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Chapter 1

THE NEAR FUTURE OF PARCEL DELIVERY

Selecting sustainable alternatives for parcel delivery

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ABSTRACT

The GHG-emissions of the transport sector are still increasing. This trend is accompanied by the strong growth of the e-commerce sector, leading to more transport movements on our road networks. In order to mitigate the externalities of the e-commerce related parcel delivery market and try to make it more sustainable, the following research question has been drafted: How could the last mile parcel delivery process become more sustainable, i.e. how to minimise traffic impacts and emissions, while maintaining the social and economic benefits of e-commerce and home deliveries?

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To answer the research question, this study follows a Multi-Actor Multi-Criteria Approach (MAMCA), which is defined especially for large projects that require high stakeholder involvement. Based on a stakeholder analysis and an analysis of their points of view, a sustainability framework has been defined. This framework consists of a set of criteria along which several ‘more sustainable’ last mile alternatives have been assessed. The most important criteria are the reduction of GHG emissions, delivery time, costs and customer satisfaction.

This study assesses the costs and benefits of the implementation of cargo bikes, electric vans, Urban Consolidation Centres (UCCs), crowdsourcing systems, and evening and night time deliveries. First, a Simple Multi-Attribute Rating Technique (SMART) method is applied to identify the alternative(s) that offer the highest utility (most benefits). According to the SMART analysis, parcel lockers, UCCs (with electric transport) and night delivery are the most beneficial alternatives for a sustainable last mile in all different cases (best-, middle- and worst-cases). After implementing these alternatives in a Discrete-Event Simulation (DES) model and conducting carefully designed experiments with it, the conclusion can be drawn that implementing or expanding the parcel locker infrastructure significantly enhances the operational efficiency. Furthermore, these lockers can easily be replenished by night, which reduces the traffic impact of parcel delivery even further.

Keywords: parcel delivery, sustainability, assessment, simulation, future

INTRODUCTION

Recent years have been marked by a spectacular growth of e-commerce shopping. Ecommerce Europe [1] reports yearly increases of e-purchases in Europe in the double digits, amounting to over two billion parcels in 2018. This development goes hand in hand with an increase in the demand for delivery services to transport the parcels to the customer, of which most deliveries are made in urban areas [2,3]. To illustrate, the largest Dutch delivery operator, PostNL [4], has experienced a growth of over 80% in parcel volumes over the preceding five years. Successfully meeting this extraordinary demand growth while safeguarding city liveability and minimising environmental impact is considered a major challenge [5]. Especially the lastmile, i.e. transportation from the final parcel sorting depot to the customer’s doorstep, is regarded as the most expensive, inefficient, and polluting part of the delivery logistics chain [6,7].

The boost in parcel delivery not only impacts the delivery supply chain, but also carries environmental and economic consequences for society [5]. Firstly, although some operators move to electric vehicles and cargo bikes for last-mile

delivery, the number of polluting diesel light-duty vehicles is still growing due to the boost in customer demand. Secondly, despite a decrease in the amount of customer shopping trips made, the surge of delivery vehicles that drive through cities every day lead to more congestion.[2]. A side effect of reduced vehicle speeds due to road congestion is that delivery vehicles emit up to 60% more CO₂ than when driving at cruising speed [8]. Schliwa et al. [5] argue that fundamental system changes are necessary to combat the negative externalities caused by parcel transport, especially in last-mile delivery.

In order to mitigate the externalities of the e-commerce related parcel delivery market and try to make it more sustainable, the following research question has been drafted:

How could the last mile parcel delivery process become more sustainable, i.e. how to minimise traffic impacts and emissions, while maintaining the social and economic benefits of e-commerce and home deliveries?

To answer the research question, this study follows a Multi-Actor Multi-Criteria Approach (MAMCA), which is especially defined for large transport related projects that require high stakeholder involvement. Based on a stakeholder analysis and an assessment of their points of view, a sustainability framework has been defined. This framework consists of a set of criteria along which several ‘more sustainable’ last mile alternatives have been analysed. Simple Multi-Attribute Rating Technique (SMART) method is applied to these last mile alternatives to identify the alternative(s) that offer the highest utility (most benefits). This selection of the most promising alternatives are studied in more detail in a discrete event simulation model.

LAST MILE PARCEL DELIVERY ALTERNATIVES

Retailers are increasingly interacting with their customers through the internet, which has opened a new market, called “e-commerce” [9]. While e-commerce was initially focussed on the Business-to-Consumer (B2C) market, it is increasingly becoming active in the Business-to-Business (B2B) market.

The logistics processes

The logistics chain for domestic parcel delivery is typically organised as explained by Borbon-Galvez et al. [10] : a customer places an order at a shipper. The transportation process starts with collecting the parcel from the shipper and bringing it to a sorting depot of a delivery operator. Depending on the configuration of the delivery operator’s network, this can be a local, regional, or

national sorting depot. There are three common methods for parcel collection: depot collect, e-retailer collect, and outsourced collect. With depot collect, the shipper brings the parcel to a nearby sorting hub of a delivery operator using its own means of transportation. Depot collect is regularly used by shippers with large parcel quantities. E-retailer collect involves a pickup by the delivery driver at the shipper. Lastly, outsourced collect relies on an intermediary location such as a parcel shop, where the parcel is dropped off by the shipper, and picked up by the delivery driver. At the sorting depot, the parcel is consolidated with parcels from different origins, and is moved towards a truck. The truck transports the parcel to the next location (referred to as line-haul), which is either a larger central hub, or another sorting depot, depending on the operator's network and final destination of the parcel. At the sorting depot, the parcel is routed through a series of conveyor belts to a load buffer, and loaded into a light-duty vehicle.

Subsequently, the last-mile delivery process starts. This involves delivering the parcel from the final sorting depot to the recipient's address or a Collection-and-Delivery Point (CDP) such as a parcel shop so that the customer can collect the parcel at a convenient moment [11, 12]. If the delivery attempt is unsuccessful, the delivery driver takes the parcel back to the sorting centre, delivers the parcel at a neighbour, or brings it to a CDP.

The Last Mile alternatives

Regarding last mile 'delivery', Edwards et al. [13] make a distinction between 'home deliveries' and 'personal shopping' and state that personal trips to shopping centres can be more energyconsuming than the entire upstream supply chain. Instead they conclude that home deliveries are likely to produce less CO₂, even after including failed deliveries in the analysis. Hence, home deliveries can still be seen as a legit sustainable option of last mile delivery, providing that the current externalities like carbon emissions are mitigated.

Collection and Drop-off Points and parcel lockers

The alternative of Collection/Drop-off Points (CDPs) has already been introduced by companies like PostNL. PostNL uses classic retail locations stores as a CDP, where PostNL collects the items one or a few times a day. Furthermore, PostNL has operationalised the use of parcel lockers in crowded public areas, where people can collect their parcels 24/7 at a moment that fits their agendas best. Zenezini et al. [14] also stress the importance of location. The installation of parcel lockers in the public space, in fact, suffers from legal constraints and the necessity for different permits. Companies, therefore, chose mainly to install them in private places such as shopping malls, where customers can easily access them and can combine different purposes for one trip. Cherret et al.,[15] also mention that parcel lockers are the independent and 24/7 accessible solution, which is an

improvement in services compared to the current collection points. Collection points are mostly located at supermarkets, gas stations or any other commercial establishment, which implies limited opening hours.

Safety of a locker has been valued as a characteristic as well, although people perceive home delivery as being safer than delivery in a locker. Vakulenko et al. [16] showed in their consumer review of four value propositions how the self-service tool provides value to consumers and the way this value is created. They conclude that the value of parcel lockers is sufficient to allow logistics service providers improving and optimizing the performance of their parcel locker networks. Groceries and webshops like Albert Heijn and bol.com, Walmart, Amazon and Tesco, have introduced 'Click & Collect' or 'Customer Pick-Up' services as a specific form of parcel lockers where products ordered online are directly delivered to the retail location nearby. The only difference is that the accessibility of these lockers is aligned to the opening hours of the retail locations. According to McKinsey and Company [17], parcel lockers (and presumably CDPs) have the ability to cut both labour costs and emissions drastically. Also Bilik [18] and van Duin et al. [19] have shown in their research findings that the usage of parcel lockers is beneficial.

Urban Consolidation Centres

Another alternative that is increasingly getting attention in literature is the implementation of Urban Consolidation Centres (UCCs). UCCs are transshipment points just outside the city boundaries that can be used to consolidate shipments with the same destinations and allow to switch to greener transport modes [20]. This can result in less traffic in the cities, reduce emissions, enhance liveability and reduce costs [21]. However, the business case is depending on a lot of uncertain variables, which makes it unattractive for parties to invest at first and thereby this solution is sensitive for subsidies [22]. Many UCC initiatives have failed in the past according to their business model [23]. However UCCs can work; Cherret et al. [24] showed in their research on delivery consolidation to halls of residence new promising insights as young people are significant generators of home deliveries. When clustered in university halls of residence, they can generate considerable freight traffic to one location. These could be consolidated into fewer than 300 vehicles for an annual service cost of approximately £18 per student, reducing congestion, parking infringements and improving air quality.

Crowdsourcing logistics services

Due to other concerns like the traffic impact of delivery vans and the corresponding emissions there is a growing need to change. The first implementation of crowdsourcing has been implemented in India, where the traffic congestion in the large cities is extremely high. The so-called Dabbawala system is a lunchbox delivery and return system that delivers lunches from homes

or restaurants to people at work and study. The Dabbawala system achieves very high service performance (highly accurate and on-time) with a low-cost and very simple operating system [25] based on numbers and colours. Every morning, a Dabbawalla-carrier will either walk or travel by bicycle to collect lunch boxes in his/her area. After collection, they will go to the local train station where they are gathering with other Dabbawalas. Next step is the sorting of the lunch boxes. They are put on the trains according to their next destination. When the boxes arrive, they are handed over to the appropriate Dabbawalas. After the train trip, the Dabbawalas deliver the lunch boxes to the owners by bicycle. The processes are the same for the return of empty lunch boxes. This particular delivery system provides job opportunities for (semi-) literated people. Dabbawalas are self-employed. They join the organisation with some capital. Their customers are business men, students, and meal suppliers. The Dabbawalla service-industry is still growing at a steady rate of 5% to 10% per year.

Similar to the principles of the Dabbawala system is the crowdsourcing initiative in Singapore. Wang et al. [26] propose a model based on pick-own-parcel (pop)-stations as used by Singapore Post. After a parcel arrives at the pop-station, the delivery job is outsourced as a crowd-task by means of an app. Wang et al. [26] state that operational and environmental benefits can be obtained due to reduced labour and handling costs. However, they excluded the amount of extra transport the crowd will make for each delivery. Kafle et al. [27] propose a somewhat similar model to Wang et al. [26], but they replaced the pop-station by a conventional delivery van as pickup point for crowd-workers to pick-up parcels at so-called relay points. Kafle et al. [27] assume that crowd-workers primarily walk or cycle when delivering parcels, which has a positive effect on the reduction of traffic movements. This is in contrast to Wang et al. [26], who assume that crowd-workers only use cars for their delivery tasks. Both studies conclude that the proposed last mile solutions are more environmental and economically friendly. However, the conclusion only reflects on the (operational) costs and lacks decent estimates of the traffic impact.

Drone Delivery

On the side, drone delivery may be an ambitious alternative for a little more into the future. The use of drones for last-mile logistics is a new and recent solution to resolve congestion, pollution and infrastructure limitation, is the use of Unmanned Aerial Vehicles (UAVs), or mostly referred todrones [28]. In the past few years, potential applications of drones and prototypes have been linked to parcel distribution. The first company who envisioned drones was Amazon, with the CEO Jeff Bezos announcing in December 2013 that the world's largest e-commerce company was carrying out several tests on drone parcel deliveries [29]. Following the same path, German courier company DHL launched its Parcelcopter Hern while Google introduced its X-Labs' Project Wing. Drones are

fast and can operate without a human pilot, saving thus time on congested roads and having a low cost per kilometre. On the other hand, given the small size of a drone and the payload limitation, there is an upper limit to the size of the package to be delivered. Moreover, the battery-powered system, causes the drone to have a limited range. To overcome the drawbacks of drone delivery, the University of Cincinnati together with AMP Electric Vehicles, has conducted a study on a combined truck-drone mode [30]. The concept is that, while the delivery truck visits a set of locations to make delivery, a drone simultaneously visits another set of locations, returning to the truck after each delivery, to pick up another package. In this way, the benefits of trucks (long range, high payload capacity) are combined with the benefits of drones (high speed and high accessibility), to provide an efficient and cost-effective delivery service. When searching into the literature of drones used for delivery purposes, several studies can be found. The common thread concerns the performance capabilities and the technical aspects of drones, focusing on the potential applications of these vehicles in different disciplines. Examples of previous studies on parcel delivery and emergency supply distribution can be found in Claesson et al. [31], Thiels et al. [32] and Scott and Scott [33]. Obviously drones seem to be an attractive alternative for the conventional delivery van, since they do not have to use roads to travel [34]. Furthermore, drones are green vehicles due to the use of electric engines in most occasions. However, still a lot has to be done before drones can actually be used for parcel delivery, like changing regulations and apply changes to public spaces [34].

Sum up the last-mile alternatives

Most of the alternatives mentioned above are analysed by McKinsey and Company [17] to provide insight in the most promising alternatives for the future. The six most promising alternatives according to the outlook are: UCCs and parcel lockers often combined with new ways of delivery like night (late evening) delivery [35], electric vehicles [36] of light electric freight vehicles [37]. However, multiple solutions have to be combined to achieve the most successful and a conclusive combination. The selection of combinations on what would be best is explained in the next section.

SELECTING LAST MILE PARCEL DELIVERY ALTERNATIVES

A typical and widely used approach for choosing between different alternatives based on a set of both quantitative and qualitative criteria, is the Multi-Criteria Decision Analysis (MCDA) approach (Ampe & Macharis, 2008; Vincke, 1992). However, it is not a given that all stakeholders' opinions are included in a MCDA and therefore, the Multi-Actor Multi-Criteria Analysis (MAMCA) approach was developed [38][39].

By including stakeholders in the early stages of the MCDA, in explicit, with the problem definition and defining the criteria, the MAMCA approach claims to aid towards more sustainable decisionmaking in large and complex transport projects [39]. Since the last mile parcel delivery problem in cities is a problem that concerns many different stakeholders with different points of view, the MAMCA approach seems to be a better fit for this research than regular MCDA approaches. Besides, the MAMCA approach not only aids the decisionmaking, but also covers implementation, which is a totally different stage in these kinds of projects.

The first step of the MAMCA-approach is the selection of the best last mile alternatives as described in the former section. The selection is based on the performance of the alternatives on the criteria in the sustainability framework and is executed by means of a Multi-Criteria Decision Analysis (MCDA) method, in explicit, the SMART-method [40]. The MAMCA-approach overlaps the SMART-method on the first steps, as the first steps of the SMART-method are the identification of stakeholders, the alternatives (decisions) to choose from and the definition of the dimensions of value to analyse the alternatives [40]. The next step is to assign weights to the criteria, or dimensions. The weights can simply be based on a ranking, or a ranking combined with assigning a relative importance. In this study, the weights will be determined based on only the ranking of the criteria, based on the perceptions of different stakeholders. The obtained ranking is already uncertain, since representatives from the stakeholder group will be consulted, without consulting more individuals from this group. Hence, by assigning a relative weight to the obtained ranking, uncertainty would only increase and possibly mitigate trends in the rankings, as one is more conservative with assigning importance than others. Finally, the alternatives have to be measured along the dimensions, followed by a calculation of their total utility.

Actors in the logistics playing field

Since all of the parcel segments consist of senders, recipients and logistics providers, these roles will be considered as three different stakeholder groups. Furthermore, these roles can be found in all B2B, B2C and C2C deliveries, so all of these markets will be considered. Hence, a sender could be an e-commerce company that delivers products to consumers, a supplier to a restaurant or a consumer to another consumer for instance. Recipients can then be seen as consumers or businesses in the city. The logistics providers can then be seen as parcel delivery companies like PostNL, UPS or DHL, distributing goods between suppliers and recipients.

Besides the three obvious roles, governmental organisations are important to consider as stakeholders. National governments and municipalities in particular are affected by the externalities of city logistics and try to find new ways for

mitigating these effects therefore. Municipalities are introducing new regulations (see for instance the ‘Uitvoeringsagenda Stedelijke Logistiek Amsterdam’), while the Dutch national government has implemented national policies to cope with rising emissions [41].

There are also several organisations that represent the 3PL branch in the governmental discussions. In the Netherlands two examples are ‘Transport en Logistiek Nederland’ (TLN), and ‘evofenedex’, both fighting for unambiguous policies regarding city logistics [42]. They state that tightening the rules regarding environmental zones (Milieuzones) in some city centres will cause 3PL providers to conduct unnecessary investments in new material for these areas. Furthermore, the depreciation on this new material will be higher than necessary, increasing the risk that many 3PL providers go bankrupt [42].

Lastly, ‘thuiswinkel.org’ represents the Dutch e-commerce businesses and offers a quality mark for its members. Businesses connected to thuiswinkel.org which have the label are guaranteed to offer the right services to the consumer. Furthermore, many big webshops are connected and have started a campaign together to make the consumers more aware of their ordering behaviour, called ‘Bewust Bezorgd’ [43].

To come up with a framework of criteria that are important for all stakeholders, it is important to first have insight in the issues they value individually. Therefore, all stakeholders have been consulted and based on the reoccurring issues among the stakeholders, the criteria were formulated. The main outcomes of the consultation are summarized in Table X-1.

Table X-1. Summarising points of view stakeholders [44]

Stakeholder	Main focus
End-Consumer and Customers	as cheap and fast as possible delivery at the doorstep, with the highest possible flexibility and security.
3PL providers	become carbon free as fast as possible, increased cooperation between parties and consumers, maintain good working environment.
Suppliers	carbon free delivery, good working conditions and highest possible customer satisfaction with the service.
Governmental organisations	decrease of negative effects of traffic movements in city, while maintaining economic growth and benefits of B2B and B2C deliveries.

Logistic branch organizations	un-ambiguous policies and regulations among municipalities, while also taking the zero emissions seriously.
Thuiswinkel.org	Increase consumer awareness of their online shopping behaviour and make them behave more sustainable.

Selected criteria from the actors' playing field

All stakeholders have to be valued equally to provide a sustainable solution in the sense that it suits everyone's desires. Therefore, most of the aforementioned concerns and objectives will be considered during the analysis and translated into criteria. However, some of these criteria are partly overlapping each other, or are interdependent. Therefore, some collective criteria have been defined to cover these overlaps. This has resulted in the following list of criteria with an explanation for each criterion, which is shown in Table X-2.

Table X-2. Final evaluation criteria [44]

Criterion	Explanation
Delivery Cost	The costs for the actual delivery (3PL perspective) or the costs that customers have to pay.
Delivery Time	The time it takes to deliver the parcel.
Emissions	Reduction of GHG emissions. This can be measured in a percental increase or decrease.
Customer Satisfaction	Increase or decrease of the overall satisfaction of customers.
Safe Working Environment	The extent to which the alternative mitigates risks in the working environment or increases risks for accidents.
Security & Responsibility	The perceived security of personal records and the product itself. Furthermore, the extent to which the responsibility in the chain of companies has to be redefined and the value that is attached to the responsibility is measured as an increase or decrease.

Traffic Impact	The extent to which the alternative is capable of reducing traffic in the city. This is done on a percental scale and refers to the number of traffic movements.
Investments in Infrastructure	The need for investments, either be in infrastructure or software. These are subjective estimates..
Policy Sensitivity	The extent to which current and intended policies can affect a certain alternative. If it is affected, then it is perceived as sensitive.

Note that not all criteria are weighing equally. Their relative importance in the analysis can differ, which can be noticed from the fifth step in the SMART method. This step tries to obtain a ranking that shows the relative importance that stakeholders attach to the criteria [40]. The usual procedure is to proceed with step six, where the stakeholders assign a relative importance to the previously obtained ranking. However, due to the high uncertainty in the ranking itself, assigning a relative importance would increase the differences even more, making it harder to distinguish any subtle differences. To cope with these differences the weights are assigned directly by calculating the averages over the different stakeholders [40]. The so-called reciprocal values have been calculated by $1/\text{rank}$. Then, the sum of the reciprocal values is taken, followed by calculating the normalised values for each criterion. If no rank had been assigned, the non-value was replaced by a zero. Finally, the average normalised value for each criterion/stakeholder combination is calculated.

Assesing the performance of the alternatives

The eighth step in the SMART method is measuring the actual performance of each of the measures (or alternatives) regarding all the identified criteria [40]. The performances are gathered from both literature research and expert interviews. More detailed analysis on the expected performances of the alternatives can be found in Daleman [44]. As many scores from the previously defined alternatives fall within certain ranges, it is hard to assign one specific number for the test. Therefore, the Best-Worst method is applied, which defines worst, average and best-case scenarios for each of the alternatives [45]. By means of this method, more consistent and reliable results can be obtained, while also respecting the uncertainty ranges.

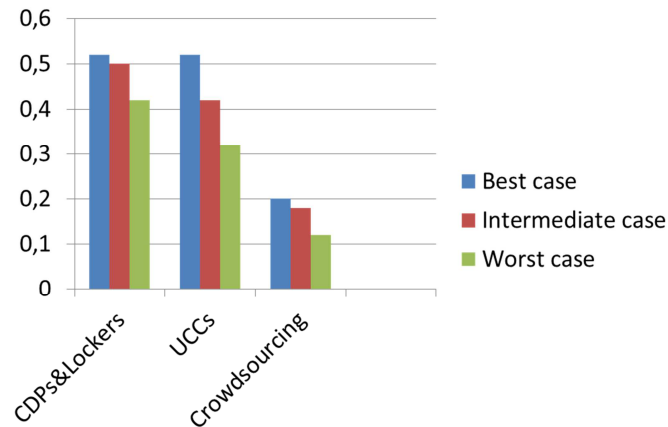


Figure X.1. Analysis of the average utility

The outcome is that CDPs and parcel lockers are the most promising alternatives in all possible cases. Another alternative that is performing very well, is the UCC. However, there are relative large differences between the best- and worst case regarding UCCs. This is due to the large range that is applied for the emissions reduction. The combination of a large range and a high weight cause the total utility to differ quite a lot.

Sum up assesment parcel alternatives

From Figure X-1 it can be noticed that the CDPs and parcel lockers are dominant in all defined scenarios. However, looking more closely to the numbers, it has to be pointed out that it is only dominating by a very small margin. Hence, a combination between CDPs and parcel lockers, UCCs and night deliveries however, seems to provide a more solid base for sustainable parcel delivery [17]. UCCs perform bad in comparison to the other alternatives in the worst case. The worst-case data is derived from studies that have analysed the performance of UCCs that applied conventional vehicles for their deliveries. The 20% reduction in emissions is not enough to compete with the other alternatives. Therefore, the UCC in the remainder of this study has to use more sustainable vehicles like cargo bikes, stints and electric vans for all deliveries. Also night deliveries can be combined with the replenishment of parcel locker as can be read in [17].

MODELLING LAST MILE PARCEL DELIVERY ALTERNATIVES

In the former section it was concluded that a more sustainable last mile parcel delivery process contains a more robust and present parcel locker infrastructure, a city hub for consolidating the shipments of multiple transporters and offers options for night deliveries. However, insight is still lacking how these alternatives all work together, and what would be the combined benefits if they are applied for the parcel delivery sector? That is why a simulation model has been created, to get more insight in the effects of these combinations for parcel delivery companies.

According to White and Ingalls (2009), a model is a simplified representation of reality for systems of interest. Models can be used for representing systems that only exist in concept, are expensive to implement and test for the outcomes. Hence, simulation models provide opportunities to aid decision-makers with insights in variables that affect the modelled system, and by generating outcomes for different settings of the input variables. The simulation model of this study is created following the Sargent modelling cycle [47]. The aim of the Sargent cycle is to create valid simulation models, in explicit, models that actually answer the questions decision-makers have. The cycle consists of the following steps: Conceptualisation, Specification, Model Building, Verification & Validation, Experimentation. The most important phases of Sargent's [47] modelling cycle will be covered in the following paragraphs. More information on Specification and Model Building can be found in Daleman [44].

Conceptualisation of the parcel delivery system

The simulation model has to provide more insight in the performance of the parcel delivery system in the city of Amsterdam when multiple new alternative systems are being combined. To get these insights, certain parts of the original process have to be modelled.

To make a demarcation the simulation model excludes the processes of collecting parcels and starts with the parcels arriving at the sorting centre close to the city under study. Normally, in case of PostNL, parcels are sorted per shift and drivers have the freedom to decide which parcels they include in their route. For each driver the simulation model has to calculate a route for the parcels in advance of the simulation, since it has to be known if the route fits within all the limits. Furthermore the drivers have the freedom to decide when to collect parcels at the collection points. There are several of these points within their routes, but whether they collect the parcels at the beginning or the end of the route is up to them. In practice though most of the drivers choose to collect the parcels at the end of the route, since their vehicles are empty and most of the parcels will fit. So these driver processes are modelled in the simulation model. Little insight is yet being

provided in the variables that influence this process and therefore have to be included in the simulation. Therefore the simulation model is further being presented as a black box model [48] and the remainder of this paragraph focusses on the information going in and the information going out of this black box. Besides, the user can have certain control over the behaviour of the model by means of settings, which will be defined as controls. The black-box representation of the model can be seen in Figure X.2.

Simulation input of the parcel delivery model

As a basis for input the geographical data of Amsterdam is used. It is decided to only use the postal code areas (4 digits). A rough level of detail for individual parcel deliveries, but it is expected that otherwise the model will become too extensive to conduct experiments with. Thus, the simulation model requires shapefiles of the city of Amsterdam, dividing the city into the postal code areas [49]. Next, the model requires demographic data of Amsterdam's population. It is assumed that the distribution of inhabitants among the postal code areas was a good predictor for the demand of parcels to deliver. This assumption has been confirmed by PostNL data. In order to determine the starting point of the vehicles from where the deliveries can be conducted, the geographical locations of the transporters' sorting centres have to be known. Google Maps has been used to find out where all the sorting centres are located near Amsterdam. Following up on locations, the simulation model needs the locations of the parcel lockers in the city if these are being used. The locker locations are fixed and can only be changed outside of the simulation model to ensure that always the same locations are being used. However, if the user desires to change the number of lockers, it could be achieved by changing some of the control variables. Following up on the number of transporting companies to include in the analysis, it is important to know their market share. Based on a report from the Dutch Authority for Consumer and Market [50] the following table X-2 was created with the market shares for each of the parcel delivery companies.

Table X-2. Market shares of parcel delivery companies in the Netherlands [50]

Company	Marketshare
PostNL	65%
DHL	25%
DPD	5%
GLS	4%
UPS	1%

However, before the demand can be split up among the five companies defined in Table X-2 an indication for the average demand the system has to deliver should be provided. By analysing the PostNL data about parcel delivery in Amsterdam, the model will be tuned for a demand between 25,000 and 50,000 parcels per day (see [44] for a detailed analysis). Finally, the model takes the vehicle data from the different companies as input. This can be divided into two different categories: the vehicle fleet and the individual vehicle data. The vehicle fleet provides the model with information about how many vehicles a certain company has. The individual data about the vehicle provides data about emissions, range and capacity.

Simulation output of the delivery model

From the list of criteria, the traffic impact, transport costs and transport time per parcel are perceived as most important for stakeholders. Furthermore, these criteria are easy to calculate numerically based on the two following indicators. Firstly, the distance travelled in total and the number of kilometres per parcel are seen as important outcomes of the simulation model, since the traffic impact of parcel delivery was one of the main motivations to conduct this study. Secondly, the total time needed in sense of vehicle use is taken as outcome of interest, as each vehicle needs an employee to drive it. Moreover, employee-related cost is one of the most important factors of the delivery costs, so this outcome could support the reflection on delivery costs. Lastly, GHG emissions of the system are perceived as an outcome of interest, since GHG-emissions reduction is a good indicator for environmental sustainability.

Controls of the simulation model

The simulation model is provided with certain control variables that are controllable by the user before the simulation run is initiated. For instance, the user has the freedom to decide the time horizon for which the simulation will be run by means of the control variable ‘Simulation Time Limit’. By default, it is set to 24 hours. Furthermore, the configurations can be changed by flipping a switch, so the existing system can be combined with the city hub, or only with the parcel lockers infrastructure, or both the city hub and parcel lockers infrastructure, it is up to the user to decide. Besides, the user has the freedom to choose between two city hub configurations: one that only delivers parcels inside the ‘Environmental zone’ of the city, or in all of the city. Lastly, the user has the possibility to change the number of participating delivering companies.

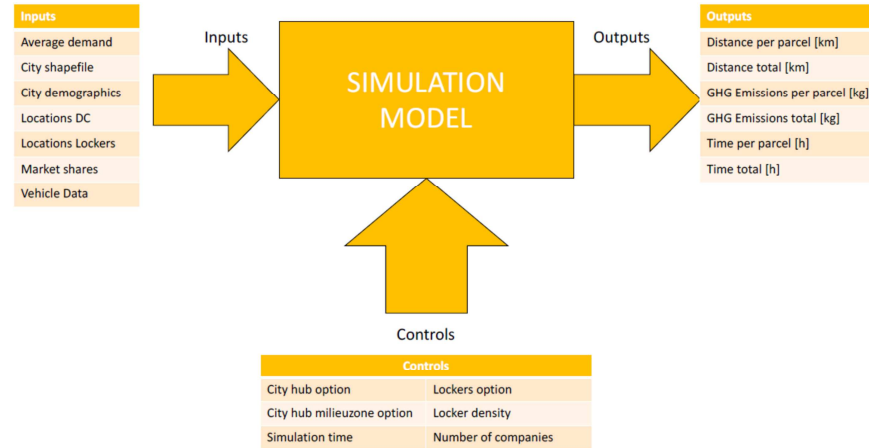


Figure X.2. A black-box representation of the simulation delivery model

The model is developed according to the Discrete-Event Simulation (DES) modelling ‘language’ [51, 52, 46]. DES describes a system’s behaviour over time by means of a series of events that occur [53, 54]. These events are triggered by entities that are flowing through the system. All these entities in the system are defined and assessed individually and all have unique properties [54]. Besides, discrete event models use statistical distributions to generate randomness in the events, which makes it an interesting technique for processes with high uncertainties regarding the variables. The simulation model is written entirely in Python.

Verification & validation of the parcel delivery model

For creating confidence in the developed model it is important to check whether or not the model works correctly. According to Sargent [47] computerized model verification is defined as ensuring that the computer programming and implementation of the conceptual model is correct. Operational validation is defined as determining that the model’s output behavior has sufficient accuracy for the model’s intended purpose over the domain of the model’s intended applicability. As a verification step, one parcel is traced through the system, with different configurations, to check whether or not the parcel has been delivered and no vehicle got stuck. Second, an extreme number of parcels is entered in the dashboard, to see whether or not vehicles get stuck transporting the amount, or that parcels just keep waiting until they are being transported. Lastly, a sensitivity test with extreme values for other simulation variables has been conducted to see

whether or not the simulation models' behaviour or outcomes change extraordinary.

Single parcel trace

The single parcel trace verification test is conducted twice, one time without the city hub implemented, and one time with the city hub implementation. From these two tests, it can be concluded that the parcel was delivered correctly two times and that the outcomes match the expectations. Moreover, the outcomes only show the results of one vehicle being utilised to deliver one parcel to one destination. All other vehicles were on standby, ready to be used the next day. The results of both tests are shown in Figure X.3a and Figure X.3b.

```

-----> RESULTS OF THE SIMULATION <-----
--> HUB option is False
--> LOCKER option is False
--> LOCKER percentage is 10
--> EVENING percentage is 10
--> Included forwarders: ['PostNL', 'DHL', 'DPD']
Total simulated time [h]: 24.00
Parcels in system [pcs]: 1.00
Parcels delivered [pcs]: 1.00
Total distance driven [km]: 43.94
Distance per parcel [km]: 43.94
Total time operative [h]: 1.43
Average time/parcel [h]: 1.43
Total emissions CO2 [kg]: 5493.10
CO2 emissions/parcel [kg]: 5493.10
Total emissions NOx [kg]: 23.95
NOx emissions/parcel [kg]: 23.95

```

Figure X.3a. 1 Parcel trace, no city hub

```

-----> RESULTS OF THE SIMULATION <-----
--> HUB option is True
--> LOCKER option is False
--> LOCKER percentage is 10
--> EVENING percentage is 10
--> Included forwarders: ['PostNL', 'DHL', 'DPD']
Total simulated time [h]: 24.00
Parcels in system [pcs]: 1.00
Parcels delivered [pcs]: 1.00
Total distance driven [km]: 55.93
Distance per parcel [km]: 55.93
Total time operative [h]: 97.81
Average time/parcel [h]: 97.81
Total emissions CO2 [kg]: 12273.56
CO2 emissions/parcel [kg]: 12273.56
Total emissions NOx [kg]: 136.87
NOx emissions/parcel [kg]: 136.87

```

Figure X.3b. 1 Parcel trace, 1 city hub

NOTE: The unit for the emissions in the Figures above should be grams, not kilograms.

Extreme number of parcels test

The extreme number of parcels test is also conducted twice, the first time without the city hub implemented and the second time with a city hub implemented. Just like the single parcel trace test, the extreme number of parcels test yields promising results, as all vehicles are fully utilised in both the day and evening shifts and conduct all possible deliveries. Parcels that did not fit in the planning, as the current capacity is too low, are still in the system waiting for the next day to be delivered.

The extensive sensitivity test of the model can be found in Daleman [44]. Only the most outstanding results from this analysis are discussed here. Firstly, it turned out that changing the number of parcels to deliver per day heavily influences the outcomes of the simulation. By an approximate 90% decrease in the number of parcels, the distance and time per parcel increase by about 350% (estimated), indicating that the results are sensitive to the number of parcels entered. Furthermore, the higher the number of parcels entered in the dashboard, the longer the simulation takes to complete.

The next variable that showed surprising effects on the outcomes, is the capacity of the vehicles. By increasing the capacity with 50%, the distance per parcel can be reduced by 16% and the time per parcel by approximately 2.5%. Besides, decreasing the capacity by 50% leads to a 21% increase in distance per parcel and about 5% increase in time. However, this is only true for the system including a city hub. For the small vehicles used, the capacity is usually the limiting factor and an increase mitigates these drawbacks. However, in the normal system, neither increasing nor decreasing the capacity heavily influences the distance and time per parcel. Lastly, the number of transporters included in the analysis can heavily affect the simulation outcomes. For all the foregoing analyses, three parcel delivery companies are included (PostNL, DHL and DPD). The first effect that can be noticed after including more parcel delivery companies into the analysis, is that the total number of kilometres decreases when the city hub gets implemented. Moreover, this effect gets stronger when multiple smaller companies with only a few destinations are included.

It can be stated that the model is verified for further use in the analysis. The model shows predictable behaviour under extreme conditions without failures. Tracing one parcel was successful in multiple configurations, while an extremely high number of parcels resulted in a large number of parcels that could not be included in a route planning. These parcels were stored to be delivered the next day. Under all other extreme value tests, the model also showed a predictable behaviour and hence, the model is verified for further usage.

The validation was done with experts from PostNL. Since the model is built upon many assumptions and based on a Euclidian ‘road’ network, the simulation results can only be indicative. Analysing real-world data from PostNL to validate the simulation model would yield high inaccuracies. The conceptual model has been validated by the experts from PostNL. They all confirmed the correctness of the process, despite some assumptions that make it easier to model. The simulation model provides PostNL sufficient insight in the performance of the alternative delivery systems and thereby, the model is valid to use for further experiments.

Experimentation with the parcel delivery model

The last and most exiting step in Sargent’s modelling cycle is to set-up experiments to conduct with the simulation model. These experiments have been defined with focus on the last mile delivery alternatives. The setup of the experiments is based on the principle to change One Factor At the Time (OFAT), since it is expected that this results in sufficient insights with less time needed for the design of experiments [55]. Hence, the following experiments are constructed in Table X.3.

Table X.3.

Case name	City Hub	Lockers	Lockers percentage	Evening delivery %
Case 0	no	no	0	10
Case 1	no	yes	10	10
Case 2	no	yes	30	10
Case 3	no	yes	50	10
Case 4	no	yes	70	10
Case 5	no	yes	10	30
Case 6	no	yes	10	50
Case 7	no	yes	40	50
Case 8	yes	no	0	10
Case 9	yes	yes	10	10
Case 10	yes	yes	30	10
Case 11	yes	yes	50	10
Case 12	yes	yes	70	10
Case 13	yes	yes	10	30
Case 14	yes	yes	10	50
Case 15	yes	yes	40	50

All lockers are placed within 500 metres of distance between each other. It is assumed that this is a reasonable distance, based on the willingness to walk and the average walking speed. Lastly, all the experiments have the same daily demand of 27,000 parcels.

The base case (Case 0) has been executed 10 times in advance of the analysis. With the outcomes of interest, an estimation about the preferred number of

replications can be made (van Soest, 1992). For the total distance, total time operative and the emissions, van Soest's formula is applied:

$$n = \frac{n_{test\ run} * \sigma}{0.5 * \max(test\ run) * 0.05}$$

In the formula, n is the desired number of replications, ntest run is the number of replications done for the test run, s equals the half width confidence interval of the set and max (test run) represents the maximum value of the variable in the set. Van Soest's formula has been applied for the total distance, total time operative and the total CO₂-emissions of the outcomes of the base case test runs. Based on the maximum CO₂-emissions and its standard deviation from the average in the set, it can be stated that the following experiment needs at least 5 experiments to yield the desired accuracy (van Soest, 1992). The calculation is shown.

$$n = \frac{10 * 25,789}{0.5 * 2,179,608 * 0,05} = 4.7$$

As a reference the base case is not using a city hub nor parcel lockers and about 10% of the daily demand is delivered in the evening. The performance of all the other cases is compared with the base case to see whether or not performance gains can be obtained by implementing the delivery alternatives in the defined way. In order to easily notice the differences in performance, the percental differences are shown in Table X-4. Furthermore, positive outcomes, or percental decreases, are highlighted in green, while negative outcomes, or percental increases, are highlighted in red. Another reason to normalise on the base case is confidentiality of data.

Table X-4. Percental outcomes of the experiments

Variable	Total distance [km]	Distance/ parcel [km]	Total time [h]	Time / parcel [h]	Emissions CO2 [g]	Emissions CO2/parcel [g]
Case 0	100	100	100	100	100	100
Case 1	95	95	95	94	92	92
Case 2	87	85	82	81	97	96
Case 3	86	84	68	67	88	86
Case 4	81	79	55	53	82	80
Case 5	111	110	98	98	100	100
Case 6	91	100	69	76	87	95
Case 7	100	112	89	99	92	102
Case 8	135	142	117	123	49	51
Case 9	136	142	116	121	48	50
Case 10	130	134	144	149	48	50
Case 11	109	110	154	156	45	46
Case 12	108	109	154	156	45	46
Case 13	126	130	189	196	54	56
Case 14	127	131	190	196	55	57
Case 15	126	131	189	197	55	57

For a better understanding of the Table X-4 the following division is applied: first, the share of parcel lockers is increased (Case 1-4), then the share of evening deliveries (Case 5-6) and ending with a combined case (Case 7). From Case 8, the same division is applied together with the usage of a city hub implementation.

From Table X-4 it can be derived that the parcel lockers implementation has the largest influence on decreasing the travelled distances and the operative times when no city hub is being used. Hence, the GHG-emissions reduce as a result of a reduction in the number of kilometres.

Another observation is that the usage of a city hub leads to significant reductions (≈/- 50%) in GHG-emissions. This is the contribution mainly of the high share of smaller vehicles that is being used by the city hub. At the same time the costs of kilometres and the operational time increase. Meanwhile the parcel lockers have a decreasing effect on the operational time in the regular case. Hence, more vehicles are being utilised to replenish each parcel locker unit. Evening delivery causes an increase on the operational time as more vehicles are needed due to the loss of efficiency caused by the lower volumes.

So based on the outcomes of the experiments (Table X-4), it can be concluded that only the parcel lockers alternative provides solid performance gains when its use is enhanced. This statement can be motivated by Case 4, which applies a 70% share of parcel locker deliveries, 10% evening deliveries and no city hub. Thereby, a 20% reduction in both travelled distance and its related GHG-emissions can be obtained, while also a reduction of 45% of the operational time can be realised. The standard deviations of these variables remain within a 1% range and thereby, the outcomes provide an accurate estimation of the benefits.

The implementation of a city hub in combination with a 70% share of parcel locker deliveries could reduce GHG-emissions by 55%, while increasing the travelled distance and the operational time by 10% and 55% respectively. Since smaller vehicles are being used that can travel via bicycle lanes, it is assumed that most of these travelled kilometres are having less impact on the traffic system in the city compared to the application of (electric) delivery vans. However, the division of these kilometres should be further investigated before more conclusive insights can be provided.

MODELLING LAST MILE PARCEL DELIVERY ALTERNATIVES

The last mile delivery process of parcel delivery can become more sustainable by implementing or expanding multiple alternative systems. Most of the alternatives are provided by McKinsey and Company [17]. The six most promising alternatives according to the outlook are: UCCs and parcel lockers often combined with new ways of delivery like night (late evening) delivery [35], electric vehicles [36] or light electric freight vehicles [37].

From the stakeholders assessment based on the Best-Worst method it is shown that CDPs and parcel lockers are dominant in all three scenarios for each of the alternatives [45]. Therefore, these alternatives and combinations of these alternatives were put to the test in a discrete simulation model.

The experiments with the simulation model showed that especially the implementation of parcel lockers reduces the total distance travelled in the city and time needed for delivery and thereby, reduces the traffic impact and personnel related costs of parcel deliveries. Furthermore, parcel lockers can easily be replenished by night, providing a more solid base for night delivery to develop and reduce the traffic impact even more. This is in line with the findings the findings of Bilik [18] in terms of parcel delivery efficiency

The UCC-option, or city hub, turned out to be less sustainable for the parcel delivery market than perceived in advance by most of the stakeholders. Despite the large potential of reducing GHG-emissions, the city hub causes a significant increase in both the total travel time and distance travelled due to the use of smaller vehicles that have to deliver multiple routes instead.

The simulation model does not provide insight on all the sustainability factors. The effect of the city hub on the distance driven per parcel becomes stronger when more small transporting companies are using the city hub. Thereby, traffic, time and especially GHG-emissions can be reduced. Moreover, the city hub could use smaller vehicles for special deliveries, like cargo bikes, to enhance instant delivery services. Model outcomes show that by implementing the three proposed options (city hub, parcel lockers & night delivery) performance can be enhanced on most of the sustainability criteria. The system offers more flexibility for customers and thereby customer satisfaction is expected to increase. By the application of electric vehicles, the system is less sensitive to the 'Environmental zoning' policies of the municipalities. Furthermore, the implementation of the city hub and the reduction of kilometres in the city reduces the traffic impact in the city significantly. However, serious negotiations have to be done in order to align the responsibilities of stakeholders with regard to the high investments needed to create/facilitate the infrastructures.

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