional van in every scenario.

The simulation shows that even 5% of crowdshipping adoption rate will increase the CO2 emission and vehicle mileage, although the addition in both KPIs are very small. However, if the car-based crowdshipping adoption become more successful, the increase in both KPIs will potentially increase. To prevent further increase in CO2 emission, crowdshipping would be better performed using a more sustainable transport mode such as bicycle or public transport. Electric car could also be a sustainable option to perform car-based crowdshipping, as the emission produced by its entire life cycle are approximately 17-30% less than the emission produced by the traditional cars and it emits zero gas emission on the operational level (EEA, 2018). However, electric cars operates in the same transport network as the regular cars, hence, the impact on vehicle mileage will still be similar with that of the regular cars. It is also interesting to execute an experiment with even lower value of market adoption rate than crowdshipping scenario C to find the threshold in which car-based crowdshipping exists while also reducing the CO2 emission and mileage.

To even reduce the detour distance, innovations in last-mile deliveries such as pick-up points or parcel lockers could be combined with crowdshipping. If pick-up points exist across the city in a frequently busy area such as metro or train stations, supermarkets, and business area, the detour of the crowdshipper could be potentially decreased. Furthermore, if public transport mode is also considered in the simulation, this should be more environmentally beneficial. However, it would possess its own challenges for the crowdshipping service providers since they have to formulate a more comprehensive matching algorithm.

Added value of the integrated model

The integrated model developed in this study offers a microscopic simulation of both transport spectrum, the passenger and parcel delivery transport, in an activity-based agent-based modelling framework. The added value that the integrated model could provide are presented in Table 6. The input to the integrated model is simulated in zonal level, and MATSim simulates them in a more microscopical way, on the coordinate level. This offers a higher level of detail in modelling a scenario.

Table 23 Added value of the integrated model

	MASS-GT	**Integrated MATSim**
Passenger transport simulation	No	Yes
Parcel transport simulation	Yes	Yes
Travel time and distance calculation	Zonal level	Coordinate level
Network congestion and background traffic	No	Yes
Route choice	Static network assignment	Stochastic, based on the initial demand and replanning module
Input data	Zonal data, household data, network	Activity schedule, network
Contribs and extension modules	Do not exist yet	Yes

MASS-GT can simulate parcels with an ABM framework, as was explained in Chapter 3.2. The parcels are simulated thoroughly, from the parcel demand generation process, the parcel distribution among the firms, parcel distribution along the network, until it reached a parcel schedule, consisted of tours and trips. The MASS-GT parcel modules also has the potential to be expanded, for instance, the inclusion of other methods in last-mile delivery such as parcel lockers, pick-up points, etc.

The integrated model provides a framework to convert the output of MASS-GT's parcel module to be simulated in MATSim. Since MASS-GT by itself offers an in-depth simulation for freight transport, by simulating the model in MATSim, the output provided would be in even more detailed. Moreover, simulating in MATSim allows the inclusion of congestions and background traffic because it can simulate all transport mode that are configured, including public transport, passenger cars, etc. MATSim simulates the route choice stochastically, meaning, it captures the uncertainties that might occur in the environment. Moreover, MATSim has numerous modules that could be used to expand the model and it could help in solving future research. For instance, the MATSim's emission module could be used to measure the hot and cold emission produced by the agents in the simulation.

Conclusion

The presented results indicates that car-based crowdshipping would not have a significant impact to the vehicle mileage and the carbon dioxide emission. The increase in the local vehicle mileage and CO2 emission are insignificant, ranging from 0.07% to 0.28% increase. This slight increase is due to the distance savings in traditional delivery vans are greatly exceeded by the increased travel distance covered by the private cars in the simulation.

In all crowdshipping scenarios, the average detour distance of the courier ranges from 2.52 km to 2.8 km per parcel, which are in line with the findings of Marcucci et al. (2017) and Neudoerfer et al. (2021) that found the average maximum detour distance accepted by the crowdshippers ranges from 2 to 2.5 km. The more successful a car-based crowdshipping, indicated by the increasing adoption rate of crowdshipping, could lead to more CO_2 emission produced by the transport activities. However, no business was made to be unsuccessful, therefore, this study could be an evident that if car-based crowdshipping succeeds heavily, it could lead to more CO_2 emission in last-mile delivery. This is in-line with the findings of Pourrahmani and Jaller (2021) which found that crowdshipping will be environmentally beneficial if performed mainly by sustainable transport modes.

The inefficiency of car-based crowdshipping simulated in this study is mainly underlined by two factors: the (still) inefficient parcel delivery system in crowdshipping and the mode choice to deliver a parcel on crowdshipper. For each crowdshipper, two extra trips are made, which means that it would require more trips to deliver parcel demand compared to the van delivery service, which can consolidate the parcels in an urban consolidation centre (UCC) before dispatching the vans. These extra trips will slightly increase the CO_2 emission produced and the total mileage, as long as they are performed using regular private cars.

A more sustainable transport mode could be a better option to perform crowdshipping, on the other hand. This is because of the difference in the CO_2 emission produced per distance travelled of the other mode. For instance, electric vehicle and bicycle emit less or even no (local) CO_2 emission while traveling. This is in-line with the finding of Rouges and Montreuil (2014) and Rai et al. (2019) that discussed if crowdshipping is performed using a sustainable transport mode, the CO_2 emission could be reduced.

Discussion

Sets of assumptions and simplifications are formulated in order to construct the model and simulate the scenarios in this study. These generalisation might cause some imperfection to the results of the model. This study model all buildings iniside of the study area in the city centre of The Hague, however, no distinctions between the building's function, for instance, schools, offices, grocery stores, etc. This could cause the model's transportation pattern to be different with the real-life situation. The study area set in this study is relatively small, therefore, the ratio between the number of parcel and its trips with the travellers might be inaccurate. The enormous differences in the number of trips between parcel vans and private cars causes the model to be relatively unresponsive to the changes in both KPIs. A study conducted in Vienna shows that passenger cars could be accounted for 86.5% of the traffic while the parcel delivery trips are around 0.6%, while in this study, the value of parcel vans' pkm is accounted for 0.3% of total pkm. Moreover, no references on car-based crowdshipping adoption rate could be found in the literatures, and therefore, the value used in this study are assumed. This could hinder the results since the number of supply and demand of crowdshipping in this study might be over or underestimate the real life case. Other sets of assumptions on the crowdshippers side are made, for instance, they have to deliver the parcel directly and can only take one parcel at a time. The demand-side of crowdshipping also represented rather minimally in this study.

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