Urban parcel delivery using lockers

Making last mile delivery more sustainable and cost efficient by using parcel lockers

Master Thesis

Y.A. van Amstel

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By

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Graduation committee

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Preface

This thesis is the last and final result of my time as a student at the University of Delft. This thesis presents the final results of the master research I conducted as part of the master Transport, Infrastructure & Logistics. After doing the bachelor Technische Bestuurskunde in Delft as well, having done research about Urban Consolidation Centres. This research focusses on last mile distribution as well. More specifically last mile distribution for the parcel market, researching how parcel lockers can be used to create a more efficient last mile delivery process. The research was conducted at PostNL, the main logistics service provider in The Netherlands. Using the skills and knowledge I obtained throughout my time as a student I did my best to create a successful thesis. Though this would not have been possible without the guidance and help of some other people.

First of all, I would like to thank the TU members of my graduation committee. First of all, my “daily” supervisor Dr. B. W. Wiegmans. Bart helped me a lot with his feedback on my report, every detail was being addressed and every time Bart challenged me to improve further and look at aspects I didn’t look at before. Being honest and direct helped me a lot during my thesis. My second supervisor Dr. J.H.R. van Duin helped me throughout the process as well. With his positive feedback, Ron gave me guidance to go further with my research and helped me with some more in depth knowledge. Finally, I would like to thank my chair of the committee Prof. Dr. Ir. B. van Arem for having the time to be the chair of my graduation committee and providing hard, honest and helpful feedback on my thesis. All of my TU Delft supervisors were honest and direct from the start of me thesis until the end, something I appreciate very much.

I would like to thank my supervisor from PostNL as well, Mr. L. Tuinhout. Laurens gave me the opportunity when we met, to select different projects he was working on. I was able to choose the project that attracted me the most and free to fill in how I approached the project. Laurens involved me from the first moment into different meetings about parcel lockers with PostNL and gave me the opportunity to see PostNL from another side than only being the intern. I would like to thank Laurens for his trust in me and going the extra mile to look for a proper department for me to conduct my research.

Not to forget to thank the department of Staff Operations at PostNL in Hoofddorp where I was able to take work on a desk at the department. More specifically the department of Depotbeheer being managed by Dave van Duuren. Whom invited me to different team meetings in order to be actually part of the team and not just the intern.

Finally, I would like to thank my family and friends for supporting me throughout my thesis. Asking about the progress I made and helping me with input and questions I had. Not only that but also the moments where I didn’t have the energy to continue they kept telling me it’s part of the process and things will turn out to be okay. It did turn out to be okay in the end.

Thank you all!

Yorick van Amstel
Delft, 2018

Executive Summary

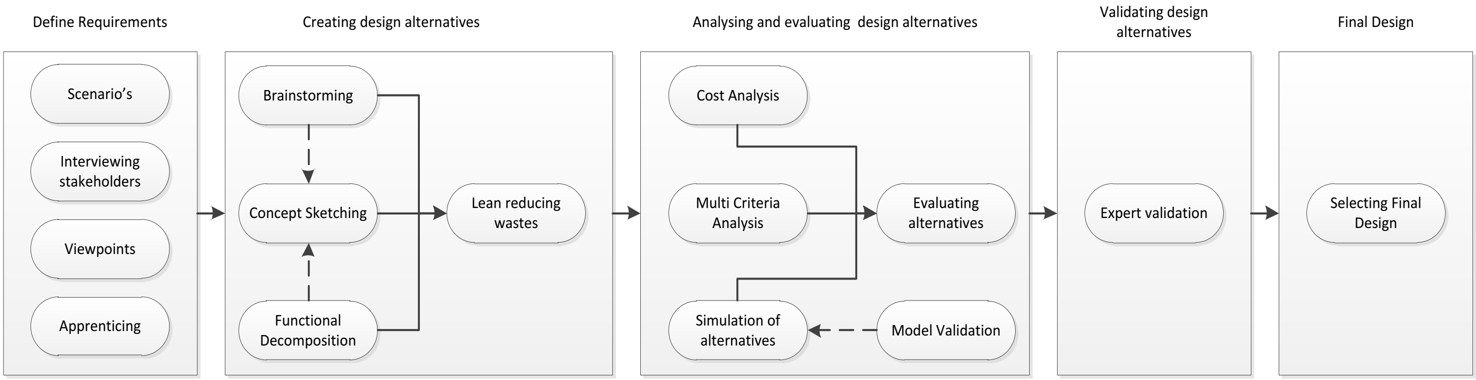
PostNL is the market leader in The Netherlands for parcel delivery. At this moment 70% of the parcels in The Netherlands are delivered by PostNL. With the growing market for parcel delivery it is important to stay ahead of the competitors, and innovation is necessary. Currently parcels are being delivered with large delivery vans which will deliver single parcels to doorsteps of customer or retail locations such as a supermarket. The critical point of parcel delivery is the last mile. Innovation during this part of the delivery is crucial, and several companies are researching methods to do so. The costs for last mile delivery are high and PostNL seeks various ways to reduce costs at this point. The literature mentions several methods to deliver parcels for the last mile leg, such as drones, AGV's and bikes. One of the methods with the most potential is delivery with a parcel locker. PostNL has installed several parcel lockers in The Netherlands to adapt to the growing parcel market. These standalone parcel lockers are a solution for last mile delivery, replacing delivery to houses and reducing chances of missed delivery. This prevents the delivery van covering the same route with the same parcel more than once to deliver the parcel. In order to come up with a solution using parcel lockers for last mile logistics a research question has been formulated:

"How can last-mile parcel delivery be conducted in a more sustainable and financially cost efficient way using parcel lockers?"

In order to answer this question, the research has been built up in five steps. First the introduction, discussing the actual problem and problem statement. The second step is to research the last mile delivery, the current and future delivery models. The third step is to gather several methods to design a delivery model with parcel lockers. In the fourth step the new delivery model will be designed and selected. And finally, a conclusion will be drawn answering the research question and mentioning possible recommendations. Only business to consumer logistics have been taken into consideration, adapting the current delivery model as closely as possible. The parcel lockers which are located in Almere have been used for this research and design to build delivery models with the usage of parcel lockers. Last mile delivery has three important aspects. The first being the first time hit rate. The goal is to have a first time hit rate as high as possible, to prevent having to bring back a parcel to the depot again to be delivered the next day. The second aspect is the density, the higher the density of the delivery area the more efficiently a parcel can be delivered. When delivery vans travel minimal distances, and can deliver parcels in a small area costs will be lower. Delivery window is the third factor. Having a small delivery window is preferred for customers but expensive for a logistics provider. The customer wants to know when a parcel will arrive. Using parcel lockers, a delivery window will be a lot easier to maintain, since the parcel can be collected when a consumer wants to. Security and the type of delivery and customer service are the most important characteristics of last mile delivery. Last mile delivery is important since customers are part of this leg, at the receiving end. Therefore, all these issues are highly important, parcels need to be undamaged, delivered on time and as cheaply as possible. Future delivery using parcel lockers is very different to the current delivery to house addresses. Future delivery offers the possibility to drive routes with only parcel lockers which need to be filled. Literature regarding parcel lockers is scarce, there has been little research done.

There are four important aspects to in this type of delivery. First the customer perspective, which centres on what the customer thinks of delivery to a locker instead of delivery to a house. The second being the location. Locations close to houses are preferred, and locations close to public transport such as bus stops or tram stops are useful. Thirdly, costs to the consumers and the logistics provider Delivery to a locker can be preferred from a customer perspective but if it is more expensive than current delivery there will be no benefits in it. Finally, economics and environment, saving money due to the fact that a delivery driver needs less time to fill a parcel locker, less time on the road and thus this solution is positive from a sustainability point of view.

To design a future delivery model with the usage of parcel lockers a framework has been designed that is able to create one design that performs the best and is able to answer the research question.



To define requirements four techniques have been used. Making scenario's, interviewing stakeholders, looking at different viewpoints and apprenticing. After the requirements have been set the design alternatives will be created. By use of brainstorming, concept sketching a functional decomposition. Using lean to reduces any possible wastes in the process and make the process as efficient as possible. The created designs will be evaluated with three methods. A cost analysis to take a detailed look in the cost and take the quantitative aspect of the spectrum. A multi criteria analysis to take a more qualitative look at the spectrum, using knowledge from experts to value the alternatives. And finally, a simulation to be able to test the conceptual models that have been created, see if they work according to expectation and look at occupancy rates of lockers and operating times. Finally, the designs will be validated by experts and a final design will come forward.

The requirements can be separated in three categories. Functional requirements, non-functional requirements and constraints. Functional requirements being minimum damage to and loss of goods for example. Non-functional requirements being proper security for example. And constraints being a maximum loading capacity for a delivery van. These requirements are used for the creation of the designs. In total nine different alternatives have been created, excluding the current delivery model. The nine alternatives can be separated in three different categories. The first category being the alternatives that replace the retail location with a parcel locker. Customers can now collect and take away their parcels to a parcel lockers instead of the retail location. The second category being the parcel lockers as a substitution for the current delivery model delivery to houses. With this category, the parcels are being delivered as much as possible to a parcel locker and if not possible to a house or retail location. Customers have the option to collect their parcels in a parcel locker but ship them via a parcel locker as well. The third category has the same characteristics as the second but with this category customers are only able to receive parcels and not ship them. It is a distribution model only. The second and the third category have a route which only delivers parcels to a parcel locker and has a route which delivers parcels to a house or retail location and does not deliver to a parcel lockers. This means two separate routes that are required for the second and third category of alternatives. Each of the categories has three different alternatives which are the same for all the categories. Varying from 88% fit in parcel lockers, 66% fit in parcel lockers to 50% fit in parcel lockers. With each fit a different percentage of parcels fits in the lockers, creating a different number of lockers to be build and a different delivery model alongside. The nine different alternatives will be evaluated in the area of De Pijp, a district located in Amsterdam.

To evaluate the nine different alternatives three methods have been used. Starting with the cost effectiveness analysis. The better the fit of the parcels in a parcel locker the more expensive the delivery model is. This is due to the reason with a large fit a large number of parcel lockers need to be placed on the streets and a lot of parcel lockers need to be built. The alternatives where house distribution is being replaced by a parcel lockers score relatively badly on costs, being more expensive than the current delivery model. Due to the costs of building a parcel locker in combination with expensive labour force for the parcel locker route and normal delivery route. Though costs can be saved by cutting labour force in half for the alternatives with the parcel locker route, instead of having 6 delivery drivers for a parcel locker route 3 delivery drivers are able to do the same work on the same day. This gives good prospects. Looking at the MCA it can be seen that accessibility and safety are two criteria that are being valued highly important. This is in line with expectation of the literature mentioned before. Regarding the alternatives that have been created and evaluated in the MCA. All the alternatives score badly on safety, the customer perspective of parcel lockers is at this moment not good. However, regarding efficiency and reliability the alternatives score highly. The same trend can be seen here as well. When the fit in the parcel lockers goes down, the alternatives are being valued worse as well. Indicating that a high fit for parcel lockers is highly preferred, the more parcels in a parcel locker the better it is. Looking at the simulation all nine alternatives are performing without any failures or bugs. This indicates that the conceptual models that have been designed are performing according to plan. The alternatives with a separate locker route show great potential to cut labour force in half when looking at the occupancy rate of the operational time of the drivers. A trend seen here as well, is that when the fit of parcel in the parcel lockers decreases the occupancy rate decreases as well, thus saving time on delivery. This is a positive point. Looking at the occupancy rate of the lockers the alternatives with only distribution are performing the worst. The occupancy rate is almost a 100% indicating that it's a close fit and the model need to perform close to perfection for it to be sustainable. The alternatives with distribution and collection are performing substantially better.

Overall all three methods have been used to evaluate the different alternatives and a ranking has been made. Taking this ranking into account and the sensitivity analysis that has been made one alternative comes forward that performs the best. This is alternative 2 S lockers. This alternative has a 66% fit in the parcel lockers, 34% of the parcels is being delivered with the current delivery model route. 66% Is being delivered with a separate parcel locker route. This alternative replaces current house distribution with distribution to parcel lockers as much as possible and still has a retail location to send parcels to as well. This final design is able to reduce labour force for the parcel locker route. When doing this, this design is able to deliver parcels in the last mile more cost efficiently than the current delivery model does. Also, due to having parcel lockers, this model requires less stops than the current delivery model and thus performing better on a sustainability aspect as well. This delivery model increases the first time hit rate, making delivery more efficient and sustainable. Due to the reason that a delivery van does not have to drive twice for one single parcel. This alternative requires 47 parcel lockers to be placed in the area of De Pijp. These parcel lockers can be placed in various locations, replacing a mailbox or being placed on a parking spot for example. This delivery model is able to reduce the number of delivery drivers by two and therefore having less delivery vans driving around at the same time. Instead of having 1475 stops for the current last mile delivery in De Pijp this new delivery model has 477 stops, this is highly beneficial for efficiency and sustainability. At the end this new delivery model is able to save €121,356.00 on a yearly basis.

To make sure this new delivery model performs successfully in daily operation further research is needed. More specifically research in the PostNL depots. Since this research has been focussing on last mile delivery the sorting in the depots is outside the scope of the research. The necessary step to take now is to see if sorting for two separate routes in one district would be possible and preferably sorting on size as well, to be able to sort for the fit of the parcel lockers.

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List of abbreviations

AGV: Autonomous ground vehicles

B2C: business to consumer

C2B: consumer to business

C2C: consumer to consumer

CBA: cost benefit analysis

CEA: cost effectiveness analysis

FTHR: first time hit rate

HC: hard constraint

HF: hard functional (requirement)

HNF: hard non-functional (requirement)

MCA: multi-criteria analysis

SC: soft constraint

SF: soft functional (requirement)

SNF: soft nun-functional (requirement)

1. Introduction

1.1 Motivation

PostNL is one of the largest companies in the Netherlands when it comes down to delivering mail and parcels. At this moment 70% of the parcels in the Netherlands is being delivered by PostNL and 25% by DHL Parcel (Rooijers, 2015). The rest is delivered by various other companies. PostNL wants to maintain its position in the market. Between 2015 and 2016 PostNL had an increase of 13.3% delivering parcels (PostNL, 2017). To stay ahead of their competitors PostNL needs to be innovating and improving every year. Since DHL is investing €80 million euro's (Rooijers, 2015) to compete with PostNL on the parcel delivery market a need for innovation is required. At this moment parcels are being delivered with large vans and drivers. A report published by McKinsey & Company mentions a future where 80% of the parcels is being delivered by autonomous vehicles (Joerss et al., 2016). To be able to cope with this future PostNL wants to research the possibility of innovative and financially efficient parcel delivery for the last mile.

1.2 Problem Statement

In 2015 300 million parcels have been transported, of which 208 million within the Netherlands and 92 million transported abroad (Autoriteit Consument & Markt, 2016). The large downside to this is the delivery, since most of the e-commerce companies offer next day delivery it is up to the transport companies to fulfil these needs. To be able to maintain the position of being a market leader PostNL sees the need for innovation. Today's delivery model of standard home delivery is an old-fashioned way of operating the parcel market. For PostNL it has quite some financial burdens looking at last mile employee costs, which amounts to be 72% of the total delivery costs of a single parcel (J. Klerx, personal communication, October 23, 2017). With the increasing demand for e-commerce and so the increasing demand in parcel delivery the last mile becomes more critical than ever (Ruan et al., 2014). Where a large part of the cost for that last mile are the employee costs, which according to the formula presented in the article of Ruan et al., 2014, are proportional to the number of parcels being delivered. Meaning the more parcels are being delivered the larger the overall costs will be. Whereas administration fees will remain constant. The goal for PostNL is to be able to deliver the parcels in that last mile at lower cost than at this moment. Being prepared for a possible future of automation is another aspect as well. Where the report of (Bughin, et al., 2017) mentions that by 2036 possibly 50% of the work hours as they are right now will be automated. Since employee costs are a large part in the costs off logistics, automating parts of this can be beneficial. In the transport sector the report mentions that there is an even higher automation potential.

The report of (Joerss et al., 2016) mentions seven different home-delivery models: today's delivery model, drones, bike couriers, semiautonomous ground vehicles, crowdsourcing, droids and autonomous ground vehicles (AGV's) with parcel lockers. Of those seven different models, there are three delivery models that are dominating the others, based on filling customer preferences and being low on cost: today's delivery model, drones, bike couriers (or droids). Together with costs and customer preferences drop density is of importance as well. Looking closely to these three dominating options for the B2C market the today's delivery model at the moment is still the best option. Joers et al (2016) predicts due to the future aspects of automation and the costs of labour with delivery, the AGV's with parcel lockers have high potential in urban areas. Important to take into account is the fact that the design of these AGV's with parcel lockers is unknown, especially their impact on current day traffic for example. One of the reasons being that it's not part of the three dominating delivery models, since customer preferences are divided. A reason for this could be the fact that AGV's are driving on the same road as the current road users.

At this moment PostNL has installed several innovative parcel and letter machines (PostNL, 2016). These machines are open 24/7 for consumers to send and receive their parcels. This is done to adapt to the growing parcel market. The machines as they are located in Almere will be used as input for this research, meaning the design will be based on these machines. Figure 1 shows one of the parcels lockers used in Almere. A short description can be found in Appendix I PostNL Parcel Lockers.

Figure 1 Parcel Locker PostNL (NOS.nl, 2016))

With this in mind, for PostNL to be strategically ready for the future, automation will play an important role. With the (smart) parcel lockers as PostNL has at the moment, a part has been automated already. Though this can be developed further by making it more dynamic and moving the (smart) parcel locker around. Temporary stay on a parking spot for example, or located permanently on strategic locations.

The main question that arises therefore is the question of how PostNL can make the current delivery of parcels financially more cost efficient and environmentally sustainable by making use of new technology such as the parcel lockers in Almere. This being the (smart) parcel lockers for example. This question will be further elaborated in chapter 1.3 below and made into a solid research question.

1.3 Research Question

The objective of this research is to design a new delivery model that can be used in an urban area with the use of future technologies. Being prepared for the expected growth in parcel delivery and keep the market position PostNL has at the moment. The design should be a feasible solution that can be adopted within the next few years. It should meet requirements and constraints that are set by PostNL or will be set during this research. To be able to come up with a solution for the problem that has been stated and achieve the objectives that have been set a research question needs to be formulated. The main research question is stated below:

“How can last-mile parcel delivery be conducted in a more sustainable and financially cost efficient way using parcel lockers?”

Along with this main research question there are some sub questions that can help to answer the main research question. The sub questions will help to answer the main research question. The sub questions that are of relevance are listed below in Table 1**.**

Table 1 Research Sub questions

	Research sub questions
1	What are the main functions and KPI’s of the current last mile delivery?
2	What methods can be used to create a design for parcel locker delivery?
3	How do the designs of a future parcel locker delivery model look like and how do they perform in relation to each other and the current delivery model?
4	How does the final design perform?

1.4 Methodology

To structure the report, the usage of a good methodology is helpful. In the literature, several methodologies can be found for researching and designing a certain problem. For example, more of a black box thinking method (Lodewijks et al., 2008). Which can be of use for the design of the future situation with parcel lockers. Another method that can be used more for the complete structure of the report because of the feedback loops is the method of Dym & Little (2014). The method of Dym & Little (2014) has been chosen to be used for this research. This method sees the design process as a spiral and not a linear process. This to make sure the design should be analysed, refined and evaluated several times for a final design is made. Since this research is focused on finding a design that is able to improve the current situation. Having a structured approach like Dym & Little (2014) helps creating a possible improvement. Figure 2 below gives the visual representation of the structure of the report together with the sub questions that belong to the different chapters.

1. Introduction

The first chapter will give an introduction about the topic of research and why this topic is being researched. The problem statement will be described where after the research question will be presented.

2. Last Mile Delivery: current delivery model and future model(s)

For the current delivery model an extensive literature review will take place together with interviews with employees of PostNL to gather necessary information about parcel lockers and last mile logistics in PostNL. When necessary conduct some field research to get a complete overview of the process and have a solid basis for new designs. The scope of the research will be specified on De Pijp, a district in Amsterdam.

3. Selecting methods for the design of parcel locker delivery

This chapter will contain all the theory that is needed to be able to build up different designs for the delivery with parcel lockers. Will the last mile logistics change much in relation to current delivery? How many parcel lockers are needed to replace the current delivery vans based on their volume? What will the environmental impact be of the parcel lockers and what are the financial costs of such a system? With all these questions, methods are required to be able to analyse the possible designs of such a system.

4. Designing cost efficient and sustainable parcel locker delivery

This chapter will create and evaluate the designs prepared in chapter 3. How will the design of a parcel locker delivery model look like? Which off the designs is performing better than the current delivery and is it even possible to come up with a realistic design that is better than the current. The analysis of the designs through different methods and simulation can answer the main research question.

5. Conclusions and Recommendations

The final chapter will contain the conclusions that can be drawn based on the previous chapters. Together with the recommendations this will conclude the final report.

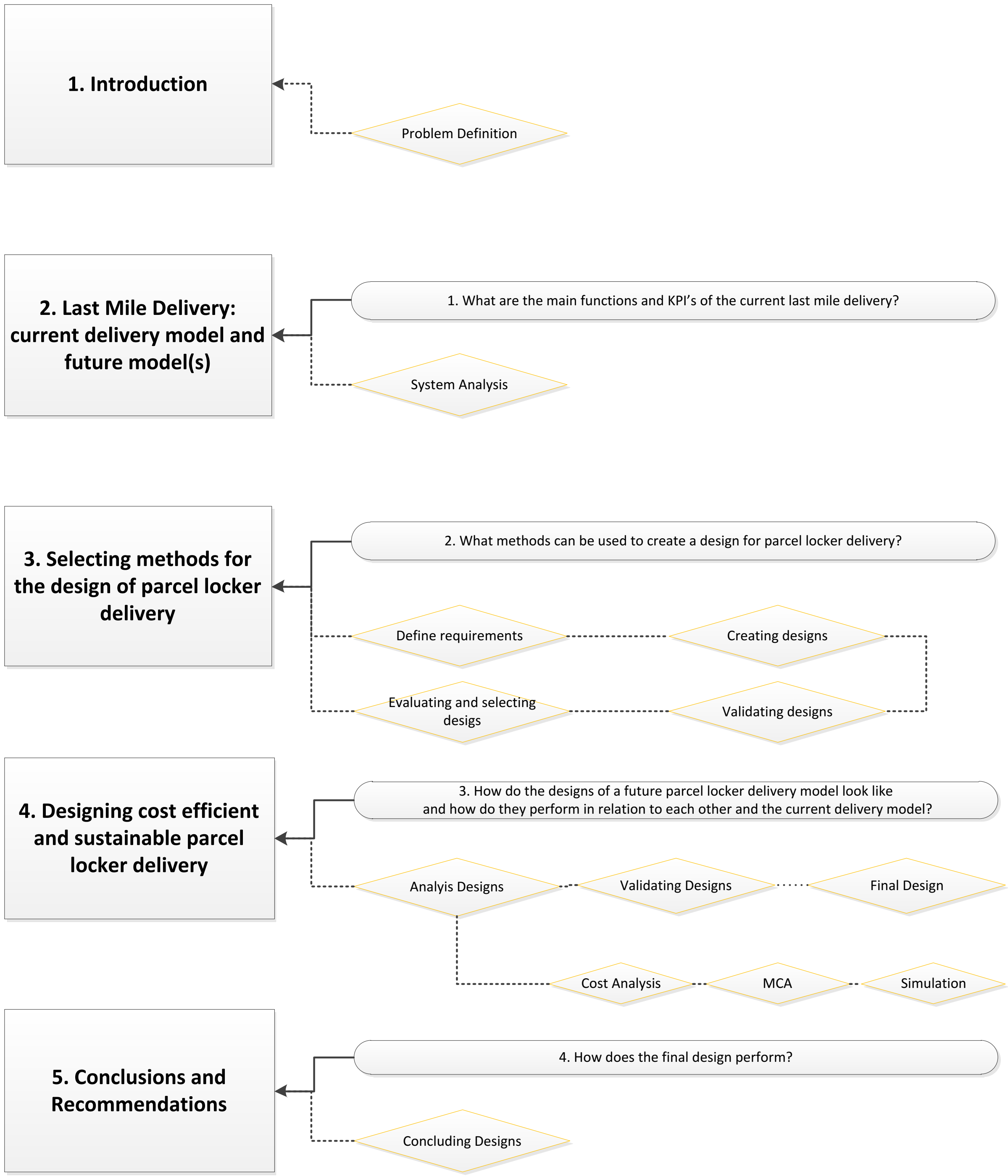

Figure 2 Structure Report

2. Last Mile Delivery: current delivery model and future model(s)

2.1 Scope and geographical location: De Pijp

There are some boundaries that need to be set to define a clear scope and geographical location of the research. The research will focus only on the last mile delivery of the parcels. According to the literature the last mile can be defined as: “The final leg in a business-to-consumer delivery service whereby the consignment is delivered to the recipient, either at the recipient’s home or at a collection point” (Gevaers et al., 2011). The final leg starts at the moment the consignment leaves the last distribution centre before being delivered to the recipient’s home (Yano & Saito, 2016). This report will focus on this part, the moment when the parcel or goods leave the logistics providers warehouse or distribution centre to the final delivery, see Figure 3 below.

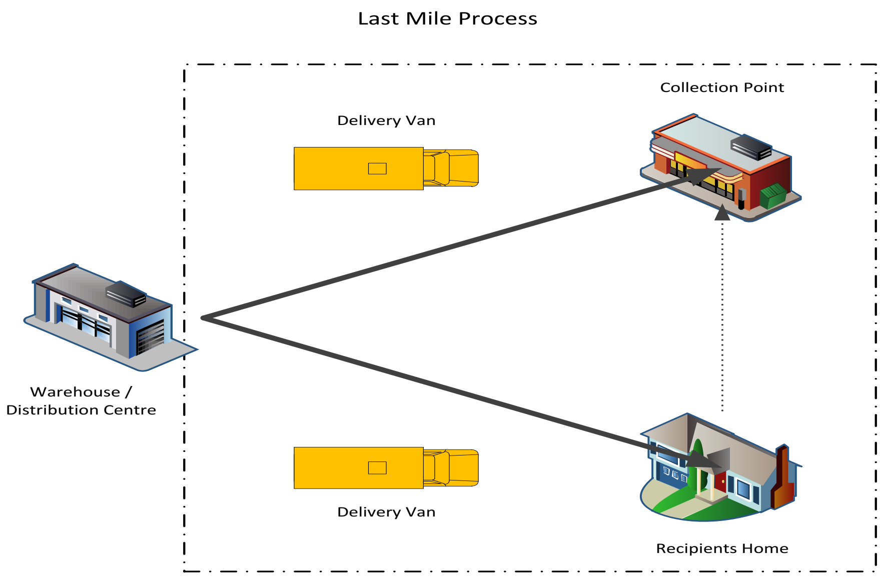

Figure 3 Last Mile Process

Another important part of the scope is the type of business, only business to consumer logistics will be researched and medium to high value products, such as books, electronics and clothing for example. These are mainly the e-commerce parcels from large online retailers. The place and type of delivery is important as well, the focus in this report will be on the current home delivery (which can be attended or unattended) and the parcel lockers (unattended).

Since there is no standard design for a parcel locker, the dimensions of the current parcel lockers located in Almere from PostNL will be used together with interviews of experts to determine correct and feasible dimensions. The mentioned dimensions are the outer dimension of the parcel locker. The size of the lockers itself can vary. To be able to replace the standard delivery vans with the usage of parcel lockers the number of parcels being delivered should be known delivered in De Pijp. The location of the parcel lockers will be determined based on the results of the research of (Stanislaw et al., 2016) and the consumer research of PostNL of their parcel lockers in Almere. The parcel lockers that will designed are stationary parcel lockers, available 24/7 and located on a street. If possible replacing a standard PostNL mailbox. Another important part of the scope is the geographical location of the research. This will be in Amsterdam in the district of “De Pijp” and more precisely the postal codes of 1072, 1073 and 1074, which is visualized in Figure 4 below.

Figure 4 Research area De Pijp (adjusted from www.spotzi.com)

2.1.1 Characteristics of De Pijp

The district of De Pijp is a part of the overall district Zuid. The district of De Pijp is as large as 149 hectares and has 35525 inhabitants (Centraal Bureau voor de Statistiek, 2017a). Looking at the households more than 60% is a single person household (Gemeente Amsterdam, 2016). Looking at the potential customers for E-Commerce and thus parcel delivery, 79% of the inhabitants is between the age of 15 and 65 and more specifically 44% of the inhabitants has an age of 20 to 39. Young people whom are working during the day but are mostly quite flexible in their behaviour and are likely to walk instead of using cars. De Pijp has relatively a lot of neighbour nuisance and due to the large number of bars, restaurants and retailers a relatively large problem with parking. However not only details about the geographical surroundings are interesting. Extensive details can be found in Appendix II "De Pijp" Geographical and Appendix III "De Pijp" PostNL Data.

Table 2 Overview parcel delivery De Pijp (1072, 1073 & 1074)

Postal Code	Parcels to be delivered (home address)	Parcels to be delivered (pick-up location)	Parcels directly delivered	Parcels delivered at neighbours	Parcels delivered to pick-up location	Parcels delivered to mailbox	Parcels returned to Depot	Percentage delivered personally	Percentage Reimbursement	Percentage Insured	Percentage of returns
Total (1072)	3283	533	2470	309	633	50	354	74%	1,25%	0,53%	9%
Average (1072)	547	89	412	52	106	8	59	74%	1,25%	0,53%	9%
Total (1073)	2776	277	2063	337	359	118	176	74%	0,64%	0,41%	6%
Average (1073)	463	46	344	56	60	20	29	74%	0,64%	0,41%	6%
Total (1074)	1619	9	1206	228	57	76	61	74%	1,25%	0,53%	4%
Average (1074)	270	2	201	38	10	13	10	74%	1,25%	0,53%	4%
Total Overall	7678	819	5739	874	1049	244	591	74%	1,05%	0,49%	6,96%
Total Average	1280	137	957	146	175	41	99	74%	1,05%	0,49%	6,96%

2.2 Current Last Mile delivery model (PostNL)

To be able to design a new delivery model by using parcel lockers it is a necessary aspect to research the current last mile delivery model. Doing this by first taking a look at the visual representation of the standard home delivery as shown in Figure 5. The black lines indicate a simplified route of the standard delivery van of a logistics provider (PostNL) that drives from the distribution centre towards the drop off places and delivers the parcels. The person receiving the parcels doesn't need to get out of his home to receive the parcel.

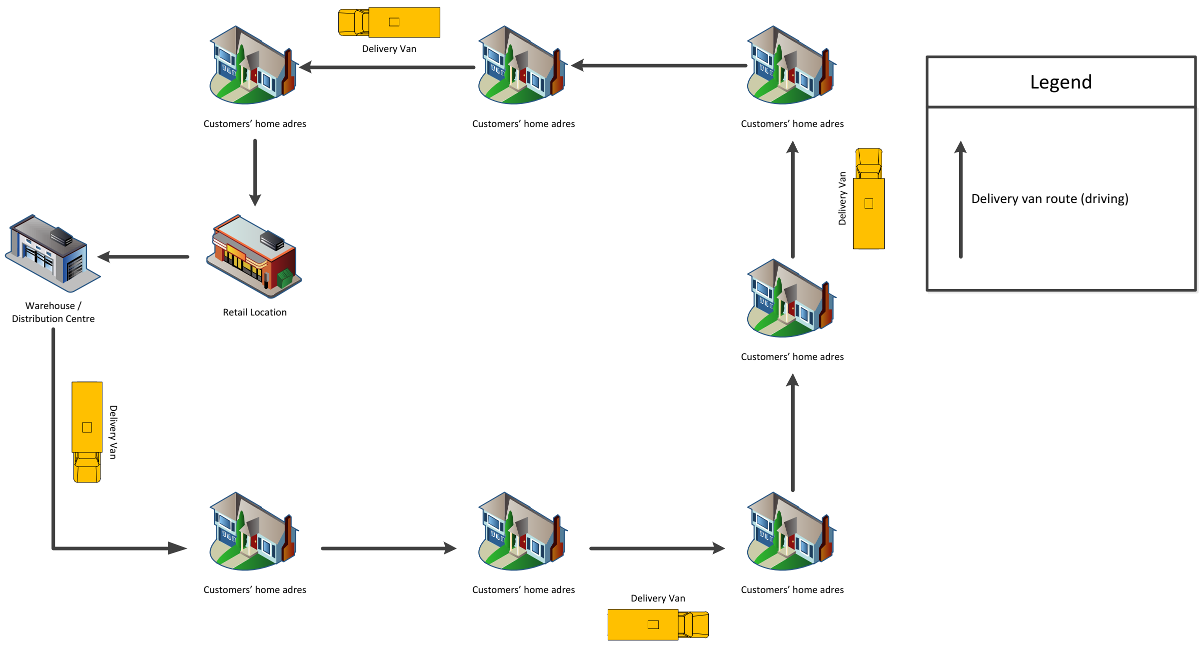

Figure 5 Visualization current delivery model

With this standard home delivery, three important last mile problems come forward that need to be taken into account (Gevaers et al., 2011). The first problem is when a parcel cannot be delivered and the delivery van needs to drive back to the warehouse with the undelivered parcel. This causes a need to a new attempt at delivery the next day and therefore creates extra costs. The second problem is the density of the delivery area, the denser the area is the higher the efficiency. Together with density the length of the delivery window is the third problem, where the logistics provider wants a long-time window due to route efficiency. The customers want a small-time window (Boyer et al., 2009). The better this time window is the smaller the changes of missed delivery and a high "first time hit rate". Where the goal for the logistics provider is to have "first time hit rate" that is as high as possible to be able to reduce costs as much as possible. Not only the costs play an important role but the environmental aspects as well, with a high density and low "first time hit rate" the impact on sustainability will have more of a negative tone to it. According to Gevaers et al (2011) five fundamental aspects define the nature of last mile, the five fundamentals are based on the three last mile problems mentioned before.

1. The level of consumer service
2. Security and delivery type
3. The geographical area and market penetration and density
4. Vehicle fleet and technology
5. The environmental factor

Using the five fundamentals of (Gevaers et al., 2011) and input of PostNL employees. No significant difference between medium and high value products can be seen. Level of consumer service and security and delivery type are the most important fundamentals. The last three score neutral. With the new future delivery model, it is important that consumer service and security are taking into account. The five fundamentals will be made into requirements for the designs. Details about the input of PostNL employees on the fundamentals can be found in Appendix IV Last Mile subdivided.

2.3 Future Last Mile delivery model(s)

The focus for a future delivery model will be on the parcel lockers in this report. This due to the potential it has, based on experiences with the standalone parcel lockers PostNL is exploiting at the moment and several sources whom mention the prospects of future automated parcel delivery as well (Stanisław et al., 2016b). The parcel locker delivery model has a different delivery model than the standard delivery model, which can be seen in Figure 5.

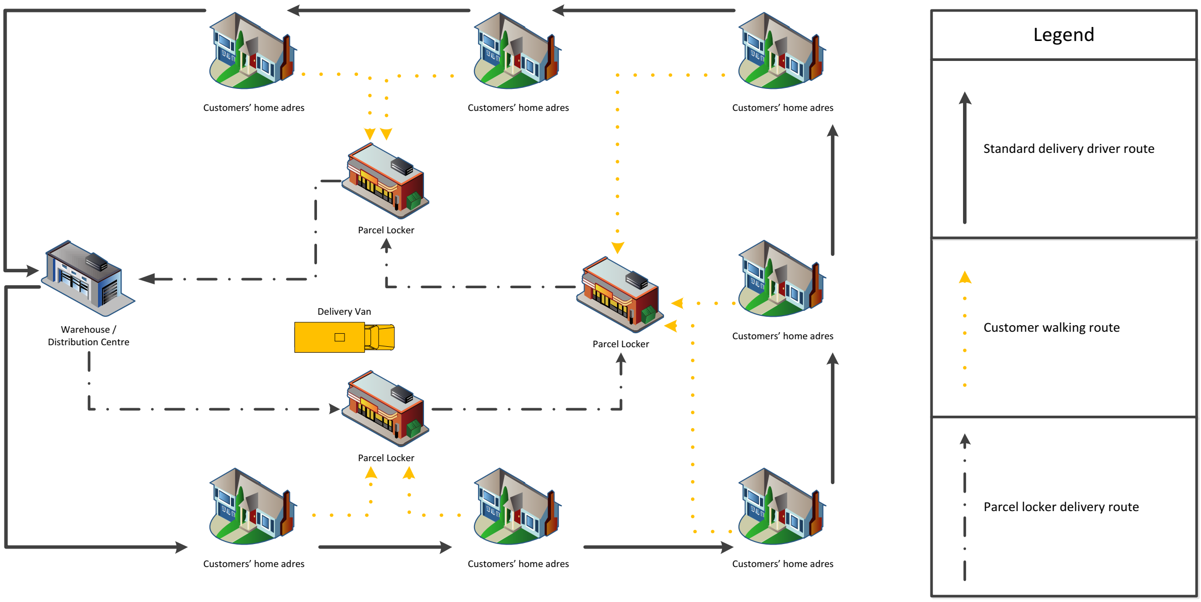

Figure 6 Visualization future delivery model

In Figure 6 the potential lay out for parcel locker delivery is visualized. The dotted black line indicates the route for the parcel lockers to be followed. This can be done by a single van whom is filing multiple parcel lockers, replacing multiple vans driving around. This can be a truck driving parcel lockers around and dropping them on specified locations in the district. The most important change is with this new lay-out the consumer needs to move as well. The consumer can make this journey by foot, bike, car or public transport. Preferably by foot since this is the most economical and environmentally friendly way. At this moment, the current design of the parcel lockers that is being used by PostNL can hold around 96% of the parcels, looking at their size (Otten, 2017). For the larger parcels which will not fit in the parcel lockers the delivery van still needs to drive around. When designing the future parcel locker delivery model in chapter 4 this will be taken into account.

Though this is only the layout and visuals of the future parcel locker delivery model. It is also important to take a closer look at the reasoning behind the parcel lockers and the potential it actually has. Taken this into account later on in chapter 4 a proper design can be created. Since the goal with the parcel lockers is to try and maintain the market leader position PostNL has at the moment. Making last mile delivery lower in cost than current distribution and trying to increase the drop density and FTHR as mentioned in paragraph 1.2 and 2.2.

Cherret et al., (2009) mentions that parcel lockers are the independent solution to the current collection points. Collection points are mostly located at a supermarket, gas station or any other commercial establishment. One of the downsides of collection points as they are right now being the combination of a normal store together with a postal office. This means limited opening hours for example. Though more and more parcels are being delivered to collection points due to people not being home during delivery (Blanquart et al., 2014). Giving the potential of parcel lockers, which aren't depended on other establishments. Customer related preferences and possible input for the design of alternatives will be retrieved from PostNL, which can be found in Appendix I PostNL Parcel Lockers. Scientific literature however is scarce on the topic of parcel lockers. Though four important aspects have been distinguished:

1. Customer perspective of parcel locker use
2. Location of parcel lockers
3. Cost (perspective) of parcel lockers
4. Environmental economics

Customer perspective of parcel locker use

The research of Stanislaw et al (2016a) has investigated this customer perspective of using a parcel locker. The research shows that with a 95% probability the parcel lockers users are satisfied with the service, the average grade was between an 8.7 and 8.9. Which is a high value for customer satisfaction. And according to this research comparing parcel lockers with the Polish Post, 89% values the parcel locker better than using Polish Post normal services. An important side note is the fact that the respondents of the survey in the research don't make use of the parcel lockers service that often. Reasons for that being the services that are not being offered by online retailers, therefore customers aren't able to select a parcel locker as a delivery option. Where price of the service and parcel locker location are two aspects that are important when wanting to make use of the parcel locker service. Speed of the service and 24-hour availability were mentioned as well as important characteristics, though they were related to price of the service. Safety of a locker has been valued as a characteristic as well, since people perceive home delivery as being safer than delivery in a locker.

Location of parcel lockers

Regarding the important aspect of location, the average grade was valued at 8,25 and 15% of the respondents would have used the parcel lockers more often if their location improved. The most favoured locations according to the respondents were nearby home addresses and the way back from work and places where it is possible to park a car. Since going by car and going on foot where the two most popular choices to reach the parcel locker. The least favoured locations were the area nearby shopping centres and bus/tram stops. And respondents whom used the parcel lockers by car where doing that on the way back from work, indicating that they were combining with doing other errands, while the ones on foot where only going to the lockers to pick up their parcels. In the large cities, however location choice of parcel lockers should be around shopping centres and Public Transport (PT) locations. Mentioned as well in the research of Stanisław et al (2016b) is the importance of location in the urban areas of a parcel locker. The research mentions a relocation of under achieving parcel lockers to the proximity of gas stations and shopping centres. Where one of the relocations to the shopping centres was one of the most successful. And the parcel lockers processed more parcels due to this relocation.

Cost (perspective) of parcel lockers

Having discussed the consumer perspective and location of the lockers, the financial side of the parcel locker is important as well. For example, how efficient the use of a parcel locker is in relation to a standard delivery model (Stanisław et al., 2016b). The comparison between a courier delivery and parcel locker delivery has been made and shows substantial differences between both. The comparison is based on a normal working day for delivery. On the left the results of a working day for a standard courier on the right the working day of a courier when making use of (InPost) parcel lockers. Shown in Table 3 below is the comparison of the two delivery models as can be found in Figure 5 for the courier and Figure 6 for the parcel lockers.

Table 3 Comparison of courier delivery and parcel locker delivery on a daily basis (Bilik, 2014)

	Courier	InPost parcel lockers
Kilometres daily per one delivery driver	150	70
Parcel daily per one delivery driver	60	600
CO_2 emission per parcel	300 g	14 g
Fuel consumption per parcel	0.23 L	0.01 L

The results in Table 3 show a difference in efficiency for a working day using a courier or using the parcel lockers. The most remarkable results are the number of parcels that are delivered in one day, when making use of parcel lockers it is possible to deliver ten times as more parcels per day than using a courier service. As well as the environmental benefits per parcel. CO2 emission per parcel is significantly lower for the InPost parcel lockers as well as the fuel consumption. Important to mention is that the research does not mention the number of parcel lockers, locations, size and costs of a parcel locker. Meaning these results only give an indication and prospects of the possibilities. The paper of Giuffrida et al (2016) mention that parcel lockers are cost efficient in use due to the courier side costing less, the customer side has not been taking into account. This could change the cost perspective significantly. This aspect is explained more in detail in the environmental economics.

Environmental economics

Looking at the paper of Giuffrida et al (2016) analysis shows an economical and environmental point of view of the use of parcel lockers in relation to home delivery that can save up to two thirds of the emissions, this includes the emissions of the customer whom needs to travel toward the parcel locker. Important to mention is the fact that the courier time is the factor that saves the most money and emissions when using parcel lockers. Due to the fact of the possibility of a drop with multiple packages instead of multiple drops with just one package. The benefits mentioned in this research are based on static change, meaning that the customers don’t need to change in their behaviour to collect the parcels. The research conducted a sensitivity analysis to see the ranges where a parcel locker became more expensive, this is important to keep in mind with for example location choice and pricing. Looking at for example the economical part for the customer a parcel locker shouldn’t be located further than 3,5 km in an urban context, if it’s further only the logistics provider will benefit.

PostNL has conducted some research as well regarding their parcel lockers which have been placed in Almere. The most important aspects that came forward were the importance of a location close by people, preferably around a supermarket, the 24/7 availability of such a locker, therefore not being home during delivery. Other interesting results are that the usage is not optimal due to the fact people didn’t know about the parcel locker or people use retail locations for their own shipments. 80% Of the people is willing to travel for 2 to 10 minutes and around 40% prefers to use bicycle or walking as transport mode. Extensive details can be found in Appendix I PostNL Parcel Lockers.

The customer perspective, location, cost perspective and the economics and environment are giving good insights and prospects for the design of a parcel locker delivery model. Since there is no such thing as a parcel locker delivery model yet this needs to be designed. This final design will be made by using the theory from chapter 2 and methods from chapter 3. The scientific literature has given four important aspects that are of importance for the future delivery model. Together with the motivation and problem statement from chapter 1, the goal is to create a future delivery model with a higher FTHR and better drop density. Creating a direction for PostNL to be able to cope up with future automation, competition and maintaining the market leader position. Based on the current delivery model and prospected future several scenarios can be developed, which will be elaborated on shortly down below. All three scenario’s will be researched for every alternative.

1. Small sized parcel lockers (50% fit in parcel lockers)
    - In this basic parcel locker delivery model only the smaller parcels will be delivered to the parcel lockers. These are the parcels that are delivered in large amount but are not large in size. The parcel lockers themselves will be strategically placed in the district of De Pijp, preferably at parking spots for cars or mailbox locations.

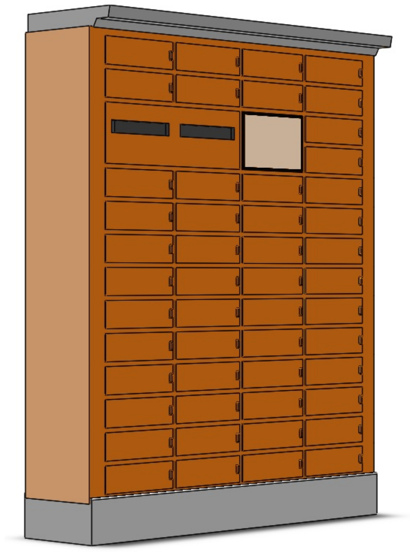

Figure 7 Parcel locker 50% fit (50 lockers)

2. Medium sized parcel lockers (66% fit in parcel lockers)
    - This model will have the same characteristics as the small sized parcels scenario but now larger parcels can be delivered as well. This will cause the need for a larger parcel locker and thus more space, but will save on costs at the side of standard delivery.

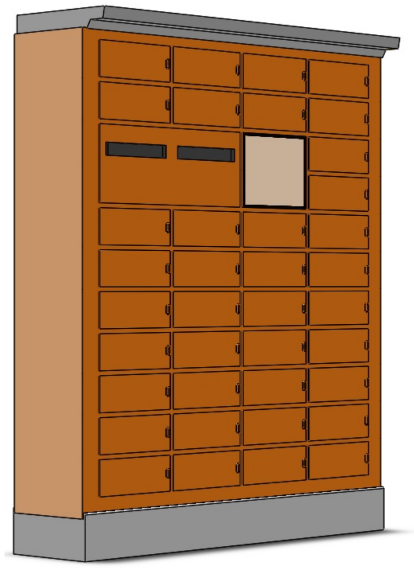

Figure 8 Parcel locker 66% fit (38 lockers)

3. Different sized parcel lockers (88% fit in parcel lockers)
    - With this scenario, the goal is to deliver 88% of the parcels that are delivered in De Pijp to a parcel locker. The remaining 12% which does not fit due to the size limitations of the locker, will be delivered with a standard delivery route. This scenario will need the most number of parcel lockers. The design of this parcel locker can be seen in Figure 1

3. Selecting methods for the design of a parcel locker delivery model

To be able to come up with a design to answer the research question the designs need to be substantiated by theory and a methodology. The theory can be found in chapter 2 and this chapter will elaborate on the methodology. Five phases can be identified according to different literature resources (Dym et al., 2014), (Beitz et al., 2007) & (Banks, 1998). Starting with the requirements for the design, the creation or generation of the designs, analysing and evaluation of the designs, the validation and at the end selecting the final design. These five steps will be substantiated by literature and will be used to analyse the final design in chapter 4. The framework that will be used is shown below in Figure 9, and has combined the evaluation and validating of the designs together, creating four phases. The paragraphs in this chapter correspond to the framework, which can be found more elaborate in Appendix VI Design Methodology.

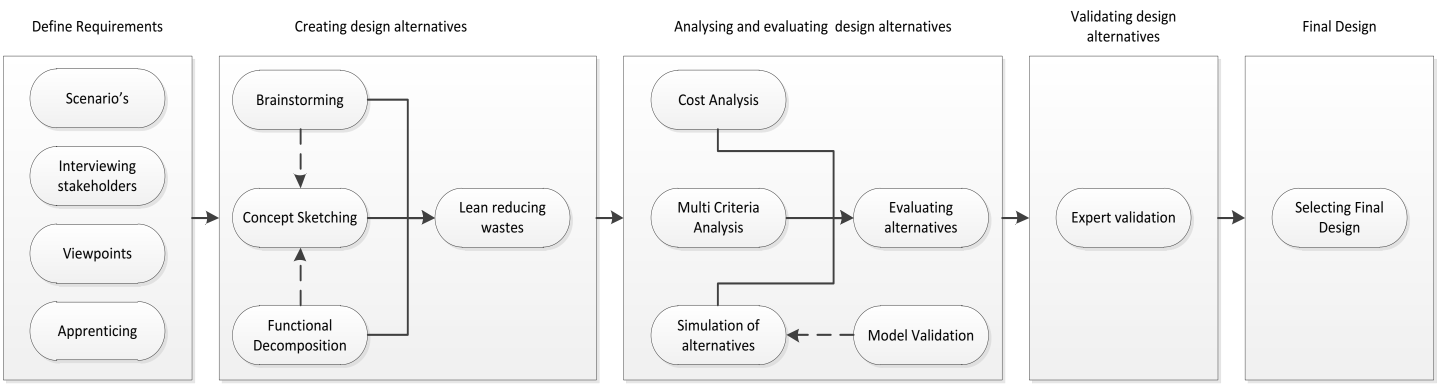

Figure 9 Methodology Framework

3.1 Defining requirements (for last mile parcel delivery)

To be able to gather requirements it is important to know what requirements are and how they are defined. According to Bahill & Dean (2009) a requirement can be defined as a statement that identifies a capability or function needed by a system in order to satisfy a customer need. It is about turning the inputs into outputs to satisfy customer needs, which in this case will be the needs of PostNL for a new type of delivery model. Important as well is the fact that requirements should state what the system is to do, not how the system is to do it (Bahill & Dean, 2009). According to the literature three different type of requirements can be identified.

1. First a distinguishing of two types of requirements can be made, Beitz et al (2007) mention demands and wishes to which requirements can be identified. Where Bahill & Dean (2009) call mandatory and trade-off as the two types of requirements. To prevent using multiple definitions, the researcher makes the choice to define the two types of requirements mentioned by Beitz et al (2007) and Bahill & Dean (2009) as hard and soft requirements. Were hard requirements are requirements that need to be met at all times, it's a fail or pass and nothing in between or out. Soft requirements are requirements that should be taken into consideration whenever possible and can be compared with each other by use of for example multi criterion analysis. Important is that the final design will be selected on the hard requirements and evaluated on the soft requirement. A hard requirement can be for example: a parcel locker should have a capacity of 50 parcels. And a soft requirement can be for example: the first time hit rate needs to be larger than 80%.

The importance of making good requirements should not be neglected, it is the start of the design phase and therefore the foundation of the design. According to Dick et al (2011) one of the three reasons for project failing are the requirements and more specifically, poorly organized, expressed, changed to much, not related to proper stakeholders and incomplete. Having a good list of requirements can contribute substantially to a successful project and so design.

2. Secondly requirements can be distinguished in two different forms. The functional requirements and the non-functional requirements (Sommerville, 2011). According to Sommerville (2011) the following definitions for functional and non-functional requirements can be explained. The functional requirements can be defined as: 'Statements of services the system should provide, how the system should react to particular inputs, and how the system should behave in particular situations'. "Things the product must do" (Roberston & Robertson, 2006). The non-functional requirements can be defined as: 'Constraints on the services or functions offered by the system. They include timing constraints, constraints on the development process, and constraints imposed by standards'. "Qualities the product must have" (Roberston & Robertson, 2006). It is important to notice that a non-functional requirement doesn't affect the system functioning. For example, a non-functional requirement can be that a car needs to have at least four windows, the main functionality of the car, which is driving from A to B, will not be affected by this. The non-functional requirements can be classified as well to structure the requirements more precisely.

3. Robertson and Robertson (2006) mention a third type of requirement next to the functional and non-functional type of requirements, which is the constraint. A constraint is more of a global issue that shapes the requirements and are mostly set up by the researcher himself. For example, the design of the parcel locker delivery model needs to be ready to operate in 2020. Taking all the different classifications of requirements such as hard and soft requirements, user and system requirements, functional and non-functional requirements into account an overview of the requirements structure can be made. This overview is made to indicate and clarify the distribution of the different requirements and can be seen in Figure 10.

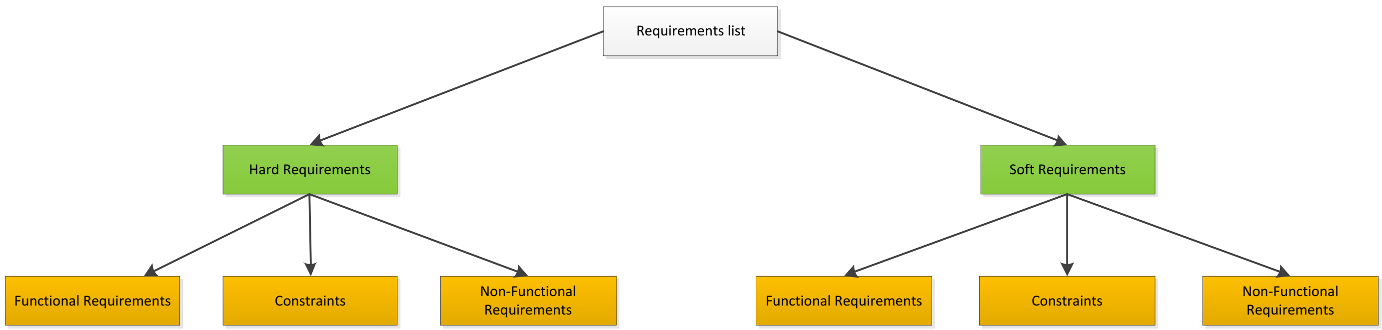

Figure 10 Requirement types

Now that is established what requirements are, how important they are and the different characteristics they have it is necessary to take a closer look at the question of how requirements can be gathered the best. There are several techniques that can be of use and the ones that are best suited for this research will be listed down below.

1. *Interviewing stakeholders.* This is the most traditional technique there is to gather information for the design. The goal is to ask the stakeholders their interests and what they want from their design or product and how their requirements should be formed (Robertson, 2001). With this technique chances are large that conscious requirements will come forward, requirements that the stakeholders are particularly aware of. The unconscious requirements, requirements which the stakeholder isn't aware of he has, are less likely to be brought forward (Robertson, 2001). The unconscious requirements occur often when a stakeholder knows a lot about the product or design and is involved so deep he doesn't see the necessity anymore to mention it. For example, a speedometer in a car. Finally, the undreamed requirements are the requirements which the stakeholder doesn't think are worth mentioning because he has a fixed idea of what is possible within a certain design. The important aspect in gathering these requirements is to get these undreamed requirements as well, this is the responsibility of the researcher.

Interviewing stakeholders is a good manner to require the correct requirements but shouldn't be the only one due to some flaws. Therefore, more techniques will be used.

2. *Scenario's.* This is a technique mentioned several times in the literature as well. It is easier for people to relate to real life cases than to abstract situations. The use of scenario's can be helpful with adding detail to an outlined requirements description (Somerville, 2011). Scenarios can include a description of what the system and the users expects when the scenario starts, a description of what can go wrong and how it's handled, information about other activities that might go on at the same time. The usage of scenarios involves stakeholders as well. Tough the input of the interviews can be used to create usable scenarios. With those scenarios, it is also possible to organize a brainstorm with external people whom are not involved in the research to question the scenarios and help building the requirements.

Viewpoints. The complexity of requirements necessitates a way of independently focusing on different points of view (Robertson, 2001). By doing this, chances are larger to finding different requirements. It is important though not to lose the connection between the different points of view. According to Robertson (2001) there are three important views to take into account: first of all, the view of the current situation, secondly the view of the future situation and thirdly the view of the product itself. This approach of having different views is a good thing to use and not be blinded by wanting to do everything simultaneously.

3. *Apprenticing.* This technique will be used to get familiar with the current delivery process and how every step works. The apprentice observes what the masters does and tries to do the work to learn some of it (Beyer & Holtzblatt, 1998). This will be used to be able to ask relevant questions to all of the involved stakeholders. This technique is really useful when a stakeholder is busy or the stakeholders is having troubles to mention all the goals he wants to or when his knowledge is limited to a small part of the system (Robertson, 2001).

Listed above are three methods to gather design requirements to be able to come up with a design to answer the Research Question. Interviewing stakeholders will be the start of defining requirements. After this the scenario's and viewpoints will be used together to define more in detail where possible. And finally, the apprenticing will be used to gather requirements people forgot to mention or are not perceived to be a requirement but are actually requirements. Using the methods and the classifications of requirements that are made above a good and solid start can be made to start the creation of the designs. One important thing not to forget is the importance of data collection. This research will require quite a substantial amount of data. This data varies from costs to number of parcels being delivered, how many of those parcels need signatures and how many of those parcels are oddly sized for example. This this type of data will be retrieved by using the internal systems of PostNL, when this is not possible the most likely used method to gather this data will be the use of interviewing staff members of PostNL whom can access the information needed.

3.2 Creating design alternatives (for future last mile delivery)

After setting up a requirements list according to the selected methods in paragraph 3.1 these requirements need to be made into design alternatives. By using the different categories of different type of requirements a design can be created. Important is that the start of the designing of the alternatives follows from the requirements list. The requirements list doesn't need to be complete for the full 100%, since some of the requirements that can be mentioned come to mind in the final stages of the design. Beitz et al., (2007) are mentioning the example of designing a car where in the final stage of designing a car the thickness of all the paint layers needs to be known. However, to develop the car itself this type of requirement is not necessary. Most important for the start of the project is to define the particular concept, influence the product structure and the determination of the overall embodiment of the product. The requirements list will be managed and extended continuously. There are several methods to generate or create new designs. In this situation, these methods are not used to create a physical product but are used to create a new delivery method. This method will be used for the future delivery of parcels by using a parcel locker instead of using the standard delivery van.

Researching the literature, several books and methods come forward which can help with the design of such a future delivery method. Kosky et al., (2010) mention four aspects of creating concepts: brainstorming, concept sketching, research-based strategies and functional decomposition. Kosky et al., (2010) mention that before the alternative concepts are generated, where concepts are in the form of a sketch and contain enough information to understand the way the concept works, but not enough

to make it. Where the alternative means that the concepts are fundamentally different in some way. And the difference is more than appearance and dimensions alone.
Looking at the four different methods of Kosky et al., (2010) all of the methods are suitable for the usage in this research. The method of brainstorming will be used extensively together with the brainstorming in the earlier phase for the requirements. After the brainstorm session, it will be necessary to document the ideas clearly. The sketching of the concepts will be used for this and in the case of designing a delivery method can be of great use. Together with the concept sketching a form of the functional decomposition will be added to that to clarify the different aspects that need more information. The four methods are elaborated in Appendix VIII Creating Designs.
Together with the chosen aspects of Kosky et al., (2010) another method can be used as well. This would be the method of lean. The lean method will be used to improve and evaluate the designs that have been created with the methods of Kosky et al., (2010). The reasoning for combining the lean method with the other methods is to be able to look at the designs from more than one perspective and improve the designs even further before evaluating and selecting them. Lean is a method that is mostly used for processes, since a new delivery model is more a process design than an infrastructural design, using lean can be useful. PostNL has the view that cost should be as low as possible, therefore there are no wastes in the logistic chain and the processes need to be constructed with use of the lean principles (Logistieke Strategie PNP, 2016). For that reason, as well lean will be used to create a future delivery model with parcel lockers that complies with the lean principles. Important is to know what lean is and how lean works. The essence of lean thinking is the reduction or removal of waste. The key element in lean is the elimination of waste and the increase of speed and flow (Goldsby & Martichenko, 2005). This method of lean thinking will be adapted in some form to design the new delivery model. The reduction of waste can relate to increasing the first time hit rate and therefore less need to return to the PostNL depot to be reinstated in the distribution process again. Increasing speed and flow relate to the new design when there is less need to stop and make better use of the working hours per day, as has been described in the research of (Stanisław et al., 2016b). It is therefore important to start with the design and think about the different steps that add value, the steps that don't add value but are necessary and the steps that do not add value and are not necessary. The lean process uses three main principles (Melton, 2005):

1. The identification of value
2. The elimination of waste
3. The generation of flow (or value to the customer)

For the first step, it is important to know what the value for the end customer is, in this case it relates to the design of the future delivery model and what PostNL sees as added value. To remove the wastes in the process, it needs to be clear what type of wastes there are to be able to solve and remove them. Based on the ideas of Toyota's Taiichi Ohno seven wastes have been identified together with an eight non-quantifiable waste (Eaton, 2013).

Table 4 Seven (Plus one) types of wastes (TIMWOODS)

	Waste	Meaning
1	Transport	The movement of information, materials and equipment.
2	Inventory	Any unnecessary queuing of activity. For example, a stack of people brought in for an appointment, a stack of letters waiting to be typed, excess stock stored in operational areas, etc.
3	Motion	The movement of human beings.
4	Waiting	Waiting for information, people, materials or anything else to arrive.
5	Over-Production	Doing more work than is absolutely required. In non-manufacturing contexts, it is often better to refer to this waste as 'over processing' rather than overproduction.
6	Over-Processing	Undertaking any activity that is explicitly not required. For example, producing unnecessary reports, doing unwarranted testing, etc.
7	Defects	Having to undertake remedial work of any kind because not everything was done correctly the first time.
8	Skills	The waste of the expertise of human beings by asking them to do things that would be better undertaken by someone else or not done at all.

Using the eight identified types it is possible to eliminate wastes in the process of a new delivery model. For example, over-processing could be scanning a parcel two times before putting it in the parcel locker. This can be a waste but added value in the sense of safety. Therefore, it is important to take the identification of added value into account while eliminating wastes. Third the generation of flow looks after the fact if the steps in the process are being performed in a logical order, this will generate a good flow in the process.

The next step is to adapt lean to the specific purpose of this research. Since the original lean theory was invented to look at manufacturing processes. However, for this purpose it can be adapted as well. The process where lean can be adapted in this research is largely the transport process, in literature a research can be found describing the use of lean to improve road transport operations (Villareal et al., 2017). Mentioned in the article of Villareal et al., (2017) is the conception that waste and unnecessary costs are normally present in most transportation networks. Therefore, the method of lean thinking could be suited as a good opportunity to complement the traditional methods of calculations and simulations. The goal with lean thinking in the road transportation is to identify and eliminate non-value added activities related to transport activities (Villareal et al., 2017). Research on lean thinking in road transportation is scare and research in supply chain has been done to some extent. The majority of lean thinking and lean research is done in manufacturing, processes and services. The research of Villareal et al., (2017) tries to complement the lack of research by conducting a case study for this particular purpose. Since the research is not only related to transportation but to a different method of delivery as well, the research of Villareal et al., (2017) will be used as assistance for the usage of lean in this research and not so much as a strict guideline. Another issue is the fact that lean is mostly used to improve and overlook existing problems not so much for future designs, when they are not related to the current designs. This is the case in this research, since the future delivery model of delivering parcels with the use of parcel lockers instead of a van is a different process, which has some similarities but differs as well. The next paragraph will elaborate on the usage of the previous mentioned methods for making designs together with the usage of lean for this particular research.

Starting with the lean process, Villarreal et al., (2017) identified five of the seven wastes as being important to transport operations. Being overproduction, waiting, over-processing, defects and transport/motion. The descriptions for these wastes can be found in Table 4. This means that it is important when making new designs these five wastes need to be taken into consideration when making a design, this to prevent the need of lean as an evaluating or validating tool. The tool of lean will be used to optimize the designs, after the brainstorm session and the concept sketching have created the new designs. The designs will be optimized with the use off the identified wastes. After optimizing the designs, they will be evaluated and the best design will be selected.

3.3 Evaluating and selecting design alternatives

After setting up the different requirements for the design and having determined the approach to make designs, the designs that have been created need to be evaluated and selected. This will be a difficult but crucial step in the process of selecting a future delivery method by using parcel lockers.

Kosky et al., (2010) mention two principles for selecting the best design: minimizing information content and maintaining the independence of functional requirements. The first principle is in line with the lean theory and more or less tries to reduces waste by minimizing all the information content. Choosing between the different designs the best designs most often are to be explained with the least amount of information and can be used without many directions. This principle is most of the time being referred to as KISS: Keep It Simple, Stupid. The second principle is based on the idea that for a good design the functions should be independent of each other. This goes in line with the first principle and the lean theory that designs should be simple, easy and have no unneeded movements or processes. Another that is mentioned in Kosky et al., (2010) is making use of a decision matrix to be able to withhold any personal biases amongst a design. This can highlight the strengths and weaknesses not only for quantitative aspects but for qualitative aspects as well. Dym et al., (2014) mention this evaluation matrix. This evaluation matrix will compare the different methods of evaluating alternatives with each other, which can be found in literature. To answer the research question as precise as possible three methods have been selected to analyse and evaluate the alternatives. The three methods used in this research are the Cost Effectiveness Analysis (CEA), Multi Criteria Analysis (MCA) and simulation. The reason for choosing the three methods is to answer the research question as accurate as possible. Being able to answer this type of research question for every city in The Netherlands. The CEA will be used to define the cost in detail as much as possible. Evaluating the costs of the different alternatives that will be designed and compare alternatives financially. The MCA will be used to value the alternatives, by PostNL experts from the Staf Operations department and Transport experts, the transport experts being TU Delft TIL master students and graduates. Valuation on the requirements that have been set and give insight in importance of variables such as safety and feasibility. The CEA will be of quantitative nature and the MCA more of a qualitative nature. Finally, the simulation will be used to simulate the created alternatives and validate whether the chosen variables such as number of lockers, unloading time are chosen correctly. Simulation also looks at the occupancy rates of the lockers and occupancy rate of the time delivery drivers are operational. Together the three methods give a complete and accurate overview of the best alternative on different levels and substantiate the final conclusion of the research question. Having a quantitative method (CEA) and a qualitative method (MCA) used together with a simulation to validate the conceptual models gives an accurate and complete evaluating of the different alternatives.

3.3.1 Cost Effectiveness Analysis (CEA) alternatives

One of the methods that is being used to compare alternatives with each other looking at costs is the use of a Cost Effectiveness Analysis (CEA) or a Cost Benefit Analysis (CBA). Looking at the difference of both, CEA is a tool that uses the costs of a program and relates it to the key outcomes or benefits. Where the CBA goes one step further and tries to compare the costs with the euro value of a program's benefits (Cellini & Kee, 2010). The CBA is beneficial when the goal is to see if the benefits of a design exceed the cost of a design, the downside of this method is however that some aspects are hard to monetize, for example perspective of people or the life of a person. Information to do this should be complete and a CBA cannot be made without solid information. When certain outcomes are difficult to monetize a CEA is better suited, however this technique lacks of proper output and is therefore more depended on the judgement of the one whom makes the CEA. With this research, it will be hard to monetize benefits of different delivery methods, which is favourable when using a CBA. Since the focus of this research is on cost efficiency, thus reducing costs. The technique which will be used to evaluate costs will be CEA, comparing the alternatives on which is most cost efficient. Though important is the question how are the costs being calculated?

Looking at literature several methods are being mentioned to calculate costs. One that comes forward and is particular suited for this research starts with a standard transportation cost function (Blauwens et al., 2010).

$$TC = T \cdot t + D \cdot d + Z \qquad (1)$$

Table 5 Symbols and variables for standard transportation cost function (1)

Symbol	Variable	Unit	Symbol	Variable	Unit
TC	Total transportation costs	€	D	Distance driven/travel for transport	km
T	Time/duration of the transport	hour	d	Distance coefficient	€/km
t	Time/hour coefficient	€/hour	Z	Extra costs not related to distance/time, like transhipment costs or handling costs	€

The total costs consist of the multiplication of the total time driven by the driver with the time coefficient and the total distance costs consists of the multiplication of the total distance driven with the distance coefficient. Together with possible additional costs this will give the total transportation costs. Which can be used for last mile logistics as well. The important factors in this function are the distance and time coefficient. Which will be used for the specific cost function to calculate the costs per parcel.

Making use of this standard transportation cost function, the work of (Gevears et al., 2014) and (Blauwens et al., 2010) a specific cost function for the delivery of parcels can be created. This function is designed especially to be able to determine the cost of delivering one parcel as accurate as possible. The function will be used for the current situation and newly created alternatives. Instead of using this cost function only on new models and using data from PostNL for the current situation. Below formula will show the cost function for the last mile costs per parcel. The function is adapted from the work of

(Gevears et al., 2014). The detailed explanation of this cost function can be found in Appendix V Cost function.

Last Mile Cost per parcel shipped:

$$\frac{(T \cdot t + D \cdot d \cdot v)}{(\frac{STOP}{w} \cdot ip \cdot ad \cdot cp \cdot P)} \cdot (1 + r) + (C_s + C_d) \cdot r + R_1 \cdot C_{rt} + (R_1 + ip) \cdot C_p \qquad (2)$$

Table 6 Used Symbols for last mile cost function (2)

Symbol	Variable	Unit	Symbol	Variable	Unit
T	Duration of route in hours	hour	ad	Area density coefficient	-
t	Time coefficient	€/hour	cp	Collection point coefficient	-
D	Distance of route in kilometre	km	R_1	Percentage sent to retailers	%
d	Distance coefficient	€/km	r	Return logistics coefficient	-
v	Vehicle type coefficient	-	C_s	Evening sorting costs per parcel	€
P	Parcel multiplication coefficient	-	C_d	Debrief costs per parcel	€
STOP	Average number of stops per delivery route per driver	-	C_p	Parcel compensation cost	€
w	Time window coefficient	-	C_{rt}	Retailer costs per parcel	€
ip	First time hit rate coefficient	-			

The output of this formula gives the costs per parcel for the last mile for PostNL. The alternatives will be valued at price per parcel, daily delivery costs and the results of the CEA, all for the area of De Pijp. Being one of the important aspects for last mile delivery, drop density will be taken into account as well with the cost calculation. More specifically the total number of stops per alternative. To be able to substantiate differences in costs for the alternatives.

3.3.2 Multi-Criteria Analysis (MCA) alternatives

A well-known form of a decision matrix is the use of a Multi-Criteria Analysis (MCA). The usage of multi criteria decision analysis is particularly useful in the situation where the consideration of different choices or courses/actions creates a certain number of conflicts to a substantial extent (Belton & Stewart, 2002). "One of the principal aims of Multi-Criteria Decision Analsis (MCDA) approaches is to help decision makers organise and synthesize such information in a way which leads them to feel comfortable and confident about making a decision, minimizing the potential for post-decision regret by being satisfied that all criteria or factors have properly been taken into account" (Belton & Stewart, 2002, p2).

The MCA has different ways of being handled, one of the most important aspects is determining the weights. The weights of the criteria will be determined using Saaty's principle (Saaty, 2008). This principle is being used for the analysis of complex decisions, in this case for example for the use of choice from different technical aspects and different type of requirements. It uses the relative importance of criteria. This is done to determine the final weights for each criterion. In order to do so the goal is to have multiple individuals compare the criteria to each other. Each individual gives a score ranging from 1 to 10 for each combination of criteria to address which criteria was assumed to be more important. The outcome of this normalization of criterion weights will be used in the final MCA. Where the different designs will be compared with the status quo design. This to be able to score the different designs on a more objective matter. Detailed explanation about this method can be found in Appendix IX MCA Model. Since this research uses a CEA to analyse the cost in detail, this MCA will not contain costs as one of the criteria to be evaluated. Only qualitative criteria will be used.

The criteria themselves will be adapted from the requirements that have been set up before. Not all the requirements that are suited for MCA. Therefore, a selection of criteria will be made, this to limit the number of criteria respondents need to compare with each other.

3.3.3 Simulation alternatives

To conduct a simulation several steps are required to perform this successfully. Banks (1999) mentions twelve different steps to conduct a simulation study. The twelve steps are shown below in Table 7 and can be found more in detail in Appendix X Simulation Study.

Table 7 Simulation steps and their position in the report

	Simulation Steps	Section in report
1	Problem Formulation	Paragraph 1.2
2	Setting of objectives and overall project plan	Paragraph 1.4
3	Model conceptualization	Paragraph 2.3 & 4.2
4	Data collection	Paragraph 2.1.1
5	Model translation	Paragraph 3.3.3
6	Verification	Paragraph 4.3.3
7	Validation	Paragraph 4.3.3
8	Experimental design	Paragraph 4.3.3
9	Production runs and analysis	Paragraph 4.3.3
10	More runs?	Paragraph 4.3.3
11	Documentation and reporting	Paragraph 4.5 & 5.1
12	Implementation	Paragraph 5.1

As can be seen in Table 7 the twelve simulation steps according to the literature are shown. For each of the twelve steps the corresponding paragraph is displayed, showing which simulation step is performed in which section of the report. Almost half of the steps are located in other paragraphs than the specific simulation steps. Due to the reason that these steps are the same as the overall structure of the report, for example the case with the problem formulation. The other half of the steps are steps related to simulation itself and therefore can be found in the simulation chapter.

Model Translation

The type of simulation that will be used is discrete-event simulation. This method is preferred over the use of continuous simulation. The reason for this being the fact that with discrete event systems, changes will be at discrete moments in time rather than continuously (Fishman, 2001). This example is illustrated in the book of Fishman (2001) with a bus travelling a certain route with passengers. The bus moves continuously, however the passengers move in and out at certain times at bus stops. The changing aspects are the waiting time of the passengers for example and how many passengers hop on and off. This type of event is typical for discrete-event simulation. And has a similar nature as parcel delivery. A delivery van will drive to a location and drop off a parcel instead of a human, drive further and do the same thing. Picking up parcels in some situations as well.

The software of choice will be Simio, one of the main reasons for doing so is the experience of the researcher with this type of software. Other reasons are the benefit of making the simulation visual instead of using lines of codes which is the case with MatLab, SIMSCRIPT, SLAM and SIMAN (Kelton et al., 2011). Simio is a relatively new and modern simulation software, which has been developed by the same people whom developed programs such as Arena and SIMAN, meaning Simio has been built up from different simulation programs and thus combines expertise (Kelton et al., 2011). Simio is a type of software that is a more object based paradigm. Using Simio, graphical process flows are being used requiring no programming. This enables easier built up of own models, such as future delivery models that do not exist yet.

According to Sargent (2011) with simulation language there are four aspects concerning the verification. First being the creation of an error free simulation language. The second the situation that the simulation language has been properly implemented on the computer. The third being that a tested pseudo random number generator is implemented properly. Finally, the model is programmed correctly in the simulation language. Structured walkthroughs and traces being the techniques to check the correct programming of the model. To check the correctness of the simulation software two methods can be used; static and dynamic testing. Static testing is more of a superficial check with walkthroughs and correctness proof. Dynamic testing is more related to deeper testing and on executional level, where it looks at the execution of the computer program under different conditions. This research will use static testing due to time limitations and lack of expertise with dynamic testing conditions.

The goal with the simulation is to see how the delivery models work with the specifications that have been set. For example, it might be impossible to reduce the number of drivers since the time it will take to fill a parcel locker varies and certain buffers will occur. In theory, it might be possible but in practice not so much. Not only trying to simulate reality, since it is impossible to test these models in real life, the simulation will try to come as close as possible. The simulation will generate two important output values: occupancy rates of the parcel lockers and operating times of the delivery vans. Together with these two output values and the goal of the simulation to simulate a proof of concept, the alternatives will be analysed and evaluated.

Together with the CEA and MCA, simulation will be used to be able to determine the best suited design. For each alternative that will be created all three of the methods will evaluate its performance. Creating three different scores for each alternative. Each alternative will get an overall score based on the three specific scores and with those overall scores the best performing alternative can be chosen. This alternative will comply with the research question the most. Details about this ranking and an example of a ranking table can be found in Appendix XI Ranking evaluated alternatives.

3.4 Validating designs

The validation of the design entails two different things. First it is about the validation of the new delivery model using parcel lockers. This includes the overall design that is supposed to replace the current delivery model. The second aspect is about the simulation model that needs to be validated or verified. The two steps are to be seen separately. Both of the steps need to be validated correctly. Where the simulation model output gives an input for the detailing of the design, to be able to upgrade the design when necessary to fulfil the needs even better.
Validating is providing objective evidence that the system, when in use, fulfils its business or mission objectives and stakeholder requirements, achieving its intended use in its intended operational environment (Walden et al., 2015). Different techniques are mentioned in the book of Walden et al., (2015) to validate the design that has been made. Since the design that will be developed is a new design and doesn't exist yet, some of the techniques that are mentioned cannot be adapted to its fullest. Therefore, a selection has been made to choose to the best suited technique. Three techniques come forward that will be used, one of these techniques is the usage of inspection. Inspection is based on the use of human interference; the technique is based on the visual inspection of an element. Since the future delivery model is not a physical product but more of a process, this inspection will be used as a peer review. The persons whom are doing this inspection are employees of PostNL involved around the process of parcel lockers and project managers in the section of Staff Operations. The goal is to have people involved whom are familiar with the process of delivery and parcel lockers to give a well-funded peer review. Simultaneously the technique of analysis is used, this technique uses analytical evidence and looks at the theoretical compliance. Most of the time this technique is used when testing in a real environment is not possible or too costly. The use of the analysis technique will be used in the inspection phase, to utilize both techniques to the fullest. The last technique Walden et al., (2010) is mentioning is simulation. Since this report is making use of simulation already for a purpose more than only validation, the next step is to describe the step to validate the simulation.

Since the simulation that will be used is a simulation of a system that has not been designed yet it is almost impossible to do a correct validation, since most of the time when validating a simulation model the model will be compared with other existing models or situations. The current situation model can be validated with the real-life situation. However, the future delivery model will differ quite substantially with the current delivery model. Therefore, it needs to be validated in another way. This will be done by validating the conceptual model (Liu et al., 2011). The validation of the conceptual model is mainly used to check if the simulation can support its intended uses (Liu et al., 2011). The two techniques that come forward in (Sargent, 2013) are face (expert) validation and traces. Face validation makes uses of experts in the problem field that evaluate the conceptual model to determine if it is correct and reasonable for its purpose (Sargent 2013). Traces is the usage of entities tracking throughout the model to check if the logic is correct and the necessary accuracy is maintained. Using these two techniques for the conceptual model validation and the validation of the model as a process, a lot of similarities in validation can be found. Since the main focus will be on the conceptual model, the techniques whom are used for this purpose will be used.

4. Designing cost efficient and sustainable parcel locker delivery

4.1 Design requirements and constraints

This chapter will contain the requirements and constraints which are necessary for the design to fully fulfil its intended use. In chapter 3.1 the theory behind the gathering of the requirements has been explained and several methods to gather these requirements have been discussed. For every method, the most important conclusions will be discussed and at the end an overview will be made of the gathered requirements.

Interviewing Stakeholders
For the design of a future parcel locker it is necessary to ask the involved stakeholders and other experts about their perspectives of current and future delivery. Elaborate details can be found in Appendix XIV Expert Meetings. Summarizing some important things came forward. The maximum travel time a consumer wants to walk is five minutes, generating a hard requirement of a maximum walking distance. Communication is key as well. Communication between PostNL and the consumer about the whereabouts of the parcel. Insured parcels are preferred not to go inside a parcel locker. Capacity is important as well, capacity in the delivery van and capacity in the parcel locker itself, only one parcel per locker. The new delivery model should be at least the same quality as the current model related to performance. And shouldn't have too much of an influence on the rest of the logistics chain. The maximum storage time at this moment in the parcel lockers is three days, after these three days the parcels are moved to a retail location. One often heard thing is that drivers are still important, they like the social contact and customers like the interaction as well. Removing this creates a new perspective which needs to be taken into account. The important aspects that have come forward from the interviews with the stakeholders have been translated to requirements. For example, the maximum capacity of a delivery van, has become a hard requirement and constraint. Reason for a certain aspect to be a specific type of requirement is based on the specific aspect in relation to the definition of a requirement.

Scenario's/Viewpoints
With making different scenario's and examples of a future delivery model it is better possible for people to relate to new delivery. The researcher has performed a guest lecture on Tuesday the 3rd of October for several students of the Delft University of Technology and the lecturer of the course. Having explained the research and possible future delivery models to the group some things came forward. One thing that mentioned was how vandal proof the parcel locker would be. It needs to be vandal proof and reasonably safe for theft. Another thing that was mentioned was the way the lockers were being filled. Since it is impossible to sort on parcel size as one of the experts mentioned the driver(s) need to sort at the end of the chute. This sorting requires possible extra work. It can be a solution to do something with labelling so the parcels whom are suitable for parcel lockers have an abbreviation on the label. So, the driver knows if they are parcel locker suited. Another remark was the fact that the system should be ready for future growth of parcel lockers. This is quite an essential aspect of a future delivery model.

Apprenticing parcel delivery
Working a day with a delivery man and working a day independent generates a lot of insight in the delivery process, the details of this working day can be found in Appendix XII Day of parcel delivery. Discussing with a delivery man whom has been working on the job for more than 30 years some things came forward. One of the aspects of delivery which isn't favoured by delivery man is the number of stops a certain route has. This meaning carrying a lot of parcels around, which creates fatigue and

physical disturbances. Another aspect is the load delivery men need to take in their vans, some delivery vans are in their perspective too full, creating inefficiency when delivering. Due to the need to move around all the parcels. A thing which is important is the need to sort parcels in the delivery van according to route, creating efficiency in the route and less need to look for parcels. This is sometimes done during the delivery as well. Knowledge about the route and people is an important factor for the driver as well, the driver knows in which street people are home and which street people are not present, especially for the streets where people are not present, delivery can be quite a burden for the driver. Needing to take parcels back to the depot again and going through the whole debrief process. For a new delivery model this is less important since usage of a parcel locker eliminates presence of customers as well is customer care, since there will be less to no contact with people. Working ICT structure is another aspect, delivery man use a hand terminal to scan the parcels at location to mark the status. Overall this terminal is valued positively, but if it doesn't work properly delivery will get more difficult. For the usage of a parcel locker this will be important as well, since a parcel locker will have its own ICT infrastructure which needs to comply with the ICT infrastructure of the hand terminal. Looking at the customers' side, accurate and up to date information is highly appreciated. Time windows and delivery in those time windows is much appreciated when people are present at home.

Having gathered several requirements with the methods of interviewing, scenario's and apprenticing, extra requirements have been gathered from a logistics vision report of PostNL. PostNL has developed a logistics vision for the year 2020 with in this vision several aspects that are of importance for the requirements for a new delivery model. In Appendix XIII Logistic Vision PostNL an elaborate description can be found of this report can be found. Below the key elements of this vision are displayed, which are used as requirements.

- Costs as low as possible
- No wastes in the process (LEAN concept)
- Damaged goods and missing items reduced to a minimum
- Closed logistic chain from security point of view
- Limited complexity ICT infrastructure
- Information provision important
- Network is no storage, parcels need to move

Using the three methods of interviewing, scenario's and apprenticing, together with the key elements of the PostNL logistic vision. Several aspects have come forward, these aspects are used as requirements which can be found in Table 8, depending on the importance and characteristics of the aspect, the type of requirement has been selected. Below in Table 8 the Hard and Soft requirements that are selected can be found. Using the codes, HF for Hard Functional Requirement, HNF for Hard Non-Functional requirements, HC for Hard Constraints, SF for Soft Functional Requirement, SNF for Soft Non-functional Requirement and SC for Soft Constraints.

Requirements and constraints

Table 8 Hard and Soft Requirements

Hard Requirements Code	Functional Requirement	Explanation
HF1	Minimum damaging and missing of goods	Delivering parcels should be done without any damage or missing parcels.
Hard Requirements Code	**Non – Functional Requirement**	**Explanation**
HNF1	Proper security	The logistic chain of delivery should be closed from a security point of view.
HNF2	Information provision important	Information provided to PostNL as well as to the customer is necessary.
HNF3	Capacity of parcel locker	The parcel locker has a maximum dimension which cannot be changed, therefore creating a capacity limit.

HNF4	Performance needs to be at least 15 parcels p hour	Normal delivery drivers can deliver 15 parcels every hour. A new system should be able to cope with this as well.
HNF5	Ready for future growth	The new delivery model needs to be able to cope with future growth.
HNF6	Walking distance	Customers only want to walk for 5 to 10 minutes' max when collecting a parcel (420m – 800m)
HNF7	Parcel locker requires a mailbox	To be placed on the street free of charge a parcel locker needs a mailbox (Dutch Regulation)

Hard Requirements Code	Constraint	Explanation
HC1	Maximum load capacity delivery van	The delivery van has a capacity of $4m^3$ to $6m^3$.
HC2	No storage but moving parcels	PostNL is not a storage facility, therefore storage of parcels should be limited to three days.
HC3	Reimbursements not in the parcel locker	Reimbursement shipments at this moment are forwarded to retail locations.

Soft Requirements Code	Functional Requirement	Explanation
SF1	Scanning of parcels	To be able to provide the information parcels need to be scanned.
SF1	Sorting at the depot	Parcels need to be sorted at the depot down the chute, to know which will fit in the van.

Soft Requirements Code	Non – Functional Requirement	Explanation
SNF1	Limiting the number of stops	Drivers prefer to have less stops due to physical labour.
SNF2	Minimize 2nd distribution parcels	The goal is to deliver as much parcels as possible. Preferably no parcel return to the depot
SNF3	Minimize operational costs	The lower the costs the better it is for the company.
SNF4	No waste in the process	Extra steps and processes in the delivery should be eliminated as much as possible.
SNF5	Working and simple ICT Infrastructure	The ICT infrastructure should be simple to understand and simple to work.
SNF6	Time Window	Time window is important for PostNL and their customers. It's a way to measure performance.
SNF7	Parcels with signature	The parcels which require a signature should be able to be delivered as well.
SNF8	Collection of parcels	Collection of parcels back to the depot, which a return shipments or c2c goods.
SNF10	Insured goods delivered personally	People prefer insured good to be delivered personally, due to high value goods.

Soft Requirements Code	Constraints	Explanation
SC1	Minimising the influence on the overall logistic chain	The new delivery model should not be of large influence on the total logistic chain of parcel delivery.

4.2 Parcel locker design alternatives

Using the requirements from paragraph 4.1 and taking into account the fundamentals of paragraph 2.2 designs will be created in this paragraph. These designs will be the future designs of a new delivery model using parcel lockers. The goal is to make designs in such a way that they will fulfil the requirements set before. Most important is to fulfil the hard requirements and the functional requirements. Since the boundary has been set to last mile delivery the design will be focused on this part. The distribution process of the parcels is bond to certain limits. This means almost nothing can be adjusted within the depot, without influencing the distribution process significantly. Indicating that the designs will start at the bottom of the chute where the parcels will come off the sorter belt and loaded in the delivery van. The first step in designing the new delivery model is the brainstorm session, where after the design will be sketched and gets a functional decomposition. After the designs have been created, the designs will be briefly checked according to the lean principles addressed in paragraph 3.2. To possibly improve small aspects and reduce any waste in the process.

Next to the requirements that have been used from Table 8. There are two aspects for the alternatives which are important to mention. These aspects are not part of the requirements since they are not specifically of usage for the design of the alternatives, but more important for the overall research and scope. The first one is that the designs will be constructed for an 11-month period per year. The 12th month of December is a special month within PostNL and is always designed separately and specifically. The second being that all parcels will be delivered with the future delivery model, parcels that fit in parcel lockers and parcels that do not.

The designs that are generated can be distinguished in three categories based on where parcels are being delivered. Below in Table 9 this is displayed in more detail. The first category is home delivery, the second category is the delivery to retail locations and the third category is the delivery to lockers. Chosen for the alternatives that can be found in Table 9 is due to the reason of trying to replace current home delivery with some form of parcel lockers and with that increase the first time hit rate. Each of the three categories has a separation between distribution and collection of parcels. In total, there is one base alternative and three new alternatives. Table 9 displays the categories on which the alternatives can be distinguished, with a Yes or No will be indicated what the alternatives do regarding to the type of delivery location and if there is distribution or collection. Distribution is the delivery of parcels to a certain location, collection is the collection of parcels from a certain location, these are mainly C2C and C2B shipments. This chapter will elaborate on all the different alternatives, within the alternatives variations can be made regarding the number of parcels being delivered to certain locations, this will be further elaborated on in paragraph 4.3.

Table 9 Design alternatives future delivery model

Alternative		Home	Retail	Parcel Locker
Alternative 0: Current parcel delivery	Distribution	Yes	Yes	No
	Collection	No	Yes	No
Alternative 1: Substitution of retail location with parcel lockers	Distribution	Yes	No	Yes
	Collection	No	No	Yes
Alternative 2: Parcel lockers as substitution for current parcel delivery model including collection	Distribution	Yes	Yes	Yes
	Collection	No	Yes	Yes
Alternative 3: Parcel lockers as substitution for current parcel delivery model distribution only	Distribution	Yes	Yes	Yes
	Collection	No	No	No

Alternative 0: Current parcel delivery

To design the future delivery models first the current delivery in De Pijp will be discussed briefly. De Pijp is being delivered with eight routes every day. The delivery vans will be loaded at the depot by the driver at the start of each shift. After loading the delivery van, the driver will drive towards the delivery area and will deliver the parcels. In this alternative, all the parcels will be delivered at home addresses, if people are not home neighbour delivery will be attempted. If this is not possible the parcels will be brought back to the depot or will be brought to a retail location. All the parcels that will be brought at the retail location, have failed delivery attempts or have been selected to be delivered by a customer. At the retail location, the delivery driver will pick up the collection parcels, these are C2C and C2B parcels. After dropping off and picking up the parcels the driver will drive back to the depot. At the depot, the driver will drop off the parcels in the van and will do a debrief. After the debrief the delivery driver is done for the day and the delivery process as well.

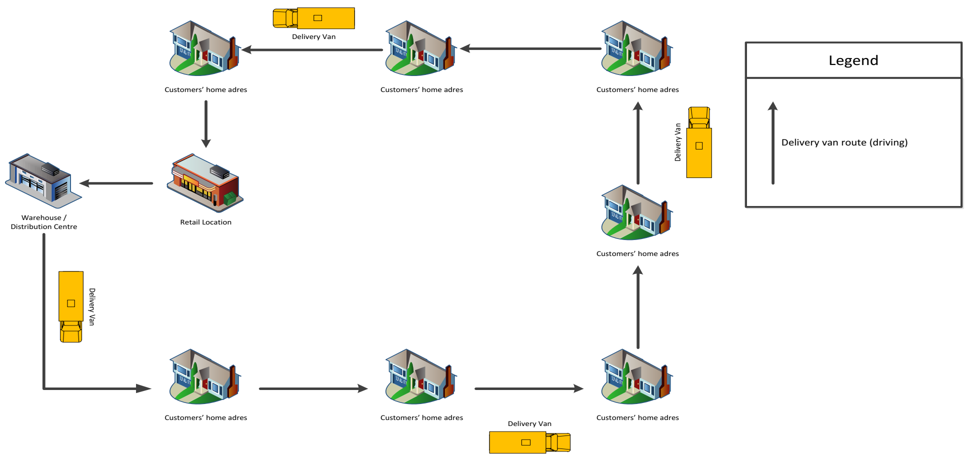

Figure 11 Alternative 0: Current parcel delivery

Alternative 1: Substitution of retail location with parcel lockers

This alternative will substitute the retail location with parcel lockers. The goal is to deliver all failed delivery attempts to house addresses in parcel lockers, the same day of attempting the delivery. With collection of parcels at the retail location, this will be replaced with collection at parcel lockers. The delivery process as explained in alternative 0 will remain largely the same. The aspect that differs is the fact that instead of delivering to a retail location the parcel lockers will be used. If a delivery fails at a home address the parcel will be delivered the same day to a parcel locker at the end of the delivery route. Together with delivering the parcels to the parcel locker the parcels destined for C2C and C2B will be collected from the lockers as well. After this the driver will drive back to the depot and do the same debrief process as alternative 0.

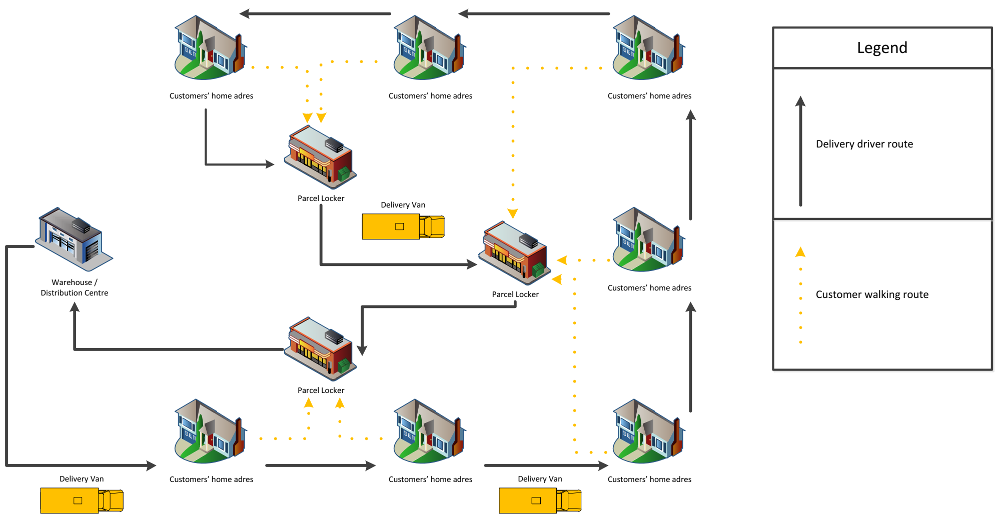

Figure 12 Alternative 1: substitution of retail location with parcel lockers

Alternative 2: Parcel lockers as substitution for current parcel delivery model including collection

This alternative will use the parcel lockers as first option for delivery. Instead of delivering all the parcels immediately to house addresses this alternative will use the parcel lockers as first option. The parcels that will not fit in the parcel locker will be sorted out in the depot by the driver and will be delivered with a standard delivery route. The parcel locker delivery model will have the same characteristics as the current parcel delivery model. However instead of delivering to home addresses, the delivery will take place to parcel lockers. The delivery drivers will collect parcels from the lockers as well when there are collections available. After delivering to all the parcel lockers the driver will drive straight back to the depot and will do the same debrief as alternative 0. The delivery route that will take the parcels that do not fit in the lockers will go to house addresses to deliver and will go to the retail location as well to pick up parcels and deliver parcels. After this the driver will drive back to the depot and will do the same debrief process as alternative 0.

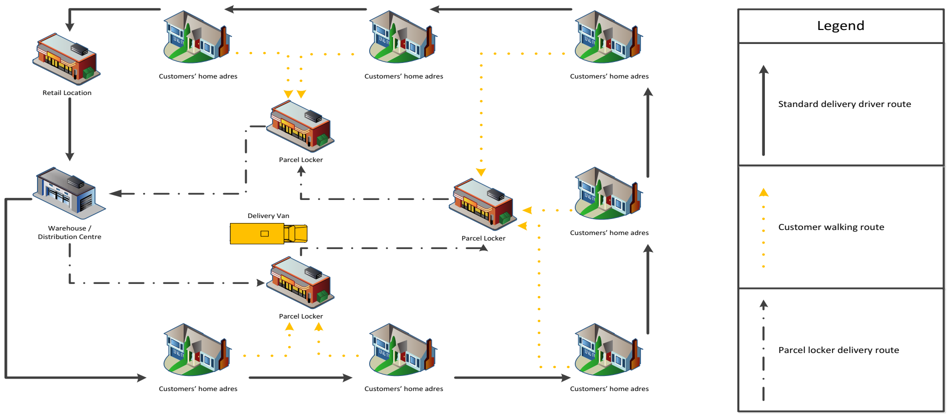

Figure 13 Alternative 2: parcel lockers as substitution for current parcel delivery model

Alternative 3: Parcel lockers as substitution for current parcel delivery model distribution only

This alternative will only distribute the parcels and will not collect any parcels, not at retail locations, not a parcel lockers and not at home addresses. The delivery of the parcels will be conducted on the same manner as in alternative 2. The parcels will be delivered to parcel lockers at first and the parcel that don't fit will be sorted out at the depot and delivered via the standard route as indicated in alternative 0. If people are not home during delivery or a parcel lockers is full the parcels will be delivered to a retail location. Only when there is no other option. When the delivery of the parcels is over the driver will go back to the depot and do a debrief, since there is no collection this will be short.

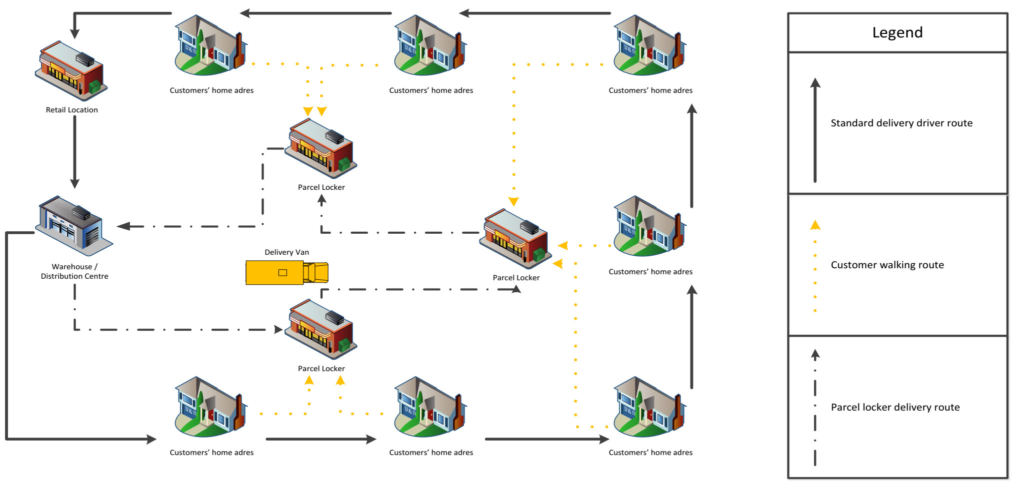

Figure 14 Alternative 3: distribution only delivery model

Looking at the lean process of the design of these alternatives, three important wastes come forward that need to be limited as much as possible. Transport, motion and waiting are the three wastes that occur the most. Transport can be reduced by driving efficiently and not driving the same route twice, for example first distribution and then collection. It's better to do this simultaneously for example. Having less parcels to bring back to the depot will reduce wastes a lot. The goal with the designs is to create variants or combinations in such a way that the parcels that will be brought back will be limited to a low number. Motion resembles the movement a delivery driver needs to make, if the driver needs to make a lot of extra movements like opening the locker door himself, walking a large distance to a locker or other employee related movements. The waiting resembles the time a driver needs to wait before he is able to process the parcels, for example waiting for the parcel locker to assign a locker to place a parcel in. Extensive details about the lean process can be found in Appendix XV Lean design improving.

The three future alternatives that have been designed are base scenario's. Meaning that with all the new alternatives different variables can and will be adjusted. Every alternative has three variants where the fit of parcels in a parcel locker will be varied. This will create three variants per alternative. The fit varies in 88% (M, L, XL lockers), 66% (S lockers) and 50% (XS lockers) fit. For every fit the outer dimensions of the parcel locker will remain the same however the number of lockers within the parcel locker will differ, creating more lockers per different fit and therefore less need of parcel lockers. The extensive details of the different variants can be found in Appendix XVI Design Alternatives. The two most important variables that will differ are based on the requirements set in paragraph 4.1. Which are the ability to be ready for future growth and minimising the operational costs, the variables that can be changed are the growth percentage regarding the number of parcels that will be delivered and the costs per hour. For the costs per hour the number of drivers will be varied, since the costs per hour are fixed but the number of drivers can vary.

4.3 Evaluation of design alternatives

4.3.1 Cost Effectiveness Analysis (CEA) alternatives

The first step is to calculate the costs per parcel for every alternative. The costs per parcel are the outcome of the formula used to calculate the cost per parcel in the last mile, as shown in paragraph 3.3.1. The costs per parcel are based on the labour costs and do not include prices of parcel lockers, the parcel lockers are part of the CEA. The costs that have been calculated are based on a daily number of 1770 parcels delivered in De Pijp. This number is based on the busiest week day in a given month in June 2017. This month is one of the months with the highest number of parcels delivered. Chosen for this number is the fact that the busiest day is usually the cheapest day for PostNL regarding parcel delivery and the need for lockers is larger. Since this research is about parcel lockers, this aspect is important. The number of drivers that are taken into account are based on the maximum capacity of a delivery van of 270 parcels (taking the average size of a single parcel into account). This means 7 or 8 drivers are used, this is important for the number of working hours used to calculate the costs. The CEA has a time span of 10 years. For every of the three alternatives and the base alternative an analysis will be made of the costs per parcel. To recap the last mile cost function from paragraph 3.3.1 is listed below, together with Table 10, which displays the used symbols.

Last Mile Cost per parcel shipped:

$$\frac{(T \cdot t + D \cdot d \cdot v)}{(\frac{STOP}{w} \cdot ip \cdot ad \cdot cp \cdot P)} \cdot (1 + r) + (C_s + C_d) \cdot r + r_1 \cdot C_{rt} + (r_1 + ip) \cdot C_p \qquad (2)$$

Table 10 Used Symbols

Symbol	Variable	Symbol	Variable
T	Duration of route in hours	ad	Area density coefficient
t	Time coefficient	cp	Collection point coefficient
D	Distance of route in kilometre	R_1	Percentage sent to retailers
d	Distance coefficient	r	Return logistics coefficient
v	Vehicle type coefficient	Cs	Evening sorting costs per parcel
P	Parcel multiplication coefficient	Cd	Debrief costs per parcel
STOP	Average number of stops per delivery route per driver	Cp	Parcel compensation cost
w	Time window coefficient	Crt	Retailer costs per parcel
ip	First time hit rate coefficient		

A lot of variables can be changed and some variables are fixed and therefore will not be changed. The variables which will be changed within every alternative are the duration of route, the distance of the route, the number of stops, first time hit rate coefficient, collection point coefficient, return logistics coefficient and the percentage sent to retailers. Most of these variables depend on the type of alternative and some of these variables will change only once or twice. In Table 11 below the variables which are needed for the CEA are displayed. Growth percentage based on PostNL (2017), cost of parcel locker (C. Smit, personal communication, September 14, 2017), maintenance cost is an assumption and the discount factor based on Rijksoverheid (2016).

Table 11 CBA variables

Variable	Value	Unit
Growth percentage	10	%
Cost of parcel locker	[redacted]	
Maintenance costs	5	%
Discount factor	0	%

Alternative 0: Current parcel delivery

The current parcel delivery model doesn't require any parcel lockers and investments. Using the formula (2) in this paragraph together with the input values of Table 12 the costs per parcel can be calculated for alternative 0: current parcel delivery. The costs per parcel can be found in Table 13.

Table 12 Input values for alternative 0: current parcel delivery

Symbol	Value	Unit	Symbol	Value	Unit
T	56	hours	ad	1	-
t	[redacted]	€/hour	cp	1.2	-
D	357	kilometre	R_1	4	%
d	[redacted]	€/kilometre	r	[redacted]	€/parcel
v	1	-	C_s		€/parcel
P	1475	-	C_d		€/parcel
STOP	1.4	-	C_p	12	%
w	84	%	C_{rt}	[redacted]	€/parcel
ip	1.31	-			

Table 13 below shows the delivery cost per single parcel, total number of stops and the total daily delivery costs (output of the CEA). The costs and total number of stops in Table 13 is only intended for delivery of parcels in De Pijp. The costs per parcel are the costs for delivery of a single parcel in De Pijp, the total number of stops is the summation of all the routes delivering parcels in De Pijp and the total daily costs (CEA) are the total daily costs for delivery in de district of De Pijp.

Table 13 Alternative 0 delivery costs

Alternative	Variable	Costs
Alternative 0	Delivery cost per single parcel	€1.14
	Total number of stops	1475
	Total daily delivery costs (CEA)	€3,210.49

Alternative 0, the current delivery model has a delivery cost per single parcel of €1.14. To deliver a single parcel in the district of De Pijp. In total 1475 stops are made, including houses and retail locations. The total daily costs are €3,210.49, the result of the CEA. This is the current situation of delivery in De Pijp, the delivery costs per single parcel are relatively low and a high number of stops is present in this district.

Alternative 1: Substitution of retail location with parcel lockers

This first alternative replaces the retail location with parcel lockers. Using the formula (2) in this paragraph together with the input values of Table 14 the costs per parcel can be calculated for alternative 1: substitution of retail location with parcel lockers, M, L, XL parcel lockers. The input values for alternative 1 S lockers and alternative 1 XS lockers can be found in Appendix XVII Cost Analysis. Highlighted in orange are the variables that change compared to alternative 0. The CEA calculation for alternative 1 M, L & XL lockers can be found in Table 15. The costs per parcel can be found in Table 16.

Table 14 Input values for alternative 1: substitution of retail location with parcel lockers, M, L, XL parcel lockers

Symbol	Value	Unit	Symbol	Value	Unit
T	56	hours	ad	1	-
t	[redacted]	€/hour	cp	1.2	-
D	357	kilometre	R_1	0	%
d	[redacted]	€/kilometre	r	[redacted]	€/parcel
v	1	-	C_s	[redacted]	€/parcel
P	1475	-	C_d	[redacted]	€/parcel
STOP	1.4	-	C_p	0	%
w	100	%	C_{rt}	[redacted]	€/parcel
ip	1.31	-			

Table 15 CEA Alternative 1 M, L, XL lockers

		Discount Factor	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
		Year	1	2	3	4	5	6	7	8	9	10
		Parcels delivered retail										
Alternative 1 M, L & XL lockers		Parcels delivered at home	1487	1636	1800	1980	2178	2396	2636	2900	3190	3509
		Parcels delivered in locker	283	312	344	379	417	459	505	556	612	674
		Number of lockers	26	29	32	35	38	42	46	51	56	62
		Number of lockers built	26	3	3	3	3	4	4	5	5	6
	-€620,000.00	Building Costs	-€260,000.00	-€30,000.00	-€30,000.00	-€30,000.00	-€30,000.00	-€40,000.00	-€40,000.00	-€50,000.00	-€50,000.00	-€60,000.00
	-€208,500.00	Maintenance	-€13,000.00	-€14,500.00	-€16,000.00	-€17,500.00	-€19,000.00	-€21,000.00	-€23,000.00	-€25,500.00	-€28,000.00	-€31,000.00
	-€8,658,945.96	Operational Costs (11 months)	-€542,467.50	-€597,020.73	-€657,090.58	-€722,983.52	-€795,312.52	-€874,997.02	-€962,649.96	-€1,059,190.78	-€1,165,232.45	-€1,282,000.88
Overall Costs	-€9,487,445.96											
Avg daily costs (11-month period)	-€2,840.55											

This alternative doesn't require two separate routes. Therefore, in Table 16 there is no separation for routes. All the three different variants are shown together with their costs.

Table 16 Alternative 1 delivery costs

Alternative	Variable	Costs
Alternative 1 M, L and XL Lockers (88% parcels fit in locker) (26 parcel lockers)	Delivery cost per single parcel	€0.92
	Total number of stops	1266
	Total daily delivery costs (CEA)	€2,840.55
Alternative 1 S Lockers (66% parcels fit in locker) (8 parcel lockers)	Delivery cost per single parcel	€1.01
	Total number of stops	1248
	Total daily delivery costs (CEA)	€2,522.88
Alternative 1 XS Lockers (50% parcels fit in locker) (5 parcel lockers)	Delivery cost per single parcel	€1.06
	Total number of stops	1245
	Total daily delivery costs (CEA)	€2,428.58

Taking a look at the delivery costs in Table 16 of alternative 1 some conclusions can be made. Starting with the delivery costs per single parcel. The delivery costs per single parcel are the lowest when having the biggest variation in lockers. Having a large fit of parcels lowers the delivery costs per parcel. Mainly due to the reason that the first time hit rate (FTHR) increases when delivering to parcel lockers. The more parcels are being delivered in parcel lockers the lower the delivery costs per parcels. Alternative 1 XS lockers has the highest delivery costs per single parcel out of the three alternatives. This alternative only has a 50% fit in the lockers, indicating that the other 50% needs to be delivered to houses. Since the retail location in this alternative is replaced by a parcel locker, this means if a parcel cannot be delivered it needs to be brought back to the depot. This creates extra costs. Looking at the number of stops this just slightly decreases. Alternative 1 XS lockers has less lockers than alternative 1 M, L, XL lockers, however due to having a fit of 50% more parcels need to be delivered at houses. Where multiple parcels can be delivered to a single parcel locker for delivery to a house this is different. Most of the time just one parcel per house. Looking at the total daily delivery costs these decreases when the variation in lockers and fit of parcels decreases as well. Delivering less parcels in lockers is cheaper than delivering a lot of parcels in lockers. This seems contradictory, especially when the delivery costs are increasing. This is due to the reason that with a large fit of parcel more lockers are needed than a low fit of parcels. The parcel lockers are high in cost to build, therefore having the need to build lesser lockers saves money on the long term. The difference between the alternatives isn't that large either. Due to the reason this alternative doesn't require a lot of lockers to be built, since the lockers only replace the retail locations and thus serve a small portion of the total number of parcels that is delivered. The reason being the difference in total daily delivery costs between alternative 1 S lockers and alternative 1 XS lockers is so small.

Alternative 2: Parcel lockers as substitution for current delivery model including collection

The second alternative is in need of parcel lockers as replacement for the house distribution. This alternative does require two separate routes. Therefore, in Table 20 there is separation for routes. All the three different variants are shown together with their costs per type of delivery route. The CEA will not be shown in full but only average daily costs over a 10-year period will be shown. This second alternative uses parcel lockers as substitution for current delivery including collection. Using the formula (2) in this paragraph together with the input values of Table 17 and Table 19 the costs per parcel can be calculated for alternative 2: parcel lockers as substitution for current delivery model including collection, M, L, XL parcel lockers. The input values for alternative 2 S lockers and alternative 2 XS lockers can be found in Appendix XVII Cost Analysis. Highlighted in orange are the variables that change compared to alternative 0. The CEA calculation for alternative 2 M, L & XL lockers can be found in Table 18. The costs per parcel can be found in Table 20.

Table 17 Input values for alternative 2: parcel lockers as substitution for current parcel delivery model, M, L, XL parcel locker route

Symbol	Value	Unit	Symbol	Value	Unit
T	48	hours	ad	11	-
t	[redacted]	€/hour	cp	1	-
D	306	kilometre	R_1	0	%
d	[redacted]	€/kilometre	r	[redacted]	€/parcel
v	1	-	C_s	[redacted]	€/parcel
P	142	-	C_d	[redacted]	€/parcel
STOP	1.4	-	C_p	0	%
w	100	%	C_{rt}	[redacted]	€/parcel
ip	1.31	-			

Table 19 Input values for alternative 2: parcel lockers as substitution for current parcel delivery model, M, L, XL parcel locker standard delivery route

Symbol	Value	Unit	Symbol	Value	Unit
T	8	hours	ad	1	-
t	[redacted]	€/hour	cp	1.2	-
D	51	kilometre	R_1	0	%
d	[redacted]	€/kilometre	r	[redacted]	€/parcel
v	1	-	C_s	[redacted]	€/parcel
P	175	-	C_d	[redacted]	€/parcel
STOP	1.4	-	C_p	16	%
w	84	%	C_{rt}	[redacted]	€/parcel
ip	1.31	-			

Table 18 CEA alternative 2 M, L & XL lockers

		Discount Factor	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
		Year	1	2	3	4	5	6	7	8	9	10
		Parcels delivered retail	35	39	43	48	53	59	65	72	80	88
Alternative 2 M, L & XL lockers		Parcels delivered at home	177	195	215	237	261	288	317	349	384	423
		Parcels delivered in locker	1558	1714	1886	2075	2283	2512	2764	3041	3346	3681
		Number of lockers	142	156	172	189	208	229	252	277	305	335
		Number of lockers built	142	14	16	17	19	21	23	25	28	30
	-€3,350,000.00	Building Costs	-€1,420,000.00	-€140,000.00	-€160,000.00	-€170,000.00	-€190,000.00	-€210,000.00	-€230,000.00	-€250,000.00	-€280,000.00	-€300,000.00
	-€1,132,500.00	Maintenance (5%)	-€71,000.00	-€78,000.00	-€86,000.00	-€94,500.00	-€104,000.00	-€114,500.00	-€126,000.00	-€138,500.00	-€152,500.00	-€167,500.00
	-€8,919,945.07	Operational Costs (11 months)	-€557,795.80	-€613,980.97	-€675,817.91	-€744,038.01	-€818,807.50	-€901,589.20	-€992,117.15	-€1,091,854.14	-€1,201,697.81	-€1,322,246.58
Overall Costs	-€13,402,445.07											
Avg daily costs (11-month period)	-€4,012.71											

Table 20 Alternative 2 delivery costs

Variant	Variable	Costs Locker route	Costs Standard route	Total delivery costs De Pijp
Alternative 2 M, L, XL lockers (88% parcels fit in locker) (142 parcel lockers)	Delivery cost per single parcel	€0.90	€1.29	€0.95
	Total number of stops	142	175	317
	Total daily delivery costs (CEA)	€3,569.14	€443.57	€4,012.71
Alternative 2 S lockers (66% parcels fit in locker) (47 parcel lockers)	Delivery cost per single parcel	€0.99	€1.35	€1.11
	Total number of stops	47	501	548
	Total daily delivery costs (CEA)	€2,115.96	€1,245.96	€3,361.92
Alternative 2 XS lockers (50% parcels fit in locker) (27 parcel lockers)	Delivery cost per single parcel	€1.02	€1.26	€1.14
	Total number of stops	27	737	764
	Total daily delivery costs (CEA)	€1,522.44	€1,789.82	€3,312.26

Taking a look at the delivery costs in Table 20 of alternative 2 some conclusions can be made. Starting with the delivery costs per single parcel. Alternative 2 has two different routes, a route which only delivers the parcel lockers and a route which delivers the house and retail locations (standard route). Looking at the locker route, having the biggest variation in lockers and the largest fit the costs are the lowest. Having a lower fit and less variation increases the cost for the locker route. Due to the reason being that less lockers can be filled, but hourly labour costs do not change and delivery drivers deliver less parcels per delivery van, thus lowering efficiency and increasing costs. Looking at the costs of the normal route a remarkable thing can be seen. First the costs are increasing and then the costs are decreasing again. This is a strange thing, but can be certified. The reason for the decrease in price is the situation that with alternative 2 XS lockers the number of parcels that is being forwarded to a retail location is lower than alternative 2 S lockers and alternative 2 M, L, XL lockers. Since the assumption has been made that the retail locations can only hold a maximum number of parcels. This means the retail costs play an important role in the costs of delivery in the last mile for De Pijp. Looking at the total delivery costs, combining the costs of the locker route and the normal route some things can be stated as well. The delivery costs per single parcel increases when the fit of parcels in the lockers decreases. Overall delivering to houses is costlier than delivering in parcel lockers. Looking at the total daily delivery costs these are decreasing when the variations in lockers and fit of parcels decreases as well, though the delivery costs per single parcel increases as well as the total number of stops. This seems contradictory, however there is a reason for this. Since the purchasing price of a parcel locker is high, when there is a need for a lot of parcel lockers the daily price will increase as well. Therefore, having less lockers saves costs on the long term, since less parcel lockers are needed to deliver parcels to. Despite the increasing number of stops the total daily delivery costs are decreasing. The difference between alternative 2 S lockers and alternative 2 XS lockers is smaller than the difference between alternative 2 S lockers and alternative 2 M, L, XL lockers. Due to the reason the difference in number of lockers between the alternatives is larger.

Alternative 3: Parcel lockers as substitution for current delivery model distribution only

The third alternative is in need of parcel lockers as replacement for the house distribution. This alternative does require two separate routes. Therefore, in Table 24 there is separation for routes. All the three different variants are shown together with their costs per type of delivery route. The CEA will not be shown in full but only average daily costs over a 10-year period will be shown. This second alternative uses parcel lockers as substitution for current delivery excluding collection. Using the formula (2) in this paragraph together with the input values in Table 21 and Table 23 the costs per parcel can be calculated for alternative 3: parcel lockers as substitution for current delivery model distribution only, M, L, XL parcel lockers. The input values for alternative 3 S lockers and alternative 3 XS lockers can be found in Appendix XVII Cost Analysis. Highlighted in orange are the variables that change compared to alternative 0. The CEA calculation for alternative 3 M, L & XL lockers can be found in Table 22.The costs per parcel can be found in Table 24.

Table 21 Input values for alternative 3: distribution only delivery model, M, L, XL parcel locker route

Symbol	Value	Unit	Symbol	Value	Unit
T	48	hours	ad	16	-
t	[redacted]	€/hour	cp	1	-
D	306	kilometre	R_1	0	%
d	[redacted]	€/kilometre	r	[redacted]	€/parcel
v	1	-	C_s	[redacted]	€/parcel
P	98	-	C_d	[redacted]	€/parcel
STOP	1,4	-	C_p	0	%
w	100	%	C_{rt}	[redacted]	€/parcel
ip	1,31	-			

Table 23 Input values for alternative 3: distribution only delivery model, M, L, XL parcel locker standard delivery route

Symbol	Value	Unit	Symbol	Value	Unit
T	8	hours	ad	1	-
t	[redacted]	€/hour	cp	1,2	-
D	51	kilometre	R_1	0	%
d	[redacted]	€/kilometre	r	[redacted]	€/parcel
v	1	-	C_s	[redacted]	€/parcel
P	175	-	C_d	[redacted]	€/parcel
STOP	1,4	-	C_p	16	%
w	84	%	C_{rt}	[redacted]	€/parcel
ip	1,31	-			

Table 22 CEA alternative 3 M, L & XL lockers

		Discount Factor	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
		Year	1	2	3	4	5	6	7	8	9	10
		Parcels delivered retail	35	39	43	48	53	59	65	72	80	88
Alternative 3 M, L & XL lockers		Parcels delivered at home	177	195	215	237	261	288	317	349	384	423
		Parcels delivered in locker	1558	1714	1886	2075	2283	2512	2764	3041	3346	3681
		Number of lockers	98	108	118	130	143	157	173	191	210	231
		Number of lockers built	98	10	10	12	13	14	16	18	19	21
	-€2,310,000.00	Building Costs	-€980,000.00	-€100,000.00	-€100,000.00	-€120,000.00	-€130,000.00	-€140,000.00	-€160,000.00	-€180,000.00	-€190,000.00	-€210,000.00
	-€779,500.00	Maintenance (5%)	-€49,000.00	-€54,000.00	-€59,000.00	-€65,000.00	-€71,500.00	-€78,500.00	-€86,500.00	-€95,500.00	-€105,000.00	-€115,500.00
	-€8,896,565.37	Operational Costs (11 months)	-€556,330.57	-€612,369.03	-€674,044.21	-€742,086.56	-€816,660.45	-€899,226.78	-€989,517.73	-€1,088,994.21	-€1,198,551.05	-€1,318,784.77
Overall Costs	-€11,986,065.37											
Avg daily costs (11-month period)	-€3,588.64											

Table 24 Alternative 3 delivery costs

Variant	Variable	Costs Locker route	Costs standard route	Total delivery costs De Pijp
Alternative 3 M, L, XL lockers (88% parcels fit in locker) (98 parcel lockers)	Delivery cost per single parcel	€0.89	€1.29	€0.94
	Total number of stops	98	175	273
	Total daily delivery costs (CEA)	€3,145.07	€443.57	€3,588.64
Alternative 3 S lockers (66% parcels fit in locker) (31 parcel lockers)	Delivery cost per single parcel	€0.97	€1.35	€1.10
	Total number of stops	31	501	532
	Total daily delivery costs (CEA)	€1,958.76	€1,245.96	€3,204.72
Alternative 3 XS lockers (50% parcels fit in locker) (18 parcel lockers)	Delivery cost per single parcel	€1.01	€1.26	€1.14
	Total number of stops	18	737	755
	Total daily delivery costs (CEA)	€1,430.74	€1,789.82	€3,220.56

Taking a look at the delivery costs in Table 24 of alternative 3 some conclusions can be made. Starting with the delivery costs per single parcel. Alternative 3 has two different routes, a route which only delivers the parcel lockers and a route which delivers the house and retail locations (standard route). Looking at the locker route, having the biggest variation in lockers and the largest fit the costs are the lowest. Having a lower fit and less variation increases the cost for the locker route. Due to the reason being that less lockers can be filled, but hourly labour costs do not change and delivery drivers deliver less parcels per delivery van, thus lowering efficiency and increasing costs. Looking at the costs of the normal route a remarkable thing can be seen. First the costs are increasing and then the costs are decreasing again. This is a strange thing, but can be certified. The reason for the decrease in price is the situation that with alternative 3 XS lockers the number of parcels that is being forwarded to a retail location is lower than alternative 3 S lockers and alternative 3 M, L, XL lockers. Since the assumption has been made that the retail locations can only hold a maximum number of parcels. This means the retail costs play an important role in the costs of delivery in the last mile for De Pijp. Looking at the total delivery costs, combining the costs of the locker route and the normal route some things can be stated as well. The delivery costs per single parcel increases when the fit of parcels in the lockers decreases. Overall delivering to houses is costlier than delivering in parcel lockers. Looking at the total daily delivery costs these are decreasing when the variations in lockers and fit of parcels decreases as well, though the delivery costs per single parcel increases as well as the total number of stops. This seems contradictory, however there is a reason for this. Since the purchasing price of a parcel locker is high, when there is a need for a lot of parcel lockers the daily price will increase as well. Therefore, having less lockers saves costs on the long term, since less parcel lockers are needed to deliver parcels to. Despite the increasing number of stops the total daily delivery costs are decreasing. A remarkable thing is the increase in total daily delivery costs from alternative 3 S lockers to alternative 3 XS lockers, where a decrease would be expected. The difference in daily costs is really small between the two alternatives. An explanation for the increasing costs could be related to the costs of normal delivery to retail locations and houses. Since having a low fit in lockers requires more delivery at houses and retail locations, combining this with a lower number of lockers to be built creates an increase in costs. Another reason can be rounding of numbers in the calculations, creating a slightly different value.

Conclusion Cost effectiveness analysis

In total four different alternatives, including the current delivery model, have been analysed for delivery costs. For every alternative, an individual conclusion has been drawn, though the alternatives have not been compared with each other. In Table 25 below the overall overview can be seen.

Table 25 Delivery costs all alternatives

Alternative	Delivery cost per single parcel	Total daily delivery costs (CEA)
Alternative 0	€1.14	€3,210.49
Alternative 1 M, L, XL lockers	€0.92	€2,840.55
Alternative 1 S lockers	€1.01	€2,522.88
Alternative 1 XS lockers	€1.06	€2,428.58
Alternative 2 M, L, XL lockers	€0.95	€4,012.71
Alternative 2 S lockers	€1.11	€3,361.92
Alternative 2 XS lockers	€1.14	€3,312.26
Alternative 3 M, L, XL lockers	€0.94	€3,588.64
Alternative 3 S lockers	€1.10	€3,204.72
Alternative 3 XS lockers	€1.14	€3,220.56

Highlighted with three different colours are the costs of the different alternatives. The orange colour is the colour of the current delivery model (alternative 0), if one of the costs is the same it will get this orange colour. A green colour for costs indicates the costs are lower than alternative 0 and a red colour indicates higher costs than alternative 0. As can be seen in Table 25 the delivery costs per single parcel are cheaper for each of the alternatives. Except for alternative 2 XS lockers and alternative 3 XS lockers which are equally as expensive. This means that delivering delivery in a parcel locker is cheaper than delivery to houses and retail location. Important to mention this is taking into account the labour costs and not taking into account the costs of the parcel locker itself. The reason for it being cheaper than the current delivery is the fact that the FTHR increases, less parcels need to be brought back to the depot and less parcels need to be brought to the retail locations. These two factors save a lot on costs. Looking at the total daily delivery costs for De Pijp, four alternatives are cheaper to operate than the current delivery model and five delivery models are more expensive to operate than the current delivery model. This includes the purchasing and maintenance of the parcel lockers. The different alternatives as they have been analysed are based on the current delivery model. This means the same number of drivers are used for the new alternatives as for the current delivery model. However, it is possible for alternative 2 and 3 to operate the parcel locker route with a lower number of drivers. And thus, changing the total daily delivery costs. This will be discussed in the sensitivity analysis below. The ranking of the different alternatives will be based on Table 25 and can be seen in paragraph 4.3.4. The reason for using the numbers of Table 25 and not the outcome of the sensitivity analysis is due to the fact that all three methods need to be evaluated on the same input for the different variables. Thus, the MCA and simulation are being evaluated based on the standard alternatives as they have been designed. Any other conclusions gathered from sensitivity analysis for example will be discussed further in the paragraph of the Final Design.

Sensitivity Analysis

In Appendix XVIII Alternatives Cost Sensitivity Analysis, the sensitivity analysis of the alternatives can be seen. Where the growth, number of drivers, discount factor and maintenance percentage are varied. The reason for varying these variables is due to the situation that the four variables are based on assumptions that have been made, therefore the base values are not hard values. The variables are depended from national economics, in the case of growth and the discount factor. Therefore, it is a necessary thing to vary these values to get a complete overview of the possible difference in costs, when economics will be changing. This will create different results. The variations can be seen in Table 26 below.

Table 26 Variables sensitivity analysis

Variable	Base Value	Sensitivity values
Growth percentage	10 %	5%, 15%
Number of drivers	Current number	Reduced in half (if possible)
Discount factor	0%	3%, 4.5%
Maintenance costs (percentage of purchasing price)	5%	10%, 15%

Having varied the four different variables displayed in Table 26 different conclusions can be made. Regarding the growth percentage, discount factor and maintenance costs. The alternatives that have been created do not change relative to each other when looking at the different values. Alternative 1 performs the best for these three variables and does not change in ranking. Alternative 2 and 3 are preforming good as well, the difference in ranking looking at the total daily delivery costs does not differ that much. However, when the number of drivers is being changed the total daily delivery costs change drastically. A normal day of delivery for a driver is assumed to be an 8.5 hour working day, including a half hour break. Alternative 2 and alternative 3 have the possibility to reduce the number of drivers, since the locker route can be operated with half the number of drivers than the standard design. This due to the reason that delivery to a parcel lockers takes significantly less time than a normal delivery route. Giving the possibility for one delivery driver to operate two routes on one day. In Table 27 below this difference is shown. The same colouring coding of Table 25 has been used.

Table 27 Results sensitivity analysis driver change

Alternative	Total daily delivery costs (CEA) (standard alternative)	# of drivers	Total daily delivery costs (CEA) (number of drivers change)	# of drivers
Alternative 0	€3,210.49	7	€3,210.49	7
Alternative 1 M, L, XL lockers	€2,840.55	7	€2,840.55	7
Alternative 1 S lockers	€2,522.88	7	€2,522.88	7
Alternative 1 XS lockers	€2,428.58	7	€2,428.58	7
Alternative 2 M, L, XL lockers	€4,012.71	7	€3,137.09	4
Alternative 2 S lockers	€3,361.92	8	€2,704.85	6
Alternative 2 XS lockers	€3,312.26	8	€2,814.50	6
Alternative 3 M, L, XL lockers	€3,588.64	7	€2,716.37	4
Alternative 3 S lockers	€3,204.72	8	€2,550.17	6
Alternative 3 XS lockers	€3,220.56	8	€2,724.71	6

Shown on the left is the standard situation, on the right the new situation. In brackets after the costs the ranking of the alternatives can be seen, the lower the ranking the better it scores. In the standard situation five alternatives were more expensive than the current delivery model. In the situation where the number of drivers for the locker route is reduced to half. All the alternatives are cheaper to operate than the current delivery model. This includes the purchasing of the parcel lockers. This means that the alternatives with the separate locker route need to cut labour force to be able to be more cost efficient than the current delivery model. Another thing that can be concluded is in the new situation the daily delivery costs of all the alternatives are relatively close to each other. Where in the standard situation the difference in costs between the alternatives is larger. For some alternatives, the ranking doesn't change that much, however they are cheaper to operate than the current delivery model. Indicating that ranking of the alternatives for cost is not the most important characteristics to determine which alternative is performing the best. The results of the change in drivers will be taken into account when selecting the final design in paragraph 4.5.

4.3.2 Multi-Criteria Analysis (MCA) alternatives

The MCA is performed to select the best alternatives based on requirements that have been set. Not all the requirements are suitable for a MCA analysis. Due to the reasons of being a hard requirement for example or a constraint that will not differ between different alternatives. One of those requirements is the requirement of having a maximum capacity in the delivery van. Since all alternatives meet this requirement there will be no difference between them and therefore impossible to score based on individual views. In Table 28 below the requirements from paragraph 4.1 are shown. As well as the criteria, they belong to or the reason for not selecting the requirement.

Table 28 Requirements and matching criteria

Requirement	Criteria/Explanation	Requirement	Criteria/Explanation
Minimum damaging and missing of goods	Safety	Sorting at the depot	Efficiency
Proper security	Safety	Limiting the number of stops	Efficiency
Information provision	Consumer service	Minimize 2nd distribution of parcels	Sustainability
Capacity of parcel locker	Hard/Constraint	Minimize operational costs	Feasibility/CEA
Performance 15 parcel p hour	Hard/Constraint	No wastes in the process	Efficiency
Ready for future growth	Hard/Constraint	Working and simple ICT infrastructure	Feasibility
Walking distance	Accessibility	Time window	Reliability
Parcel locker requires mailbox	Hard/Constraint	Parcels with signature	Hard/Constraint
Maximum load capacity delivery van	Hard/Constraint	Collection of parcels	Reliability
No storage in lockers	Hard/Constraint	Insured goods delivered personally	Consumer service
Reimbursements not in parcel locker	Hard/Constraint	Minimising the influence on the overall logistic chain	Sustainability
Scanning of parcels	Hard/Constraint		

The MCA is conducted with two types of people, employees from PostNL and transport and logistics experts. Both are familiar with last mile logistics and have sufficient transport knowledge. The persons have been asked to fill in the MCA based on their perspective and how they feel about the criteria and delivery model, 25 respondents filled in the MCA. Seven different criteria have been selected to be part of the MCA and are listed in Table 29 below with a short explanation what the criteria entails.

Table 29 Criteria with explanation

Criteria	Explanation
Accessibility	How easy is it for customers to collect their parcels, is a large travel distance required?
Consumer Service	How easy to use is the delivery model for consumers? Do customers get notifications by email/sms, operating system easy to use, delivery close to home?
Efficiency	How efficient is the delivery model to use for a logistics provider? Does it require a lot of steps to operate or is it simple to operate?
Feasibility	How feasible is it to build and operate the system? Building a lot of parcel lockers on street locations can be perceived and unfeasible.
Safety	Is the delivery model safe to operate? Is it possible for people whom shouldn't be involved in the process to intervene and take away parcels?
Sustainability	Regarding the environment is the delivery model sustainable. Having a lot of stops is less sustainable and having a lot of delivery vans is not preferred.
Reliability	How reliable is the system when operating? Does it always end up in a parcel locker or does this change depending on availability?

Each of the seven criteria has been evaluated by the respondents based on their importance. Which criteria do they think is more important than the other and which criteria is less important than the other? Every respondent filled in a value from 1 being equally important to a 10 for being extreme important. Collecting all the responses for every criterion the values have been normalized, creating values between 0 and 1. Below in Table 30 the normalized weights for the criteria are shown, the sum of all the weights amounts to be 1.

Table 30 Criteria weights

Criteria	Overall weights	Standard Deviation
Accessibility	0.191	0.090
Consumer Service	0.125	0.075
Efficiency	0.135	0.061
Feasibility	0.115	0.049
Safety	0.194	0.133
Sustainability	0.080	0.062
Reliability	0.160	0.085

Safety and accessibility are the two criteria that are valued the most important criteria. Safety being the most important criteria. This is in the line of expectation; the parcel delivery market needs to deliver parcels as safe as possible to customers. Customers don't want to lose parcels which they paid for or receive damaged parcels. Accessibility is important as well, literature has mentioned several times that people still prefer current delivery due to the reason being that a delivery driver comes straight to your house and you don't have to travel far. When collecting parcels from a locker, people do not want to travel far and thus is a parcel locker nearby an important aspect. This is in line with the high score for accessibility. Sustainability scores the worst of all criteria. This doesn't mean it is not important, in this MCA it means relative to the other factors it is the least important to take into consideration. Costs have not been included in this MCA due to the reason costs are being evaluated in detail with a CEA analysis. The MCA has been used to evaluate more on a qualitative manner than the CEA which is of quantitative nature. The standard deviation of the criteria is fairly high, the most important criteria safety has a large standard variation. Indicating a lot of spread in the data. As well as sustainability, where sustainability has a standard deviation almost as high as the weight itself. The high standard deviation indicates a high spread in data, therefore making hard conclusions stating that safety is the best overall weight is not possible. However, it gives an indication of the importance, the high standard deviation can be explained by the fact that with 23 respondents the number of respondents for this MCA was low. The high standard deviation will be taken into account when choosing the final design and making the ranking. Paragraph 5.3.1 will go more in detail about the reflection on this standard deviation.

Every alternative has been scored by the respondents with a value from 1 to 10, for every criterion of the eight criteria. The base alternative is always valued at a 5, being the "neutral" alternative.

Respondents valued the new alternative relative to the base alternative. Being higher than a 5 is better and lower than a 5 is worse. Below in Table 31 the overviews of the scores can be found.

Table 31 Overall scores alternatives

	Accessibility	Consumer Service	Efficiency	Feasibility	Safety	Sustainability	Reliability
Alternative 0	5	5	5	5	5	5	5
Alternative 1 M, L, XL lockers	6.826	6.565	5.913	5.826	4.957	5.174	5.739
Alternative 1 S lockers	5.609	5.565	5.783	5.739	4.870	5.261	5.261
Alternative 1 XS lockers	4.739	4.826	5.522	5.870	4.826	5.478	5.000
Alternative 2 M, L, XL lockers	7.913	6.391	6.565	4.391	4.783	4.696	6.130
Alternative 2 S lockers	6.652	5.652	6.522	5.043	4.652	5.391	5.913
Alternative 2 XS lockers	5.652	5.087	6.087	5.217	4.652	5.739	5.913
Alternative 3 M, L, XL lockers	7.609	6.087	6.348	4.826	4.435	4.717	5.739
Alternative 3 S lockers	6.196	5.152	5.674	4.804	4.370	5.217	5.630
Alternative 3 XS lockers	5.022	4.413	5.413	5.239	4.283	5.500	5.457

Important to keep in mind is that these values are not the final values, since they have not yet been adjusted based on the weights the respondents have given to the criteria. Though some conclusions can be drawn. Starting with the two most important criteria safety and accessibility. Safety is being valued worse every new alternative than the current situation. This is a surprising and unexpected result. The reason for this could be the fact people have a lower value for safety when it comes to a parcel locker compared with delivery to a house address, where a customer receives it personally. This is not a remarkable thing to think of the respondents. However, this research is not focussed on customer perception of parcel lockers but looks into the possibility of last mile logistics using parcel lockers. Though this is an important aspect. Regarding the accessibility, every alternative besides alternative 1 XS lockers scores better than the current delivery model. This has good potential, reason for this score can be the fact that with the alternatives not only house and retail distribution are an option but parcel distribution as well. As well as collection making it easier for the customer to access. Though as can be seen as well, the smaller the locker size and thus the lower the number of lockers available the lower the scores are for the alternatives. Which is in the line of expectation, since the customer has to travel further to find a locker nearby. Taking a look at consumer service, only alternative 1 XS lockers and alternative 3 XS lockers score lower than the current delivery model. The more variations in lockers and the more lockers available the better the score is for consumer service. The consumer has more options to choose from and the changes of successful parcel delivery are higher as well, this is all in benefit of the consumer. Efficiency scores good as well for every alternative. Every alternative scores better than the current delivery model, this is due to the reason that with the future delivery models the FTHR increases and the number of parcels that is being brought back to the depot is lower than the current delivery model. Making operation more efficient. A trend is visible here as well, when the fit in the lockers decreases and thus more parcels need to be split between routes the lower the efficiency scores. This is an expected result. Since simplicity is key for PostNL, having to make more of a selection is not preferred. Looking at the feasibility a trend can be seen as well, the alternatives with a large number of parcel lockers score worse than the current delivery model. Only alternative 1 is overall better in feasibility since this alternative doesn't require a large number of parcel lockers. The number of parcel lockers required for this alternative can replace current mailboxes. Alternative 2 and 3 need to place a lot of parcel lockers on the streets, therefore the low scores. Alternative 3 scores the worst overall, possibly due to the reason of being a distribution model only. For sustainability, almost all the alternatives score better than the current delivery model. Mainly due to the reason less stops are required to make. Though the sustainability scores better when less lockers are needed to be built, the number of stops does increase. Since the stops for houses are increasing. This is a thing which cannot be seen in this MCA, since the scores become better and not worse. Indicating that stops as houses are not seen as unsustainable. Looking at reliability every alternative scores better than the current delivery model. The trend here as well, the lower the number of lockers and thus the lower the percentage fit the lower the score gets. Due to the reason being that the delivery model becomes more complicated and thus changes are larger for a mistake with delivery, making it less reliable. Overall the scores do not differ that much from the current delivery model, indicating the future delivery models are being valued relatively as good or bad as the current delivery model. For the overall scores on the alternatives the standard deviation is high as well, the exact scores for the standard deviation can be found in Appendix XIIX MCA Results. Since safety is scoring worse than the current situation this is an criteria to take into account when looking at the standard deviation, which is on average around 2. This is high, indicating a high spread in data therefore. This means that making a hard conclusion stating safety is scores is worse for every alternative in relation to the current situation is not possible. It only gives an indication, the same with the criteria from Table 30. This does not mean that the scores that are used to evaluate this MCA are unusable, they are giving an indication for the different alternatives. Hard conclusions cannot be made, respondents value the alternatives differently. A reason can be the fact that respondents are unknown with such a future design. This will be further discussed in Paragraph 5.3.1.

Taking the (normalized) weights into account as well from Table 30. Together with the scores on the alternatives from Table 31 the final scores and thus ranking of the alternatives can be determined.

Table 32 Final scores and relative scores alternatives

Alternative	Overall (absolute) score	Relative importance
Alternative 0	5.000 (9)	84.9%
Alternative 1 M, L, XL lockers	5.887 (2)	98.3%
Alternative 1 S lockers	5.415 (6)	90.4%
Alternative 1 XS lockers	5.103 (8)	85.2%
Alternative 2 M, L, XL lockers	5.988 (1)	100.0%
Alternative 2 S lockers	5.719 (4)	95.5%
Alternative 2 XS lockers	5.446 (5)	90.9%
Alternative 3 M, L, XL lockers	5.784 (3)	96.6%
Alternative 3 S lockers	5.313 (7)	88.7%
Alternative 3 XS lockers	4.988 (10)	83.31%

As seen in Table 32 not only the absolute scores are displayed but the relative scores as well, this to indicate the scoring relative to each other. The first thing that can be concluded is the fact that all the alternatives score between a 4.9 and a 6. Indicating that the alternatives are better than the base alternative, except for alternative 3 XS lockers but not by much. They are just slightly better, this can be seen better when looking at the relative scores. The relative scores are quite close to each other. Some even differ from just 0.1% point. Since the alternatives are quite similar to each other this is not strange. Alternative 2 and 3 only differ in the aspect that alternative 3 is a distribution only model and alternative 2 is not. Though when looking at the scores alternative 2 scores better than alternative 3. Despite alternative 3 having less parcel lockers, less stops and being cheaper to operate. This indicates that the respondents valued the option for collection in alternative 2 to be important. This can be seen looking at the scores for consumer service in Table 31 which are valued higher for alternative 2. Therefore, collection in parcel lockers is seen as an important aspect for a future delivery model.

Looking solely at individual scores for every alternative, Alternative 2 M, L, XL lockers is the best performing alternative according to the MCA. Followed closely by alternative 1 M, L, XL lockers and then Alternative 3 M, L, XL lockers. Which indicates that when delivering parcels in a parcel lockers great value is given to options where all different sizes of parcels are being delivered in lockers. Lockers where only the smaller parcels are being delivered perform relatively worse. Not only size matters but the possibility for collection as well, since alternative 3 scores relatively lower than alternative 1 and 2 whom have the option for collection. Looking at the overall alternatives and thus the main three different alternatives. Alternative 2 scores the best, indicating that delivering parcels as much as possible in a parcel locker with a separate route for parcel lockers and normal distribution is valued positively. This is important to take into consideration when making the final design and making a conclusion.

4.3.3 Simulation alternatives

In Figure 15 the conceptual model of the simulation is displayed. This model includes two different inputs and one output. The fixed model input are the variables that do not vary for the different simulation scenario's. Out of the four variables, highlighted in blue, the number of delivery vans and distribution of the parcels differs per alternative, depending on the characteristics of the alternative and locker type. Regarding the other input variables, they differ amongst the different scenarios, depending on the scenario which of the nine simulation variables differs. In total 18 different scenarios per alternative have been simulated, of those 18 scenarios one base scenario is the most important scenario and will be discussed elaborately in this chapter. The remaining scenarios are sensitivity analysis and will be explained briefly. The nine different simulation variables can be found in Table 34 as well, with the corresponding number and the type of variable and unit. The goal of the simulation is to validate the conceptual design alternatives that have been created in paragraph 4.2. The simulation will validate in detail the assumptions that needed to be made and validates if the number of lockers is sufficient and if the delivery drivers are able to operate within their working day of 8.5 hours. Therefore, the model output consists of the occupancy rate of the lockers, the occupancy rate of the delivery drivers shifts and the delivery time.

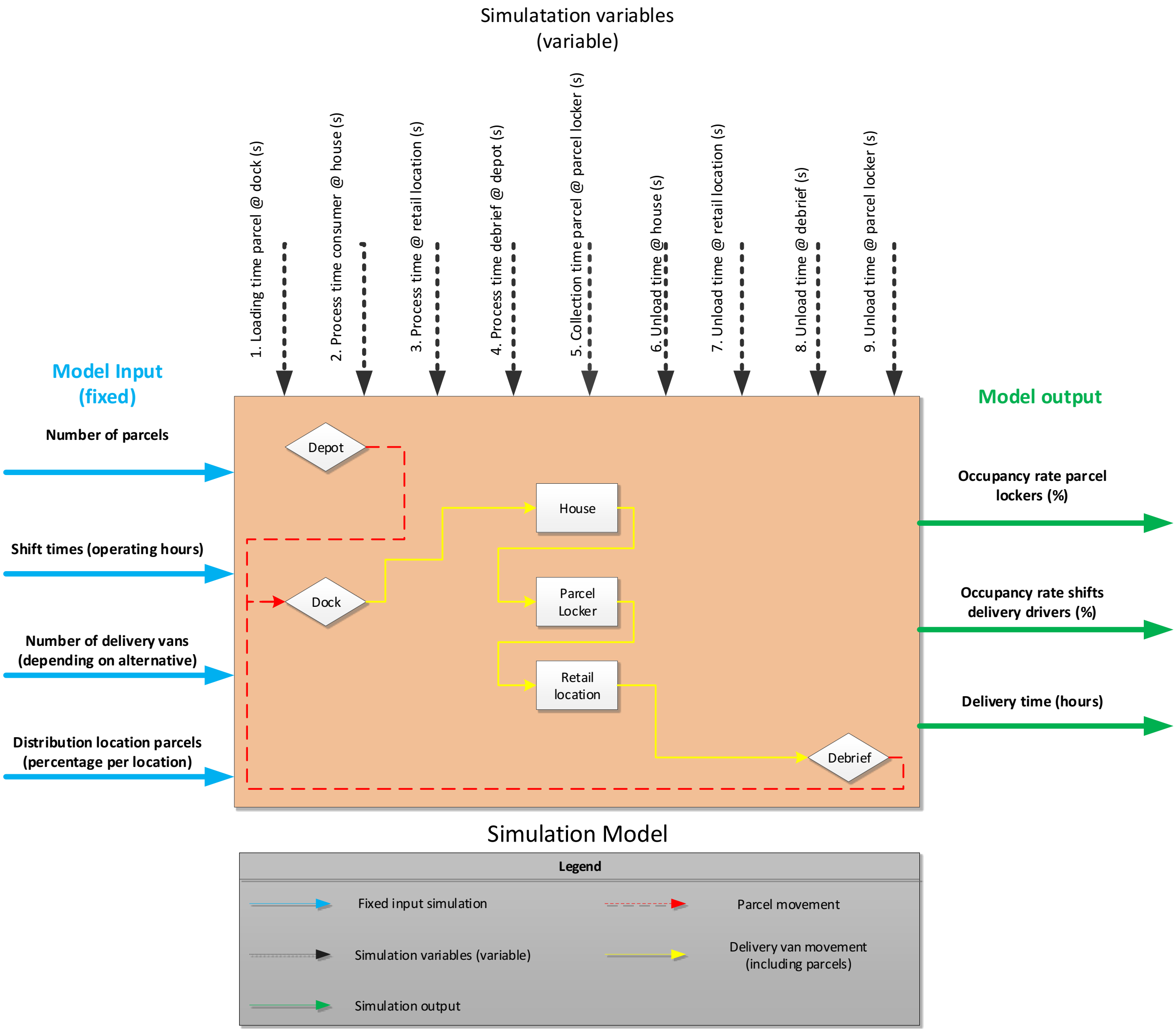

Figure 15 Conceptual model simulation

Figure 15 shows a simplified scheme of the simulation model, extensive details about the model itself and the visuals in the simulation program of Simio can be found in Appendix XIX Simulation Results. The dotted red line resembles the flow of parcels, this flow does not include movement of the delivery driver or delivery van, this movement can be done on a conveyer or container but the type of transport is not relevant for this research. The yellow line indicates the route the delivery driver and thus delivery van drives, including the parcels. Depending on the alternative the house, parcel locker or retail location can be skipped, though the debrief always occurs, independent of the alternative. The time it takes from the dock (this is the location at the depot where the delivery van will be loaded) to the debrief (the location at the depot when the parcels have been delivered and a debrief takes place) is the total delivery time. With this delivery time the occupancy rate of the shifts can be calculated. The occupancy rate of the parcel lockers will be determined based on the output of the parcel locker square.

For the simulation, a basis scenario has been designed. This basis scenario has input variables that are based on the current situation and data given by PostNL. The variables for the base scenario can be seen in Table 33 and Table 34. In Table 33 the distribution percentages of the different alternatives can be seen; the percentage indicate how much percent of the parcels are destined for a certain location. The percentages are based on data retrieved from PostNL and own calculations. In Table 34 the input variables for the simulation is shown.

Table 33 Distribution Percentages

Alternative	House Distribution	Retail Distribution	Locker Distribution	Debrief/Undelivered
Alternative 0	84%	12%	0%	4%
Alternative 1 M, L, XL lockers	84%	0%	16%	0%
Alternative 1 S lockers	84%	0%	11%	5%
Alternative 1 XS lockers	84%	0%	8%	8%
Alternative 2 M, L, XL lockers	10%	2%	88%	0%
Alternative 2 S lockers	29%	5%	66%	0%
Alternative 2 XS lockers	42%	7%	50%	1%
Alternative 3 M, L, XL lockers	10%	2%	88%	0%
Alternative 3 S lockers	29%	5%	66%	0%
Alternative 3 XS lockers	42%	7%	50%	1%

Table 34 Input variables simulation

	Variable type / Action	Input value variable	Unit
1	Time loading parcel in delivery van at the dock	Random.Triangular (7,10,13)	seconds
2	Process time consumer at house	Random.Triangular (5,7.5,10)	seconds
3	Process time parcel at retail location	Random.Triangular (8,10,12)	seconds
4	Process time debrief at depot	Random.Triangular (7,10,13)	seconds
5	Time consumer takes to collect parcel from locker	Random.Triangular (1,4,72)	seconds
6	Unload time delivery van at house location	Random.Triangular (40,60,80)	hours
7	Unload time delivery van at retail location	Random.Triangular (40,60,80)	seconds
8	Unload time delivery van at debrief	Random.Triangular (30,40,50)	seconds
9	Unload time delivery van at locker	Random.Triangular (10,20,30)	seconds

For every variable, a Random.Triangular distribution has been used. This means there is a minimum, a mean and a maximum. With this the simulation has been performed. Process time consumer at house represents the time it takes a customer to process its parcel, this includes signature, opening the door and acceptance of the parcels. The assumption is made this will not influence the overall performance. However, the unloading time includes the performance of the driver. The time consumer takes to collect parcel from locker is the time it takes a customer to collect their parcels. This is a minimum of 1 hour and a maximum of 72 hours (three days). The three days' maximum is based on the requirement that the parcel lockers shouldn't be used as a storage locker. After three days, the parcels will be removed from the parcel locker. Since this was hard to simulate the assumption is made that customers take a maximum of 72 hours of collecting their parcels and thus there is no need to empty the parcel locker. On average it takes 14 hours, the reason for this 14 hours being the fact that 90% will collect its parcels within 24 hour, 5% within 48 hours and 5% within 72% hours.

The first four variables do not differ amongst the different scenario's. These times will not influence the time of the delivery van and its driver. This paragraph will only discuss the results of the base scenario, since every alternative has several simulation scenarios this will be to elaborate to discuss. Though the sensitivity analysis that has been performed with creating these different scenarios will be taken into account with the analysis of the simulation. More details about the sensitivity and the different scenarios can be found in Appendix XIX Simulation Results.

Overall Simulation Results

The simulation simulated a week of delivery, delivering every day 1770 parcel for five days. Every alternative that has been designed performed without any bugs or failures. The designs as they are right now, are performing accordingly. The simulation has been conducted with Simio and operated on a windows computer. For the simulation experiments a number of 20 repetitions for every scenario has been used. The initial goal was to have at least 50 repetitions, due to the situation that having more repetitions the data would be more accurate. However, when performing the simulation with 50 repetitions Simio stopped working and needed to be rebooted. The performance of the operating system was not high enough for this number of repetitions, being the reason the number of 20 repetitions has been chosen. The simulation that has been conducted only looks at the distribution of the delivery models. Taking collection into account would require a substantial amount of work and effort, especially since the simulation software Simio would require certain aspects for this type of performance which makes it hard to handle. Making an analysis out of the simulation this will be taken into account when making conclusions.

Looking at Table 35 the percentages and hours are based on an average day of delivery in the simulated week. The total number of parcels delivered is the cumulative number of the entire week. Looking more closely per alternative and seeing alternative, 0 this alternative performs like the real-life situation, when taking only distribution into account. The minimum delivery time of 2.49 hours is low, however when everything goes without any hassle this can be the case. The maximum delivery time of 6.41 hours is realistic in comparison with normal operations. On average a delivery route in the current situation takes 5 and a half hours. The researcher has delivered parcels as well as part of his research and has been working for the same number of hours. Unfortunately, quantitative data of operating performance was not available within PostNL. This data is not being recorded. Asking delivery drivers

Table 35 Simulation output (results)

	ShiftOccupancyRate Normal Route (percentage)	TotalDeliveryTimeAVG Normal Route (hours)	TotalDeliveryTimeMIN Normal Route (hours)	TotalDeliveryTimeMAX Normal Route (hours)	ShiftOccupancyRate Locker Route (percentage)	TotalDeliveryTimeAVG Locker Route (hours)	TotalDeliveryTimeMIN Locker Route (hours)	TotalDeliveryTimeMAX Locker Route (hours)	LockerOccupancyRate (percentage)	Parcels loaded in delivery van at the depot	House Distribution	Locker Distribution	Retail Distribution	Undelivered
Alternative 0	64.83%	5.51	2.49	6.41	X	X	X	X	X	9263	7777	X	1115	371
Alternative 1 M, L, XL lockers	64.55%	5.49	2.37	6.34	X	X	X	X	66.50%	8893	7464	1428	X	X
Alternative 1 S lockers	67.14%	5.71	2.74	6.47	X	X	X	X	65.95%	9344	7846	1038	X	460
Alternative 1 XS lockers	68.83%	5.85	3.15	6.53	X	X	X	X	59.10%	9634	8084	779	X	771
Alternative 2 M, L, XL lockers	80.68%	6.86	6.62	7.10	45.47%	3.86	3.77	3.95	68.78%	8833	1054	7576	203	X
Alternative 2 S lockers	66.52%	5.65	2.59	6.53	40.55%	3.45	2.42	3.74	60.92%	8862	2822	5546	494	X
Alternative 2 XS lockers	66.39%	5.64	2.61	6.53	40.53%	3.44	2.42	3.76	64.37%	8836	3779	4431	626	87
Alternative 3 M, L, XL lockers	80.68%	6.86	6.62	7.10	45.47%	3.86	3.77	3.95	99.66%	8833	1054	7576	203	X
Alternative 3 S lockers	66.52%	5.65	2.59	6.53	40.55%	3.45	2.42	3.74	92.37%	8862	2822	5546	494	X
Alternative 3 XS lockers	66.39%	5.64	2.61	6.53	40.53%	3.44	2.42	3.76	96.56%	8836	3779	4431	626	87

themselves this operating time is indeed average for delivery of parcels. This means the simulation performs close to reality, thus having good perspective for the alternatives that have been designed. Looking at the number of parcels that are loaded in the delivery van and thus out for delivery, this number is higher than the other alternatives. Though the initial number of parcels is equal for every alternative. The reason for this being the case that parcels that are undelivered will be brought back from the debrief to the dock again where the parcels are being loaded in the delivery van, this causes the higher number of parcels that are loaded in the delivery van.

Having discussed the overall performance of alternative 0, the current delivery model. The variables that are displayed vertically in Table 35 will be discussed. To start with the Shift Occupancy rate of the lockers. Since alternative 0 and alternative 1 M, L, XL lockers, alternative 1 S lockers and alternative 1 XS lockers don't have a separate locker route no information is available for these alternatives. For the remaining alternatives, it can be seen that the alternatives with the large variation in lockers and thus more lockers have a larger occupancy rate than the alternatives with the smaller variation and thus lower number of parcel lockers. This can be explained due to the reason that having a large variation of parcel lockers requires more parcels to be delivered to a locker. This can be seen in the column of the locker distribution. The total number of parcels being delivered to lockers is higher with alternative 2 M, L, XL and alternative 3 M, L, XL than with the other alternatives. Thus, costs more time to operate. Despite having a different number of parcels delivered to a parcel locker alternative 2 S lockers and alternative 2 XS lockers score the for the occupancy rate. Having an occupancy rate lower than 50% indicates that one delivery driver is able to operate the same route twice per day, and still have an occupancy rate lower than 100% in total. Though since this simulation is a distribution model only and collection has not been taken into account, having a 45% occupancy rate leaves limited room for collection. Alternative 2 S lockers and alternative 2XS lockers are performing better with a 41% occupancy rate. Leaving potential time for collection.

Looking at the shift occupancy rate of the normal routes some things come forward. Every newly created alternative has a higher occupancy rate than the current delivery model. For alternative 1 M, L, XL lockers, alternative 1 S lockers and alternative 1 XS lockers this can be explained due to the reason these alternatives are delivering to parcel lockers as well. Thus, creating extra time operating, the same number of parcels are sent to house distribution only the retail location is being replaced by the lockers. Having more parcels undelivered causes extra time as well for alternative 1 S lockers and alternative 1 XS lockers. Interesting to see is for alternative 2 M, L, XL lockers and alternative 3 M, L, XL lockers the shift occupancy rate is 81%. This is quite a bit larger than the current delivery model, alternative 0. Though the route of these two alternatives is exactly the same as alternative 0. The reason for this high percentage can be explained due to the fact that instead of having eight delivery vans, for these two alternatives only one delivery van is driving a normal delivery route. Thus, having less delivery vans to spread, causing less repetitions in the simulation as well. Being less accurate than alternative 0.

The variable average time in parcel locker is almost the same for every alternative. This is expected to be so, since the input variable for the time consumers take to collect their parcels, is the same for every alternative with parcel lockers and thus almost no variation should be seen.

The final variable that is of importance is the occupancy rate of lockers. For the alternatives whom are having collection as well the number of lockers is larger than the alternatives whom have collection only. This can be seen in the occupancy rate as well. Alternative 1 M, L, XL lockers, alternative 1 S lockers, alternative 1 XS lockers, Alternative 2 M, L, XL lockers, alternative 2 S lockers, alternative 2 XS lockers have an occupancy rate around 65%. This occupancy rates decreases when the variation in parcels and number of lockers decreases as well. However, when looking at Alternative 3 M, L, XL lockers, alternative 3 S lockers, alternative 3 XS lockers the occupancy rate is fairly high. Almost reaching a 100%. This means the lockers is almost always full, for a delivery driver this is not beneficial, since this means that if there is an unforeseen external factor causing a locker to fail or when people do not collect their parcels within the expected time, parcels cannot be delivered to parcel lockers anymore and the delivery model does not operate to standard.

Important conclusions can be drawn for the different scenarios that have been simulated in the sensitivity analysis. Which can be found more in detail in Appendix XIX Simulation Results. When a delivery model such as alternative 1 M, L, XL lockers, alternative 1 S lockers or alternative 1 XS lockers, where the bottleneck is house distribution, gets an increase in the unloading time for house distribution, the occupancy rate for the operating time increases significantly. It can cause the occupancy rate to increase over 100%, meaning the delivery driver works overtime. Looking at the alternatives with the parcel locker the important aspects are the unloading time for the parcel locker and the time it takes a customer to collect their parcels from a parcel locker. Alternative 2 is performing relatively good in this aspect since it has a larger number of parcel lockers available and thus more room available. However, for alternative 3 the occupancy rate would be above a 100%, which means parcels need to be diverted to a retail location, which is possible in this alternative but not preferred. Looking at the operation time of the delivery driver it will still be well within the operation time looking at performance. However, the possibility to drive a route twice will be reduced. Since the occupancy rates rises above 50% and thus two routes driven by one driver would be impossible without overtime. This is important to take into consideration when selecting the final design.

Comparing the different alternatives with each other it is hard to make a selection which alternative performs the best. All alternatives are performing without any bugs or failures, this is a positive result. Due to lack of time and expertise it wasn’t possible to add collection to the simulation, this affects the conclusion that can be drawn from the simulation results. Since assumptions need to be made for alternative 1 M, L, XL lockers, alternative 1 S lockers, alternative 1 XS lockers, alternative 2 M, L, XL lockers, alternative 2 S lockers, alternative 2 XS lockers. These models are designed with collection as well, the simulation didn’t have collection, thus operating time and occupancy rates couldn’t be simulated to full operation. However, it is still possible to make an assumption based on the results of the simulation as it is right now. Ranking the alternatives is therefore hard as well. Since alternative 0 is the current alternative and performs similar to alternative 1 M, L, XL lockers, alternative 1 S lockers, alternative 1 XS lockers, it is not possible to draw the conclusion that a difference is noticeable. alternative 1 M, L, XL lockers, alternative 1 S lockers, alternative 1 XS lockers and alternative 0 perform similarly. Alternative 2 M, L, XL lockers, alternative 2 S lockers, alternative 2 XS lockers are performing better when looking at the overall simulation, there is room in the lockers and the locker routes have good potential to save on labour force. For alternative 3 M, L, XL lockers, alternative 3 S lockers, alternative 3 XS lockers the potential to cut on labour force is even better since no collection is required. However, when looking at the occupancy rate of the lockers this alternative performs relatively bad. Taking all this into consideration it can be concluded that alternative 3 performs the worst, alternative 0 and alternative 1 perform equally good being average and alternative 2 performs the best. More details about the ranking will be discussed in the next paragraph.

4.3.4 Ranking of alternatives based on CEA, MCA and Simulation

There are three different methods that can evaluate the different alternatives. The CEA evaluates the alternatives solely on their cost effectiveness. Based on a fixed number of parcels per week and the price of a single parcel and the costs of a parcel locker. Every alternative will get a ranking based on their costs, the cheaper the alternative the better the ranking. The MCA ranking will be based on the output of the MCA, the best performing alternative will get the best ranking. The ranking of the simulation will not be used, since the simulation is used largely as a validation and ranking the different alternatives based on simulation is hard. Since the output of the simulation is not sufficient enough to make a hard ranking. The ranking will be based on points, the more points an alternative has the worse the alternative is. Therefore, a low score on ranking will be better. The best performing alternative will get 1 point, the worst performing alternative will get 10 points. This will be done for every method individually, the scores of the different rankings will be added together and the alternative with the lowest total score will be the best performing alternative. Since the CEA is the most important evaluation method in this research this ranking will account for 75% and the MCA ranking for 25%. The reason for the MCA being 25% is the high standard deviation and thus high spread in data making the MCA an indication of importance of the alternatives and hard conclusions shouldn’t be drawn. The weighted ranking can be seen in Table 36.

Table 36 Ranking CEA, MCA and Simulation methods

Alternative	CEA Ranking	MCA Ranking	Weighted Ranking	Weighted Ranking (change in number of drivers)
Alternative 0	5	9	4	8
Alternative 1 M, L, XL Lockers	3	2	1	5
Alternative 1 S Lockers	2	6	2	2
Alternative 1 XS Lockers	1	8	1	1
Alternative 2 M, L, XL Lockers	10	1	8	6
Alternative 2 S Lockers	8	4	6	3
Alternative 2 XS Lockers	7	5	5	7
Alternative 3 M, L, XL Lockers	9	3	7	4
Alternative 3 S Lockers	4	7	3	3
Alternative 3 XS Lockers	6	10	6	6

As can be seen in Table 36 for every method a ranking has been made based on their performance. The total of the three rankings is shown in the rightest column. Where the total scores are displayed. A high score indicates a bad ranking and a low score indicates a good ranking. Alternative 1 M, L, XL, S lockers and XS lockers being the best performing alternatives. This ranking in Table 36 gives the best scores in the base scenario without taking any sensitivity analysis in mind. When taking sensitivity analysis in mind, especially for the CEA ranking the scores would be different. Since the alternatives where it would be possible to save on labour costs would get a better score and thus the overall ranking would differ as well. When taking this sensitivity into account the best performing alternative would be alternative 1 XS lockers, this score does not differ due to sensitivity. Though alternative 2 S lockers and alternative 3 M, L, XL lockers improve on overall ranking. The locker route is able to save hugely on costs by cutting labour force in half. Since the goal of this report is to create a delivery model with parcel lockers that is cost efficient and sustainable as well, the option to reduce the amount of delivery vans is highly favoured. It does not only save on labour costs but it saves on pollution as well. Less vehicles will be operating at the same time in an urban area. This will benefit the air quality in the city and helps with congestion problems. When selecting the final design in paragraph 4.5 this needs to be taken into account.

4.4 Validating design alternatives

Mentioned in paragraph 3.4 is the situation that the designs that have been created are future designs. Therefore, not comparable with a current situation. This means a different type of validation that is required to validate the delivery models. Two types of validation are used, this is expert validation and validation with the use of simulation. To start with the expert validation. Several experts within PostNL have been asked to evaluate the delivery models as they have been designed. This has been done face to face but as well in team meetings. When discussing the designs in team meetings the team that was present commented on the designs that have been created. One of the points that was addressed was the option to choose for a selection of parcels to be delivered instead of delivering all the parcels. This remark made the researcher choose for different variants within the alternatives. The rest of the designs has been valued positively. Being possible to operate within the near future. Especially the design of alternative 1, where nothing special needed to be adjusted and seemed as a high favoured alternative. The other remarks that came forward where the question how the parcels would be sorted to arrive at the right loading dock. Since the research focusses on last mile logistics and not on warehouse distribution this has not been taken into account with this research. The assumption has been made that parcels could be sorted easily to the right loading dock where a delivery van could be loaded. Another remark was the situation of paying rent to place the parcel lockers, does PostNL need to pay a certain fee or is it even allowed by law. The assumption has been made by the researcher that the lockers could be placed on the streets free of charge since a mailbox is located in every parcel locker, thus replacing the mailboxes as they are right now. Since the operation of delivery does not differ from the current situation the experts validated the designs as plausible to be made.

The simulation needs to be validated as well. Since the base alternative (alternative 0) is the current situation the goal was to build up from this current situation and adjust slightly where needed. Instead of delivering to retail, the retail location was replaced by lockers. Maintaining a certain base level. Alternative 0 has been simulated successfully and shows great resemblance with the current situation. The researcher has delivered parcels himself on multiple occasions and can confirm the resemblance in operating time. Asking other drivers as well about their average operating time, the simulation model showed good resemblance. Quantitative data of operational time is not recorded by PostNL therefore the resemblance is hard to make quantitative. However, having discussed with delivery drivers themselves operating times does show resemblance with the simulation. The input variables that have been chosen are therefore of good choice and have been used for the future alternatives. Where this was not possible PostNL has been asked to provide an estimate on how long certain aspects would take. Taking these estimates into account the simulation has been conducted. No errors, bugs or failures have been noticed at the end of the simulation. The results required from the simulation have been used in this report. When trying to simulate the delivery models in more detail the simulation did not perform according to this standard. Error messages where shown and the model behaved differently, resulting in illogical results. Therefore, the simulation did not have a collection part in it. Since the results with collection would be to unreliable to draw conclusions. The assumptions that have been made based on the stable simulation are of higher value than having doubtable simulation results.

4.5 Final Design

The final design that has been chosen is based on the ranking of paragraph 4.3.4, sensitivity analysis of the costs and the simulation and personal expertise. Looking at the ranking of Table 36 the best possible delivery model would be alternative 1 M, L and XL lockers or alternative 1 XS lockers. In this delivery model, every single parcel that is sorted in the distribution centre will be delivered. This can be to a house location or in a parcel locker. This delivery model is adapted from the current delivery model and only requires an extra addition in the form of parcel lockers. The downside of this delivery model is the situation that insured goods and reimbursement goods can only be delivered to a house location. If this is not possible it should be brought back to the depot since the retail location has been replaced by a parcel locker. One of the requirements being that an insured parcel or parcel with reimbursement should not be delivered in a parcel locker, only at a house address or at a retail location. This means the parcels needs to be delivered in another area to another retail location. Since the percentage of parcels that have insurance or reimbursement is almost zero percent this is not a huge problem for delivery. However, it is of course not preferred to happen. As mentioned in paragraph 4.3.4 as well is the sensitivity analysis that has been conducted for simulation and for costs. This is important to take into consideration with the final design since perfect performance does not exist in reality. It can be the situation that a customer takes a bit more time than expected to retrieve its parcel or unloading the parcels to a house takes more time than the optimal situation. Taking sensitivity from the simulation into account, alternative 1 M, L, XL is more sensitive regarding the unloading time than alternative 2 S lockers, alternative 1 S lockers scores better as well but has the same problem with the retail locations. Since the unloading time for house distribution is a larger factor than the unloading time for parcel lockers. Alternative 1 M, L, XL locker has delivery in one single route, this means if something happens on this single route the entire performance of the model will be affected. However alternative 2 S lockers has two separate routes. Therefore, extra time unloading at house distribution will not affect the parcel locker route. The parcel locker route only delivers parcels to a parcel locker and nothing else. Creating a simplified route as well. Looking at the sensitivity in costs, alternative 1 S lockers and alternative 1 XS lockers do not chance in ranking. Alternative 1 M, L, XL locker goes from being the best to being in the middle. Though alternative 2 S lockers performs better when performing the sensitivity analysis, instead of being ranked 6th it is being ranked 3rd due to halving the number of drivers. Though one aspect makes alternative 2 S lockers perform better than alternative 1 S lockers and alternative 1 XS lockers. This being the number of drivers. Alternative 2 S lockers has the potential to reduce the number of drivers. More specifically to half the number of drivers operating the parcel locker route. Since one delivery man is able to drive two routes in one day. This can be concluded from the simulation that has been conducted. Therefore, taking a closer look to the costs of alternative 2 S lockers, when halving the number of drivers conducting the parcel locker route this alternative becomes cheaper to operate than the current situation. And almost operates at the same costs as alternative 1 S lockers and alternative 1 XS lockers. For short term planning alternative 1 S lockers and alternative 1 XS lockers would be a good solution, since the current delivery model only needs to be adjusted by adding parcel lockers. Though alternative 1 S lockers and alternative 1 XS lockers have some issues as discussed earlier, regarding performance and lack of retail location for example.

Overall alternative 2 S lockers performs better when looking at unforeseen circumstances, such as having a higher unloading time than expected and having a lower number of drivers. Since this research is focused to have a delivery model that can operate more cost efficient and more sustainable than current delivery, alternative 2 S lockers performs the best. This delivery model has a complete performance. It is also possible to deliver at a retail location when necessary. Something alternative 1 is lacking off and performs good on safety. Something that has been valued as being important in the MCA. Figure 16 shows the layout of this delivery model, having two separate routes one for parcel lockers and one for normal delivery.

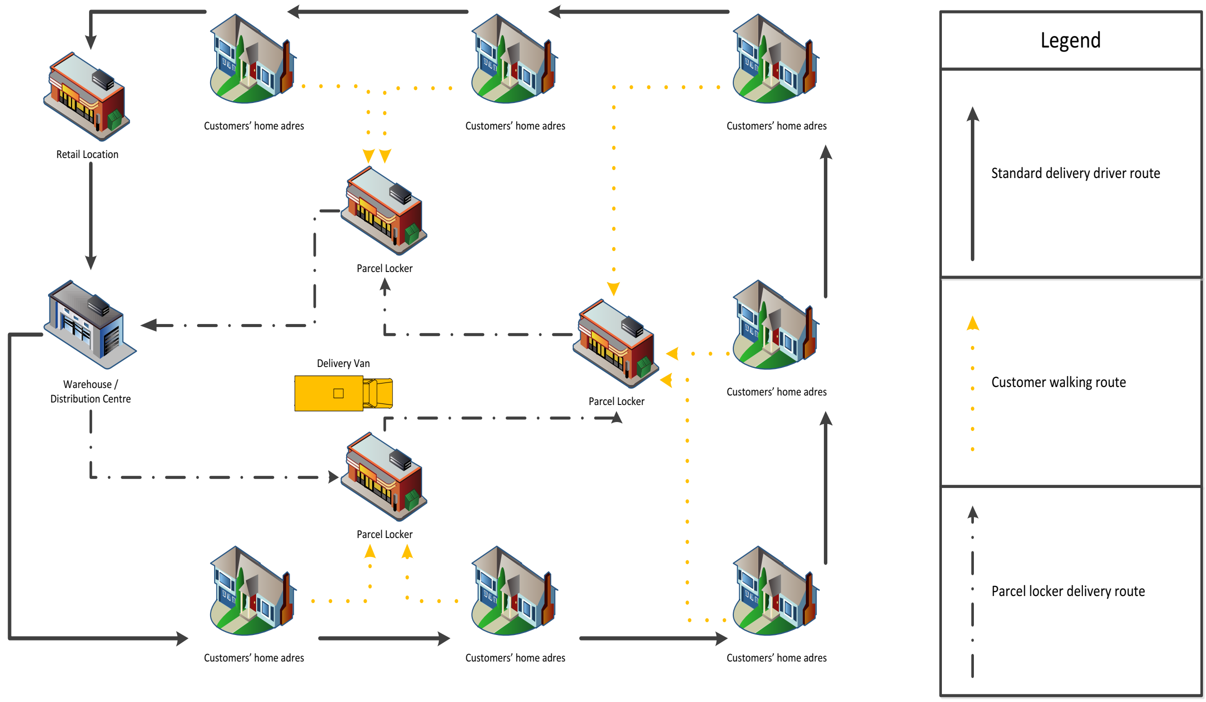

Figure 16 Alternative 2 S lockers visual layout delivery model

In Figure 16 the process of the final design is shown. Not only the process of the delivery model is important to mention but the infrastructure as well. How does the final design look like located in the area of De Pijp? Customers do need to walk a minimum distance to the parcel lockers, but can receive some parcels at their homes as well. The benefit of this delivery model is that all the parcels will be delivered to a house, parcel locker or retail location. Due to the situation that the parcel lockers will have a 100% FTHR, the rest of the parcels that will be delivered can be delivered at home and at the retail location. Taking the percentage into account that normally would account for the undelivered parcels, these parcels can be delivered directly in a parcel locker or a retail location. Thus, saving on processing costs at the depot of PostNL.

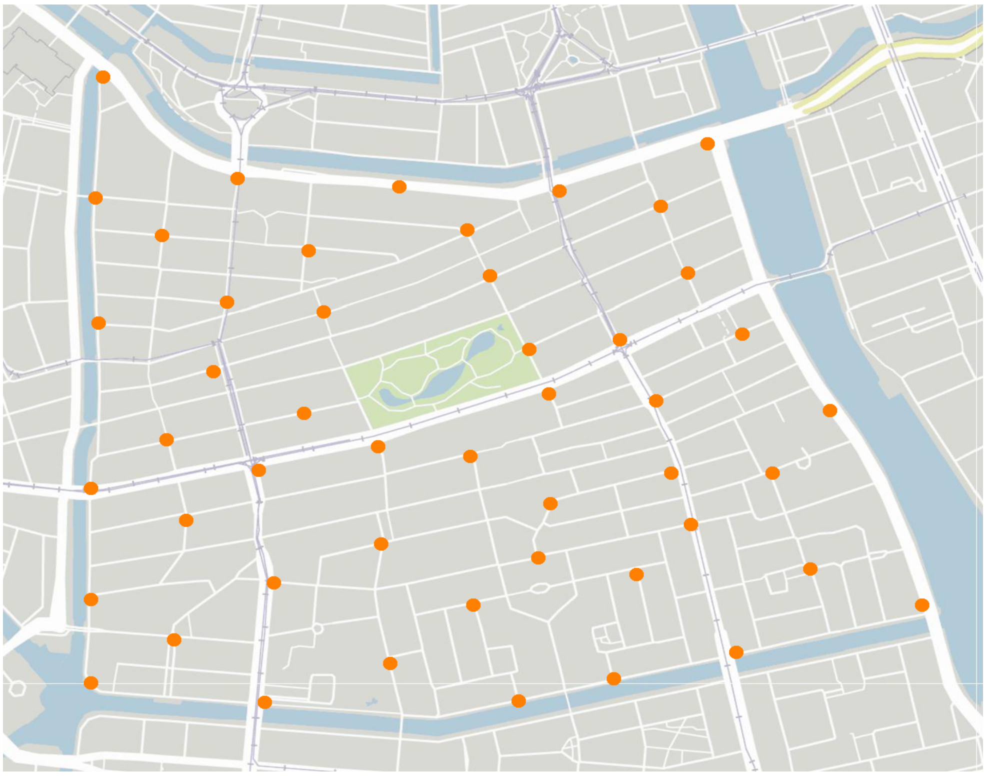

Figure 17 Parcel locker locations De Pijp

Figure 17 displays the physical locations of the parcel lockers located in De Pijp. The parcel lockers are distributed evenly across De Pijp, making it easier for customers to reach a parcel locker. Walking distance on average would be less than 5 minutes. The number of parcel lockers located in the city is 47. These parcel lockers are being delivered by 3 delivery drivers (5 in the situation without halving the number of drivers) and the normal parcels are being delivered with 3 delivery drivers as well. Instead of having a total of 1475 stops, for the delivery of 1770 parcels. This delivery model has 430 stops for the normal delivery route and only 47 stops for the parcel locker route. This is beneficial for sustainability as well.

Regarding the daily delivery costs this delivery model is able to deliver parcels for €2704.85 per day. Instead of the current delivery model which costs €3210.49 per day. On a yearly basis, this could save up to €121,356.00 for the area of De Pijp alone. This does not only save money on labour costs it has positive influence on sustainability as well. Since with this delivery model less delivery vans will be driving in the crowded city centre, causing less congestion. The parcel locker route has less stops than the normal delivery route. Having less stops creates better efficiency driving. Due to the reason the delivery van does not have to drive small bits again and again. Having the benefit of collection with this delivery model, there will be less need for an extra delivery van in the area collecting parcels. The delivery van that is distributing the parcels is able to collect them as well.

5. Conclusions and recommendations

5.1 Conclusion

Before the research question can be answered, the problem statement and the different sub questions need to be answered first. The main objective of this research is to make last mile delivery as it is right now more cost efficient and sustainable by using parcel lockers. This is particularly interesting since most of the last mile costs consist of employee costs. Being able to reduce these costs would save money. One of the benefits PostNL has at the moment is the experience of using parcel lockers for parcel delivery. This research has used that experience and went further to look if it was possible to deliver every parcel in a parcel locker.

The start of this problem was to discover the most important characteristics of the current last mile delivery for PostNL and how to improve this for future delivery using parcel lockers. At the moment, current last mile delivery in De Pijp is being conducted with standard PostNL delivery vans. Seven to eight routes, depending on the number of parcels, deliver parcels daily in this area. Several important aspects have been identified for this last mile delivery. The first being to have a FTHR that is a high as possible, reducing the number of parcels that are going back to the depot. The second being safety, the parcels need to be delivered as safely and securely as possible. No damages should occur and valuable goods need to be delivered with care. The third important aspect is accessibility, consumers want to have a proper access to gather or receive their parcels. This is an important aspect not just for customers but for PostNL as well. In urban areas accessibility is more difficult than with non-urban areas. Concluding the different aspects, the most important thing is the consumer service. Delivery needs to be operated on such a level that the customer has the best options to receive his parcels. Having a delivery model where a customer needs to walk 15 minutes to receive his parcels is not preferable. Having more than one option to receive parcels for customer has been valued as a positive situation as well. The customer perspective is actually the most important aspect of last mile delivery.

Since this research is considering the possibilities for a future delivery model with parcel lockers, several methods need to be employed to design a future model. It starts with researching the literature to look at what has been done at this moment regarding parcel lockers. Since the literature regarding parcel lockers is scarce at the moment not a lot of information could be found. The things that were important were the location of the parcel lockers, the cost perspective, the economics and sustainability and again the customer perspective. To design this future parcel locker delivery model four steps have been identified. The first step being to define the requirements. The second step to create to design alternatives. The third step to evaluate and select the design alternatives. The fourth and final step is to validate the designs.

To start with the first step, defining and gathering the requirements. This method has set the requirements for the different alternatives that have been created. Different type of requirements, such as hard and soft requirements have been discovered. Hard requirements are the requirements a new alternative should definitely comply with, for example having a mailbox in every parcel locker. To be able to place it on the street. Conducting interviews with experts within PostNL, having different viewpoints of proper last mile delivery and apprenticing parcel delivery. These three methods helped the researcher create the different requirements. After having created the different requirements the second step was to create the design alternatives. The creation of these design alternatives has been based on the requirements that have been set, brainstorming with employees of PostNL and making concepts to see what different future designs could be. The most important thing to do was to be able to make designs that were significantly different from each other. Which in this research was having collection and/or distribution, the size of the lockers and the location of the delivery, for example, a house, retail location or a locker. In total three different alternatives have been created.

Each alternative had three different size of locker configurations as well. This is to be able to define the possibilities of a different locker design of the current locker for the future. After these alternatives had been designed they needed to be evaluated. Three different methods have been selected to evaluate the different designs. The first being a cost analysis, the second being a MCA and the third being a simulation of the different designs. With every method, a ranking is made of which alternative performed the best and which the worst. The total score of the three different methods has been summed up and a best design has been identified. Finally, the designs have been validated by experts of PostNL to evaluate if they were plausible designs. Not only the delivery models have been evaluated but the performed simulation has been validated as well. With the different methods, a final design for parcel locker delivery has been created. It is valuable to discuss the different design alternatives.

A total of three different alternatives have been made. Alternative 1 is a delivery model that uses the current delivery model and replaces the retail location with a parcel locker. Alternative 2 is a delivery model that uses a separate route for delivery to parcel lockers and the normal route for the parcels that do not fit in the parcel locker. Alternative 3 is the same delivery model as alternative 2 except this delivery model only has distribution and does not have collection like alternative 1 and alternative 2. The three alternatives have three variants as well, which are the same for every alternative. The variants vary in the sizing of the parcel lockers. Three different methods have been used to score the different alternatives on their performance. Looking only at cost alternative 1 XS lockers scores the best and alternative 2 M, L, XL lockers the worst. The MCA ranking values alternative 1 M, L, XL lockers as the best alternative and alternative 0 as the worst. The ranking for the simulation scores alternative 2 S lockers as the best alternative and alternative 3 M, L, XL lockers as the worst. Taking all the different rankings into account as well as the sensitivity analysis of the different methods the best alternative that comes forward is alternative 2 S lockers. This alternative has been assigned as the best available design.

Having discussed all the previous aspects in this conclusion an answer can be given to the research question.

"How can last-mile parcel delivery be conducted in a more sustainable and financially cost efficient way using parcel lockers?"

The last mile delivery as it is right now can be replaced successfully with the use of parcel lockers. It will not be possible to deliver every parcel in a parcel locker but a selection needs to be made that can be delivered in a parcel locker. Having made this selection people will still be able to receive parcels at home and go to a retail location as well. But with the alternative 2 S lockers more than half of the delivered parcels will be delivered in a parcel locker. This will increase the first time hit rate of the delivery as well. By using the new delivery model, it will also be possible to reduce the number of drivers currently operating the delivery in De Pijp. Not only will it reduce the number of drivers it will also be possible to reduce the number of delivery vans that are needed to deliver the parcels. This will be beneficial for the sustainability of the delivery. The new delivery model will have less stops than the current delivery model and therefore be more efficient to operate. This particular alternative is able to save €121,356.00 on a yearly basis. It is important to mention that this research has focussed on the last mile delivery of parcels. The distribution in the depots of PostNL itself has not been researched. Therefore, before implementing such a solution it is necessary for PostNL to research how the new delivery model can be adapted to the distribution in the depot as it is right now. More specifically does this delivery model require a new sorting process or can it be adapted without any major changes?

5.2 Recommendations

5.2.1 Scientific Recommendations

Several methods have been used to create this research. One of those methods being the principle of lean. The usage of lean was employed to limit any wastes in the process of the delivery of parcels. To be able to take a closer look to the time the different processes took. It helped to overlook to current delivery process and research every step used. To be able to use this in the process of creating requirements and improving the designs. However, the lean process is of better use in a production process than an operational process such as this research has covered. Thus, the lean principle has not been used to its fullest extent.

The other methods that have been used in this research such as the CEA, MCA and simulation have been successful The CEA served great purpose and was better suited than using a CBA, since the benefits were hard to monetise. Not every customer of PostNL is paying the same fee for parcels. Therefore, when looking at cost reductions in research a CEA is highly recommended. Using the MCA can be of great benefit as well to see what aspects of the delivery models are important for different players. In this research, the experts of PostNL and the transport experts valued certain aspects differently. This can be beneficial for research that is not fully focused on just serving one player. The simulation was of great use to be able to see that the delivery models, that have been designed with the variables acquired from research and assumptions, are actually working as expected. To be able to see where bottlenecks could occur is of benefit as well. In case of an operational process like this it can be useful to see where extra focus can be necessary.

Since this research is mainly focused on solving a problem for PostNL it can be a little more practical than scientific. This is not a disadvantage, and the expertise of people whom are active in the field of research can add a lot of information to the research Information that has not been published in scientific literature for example or information from personal reflection.

5.2.2 PostNL recommendations

Having performed research within PostNL some things have emerged that could become future recommendations. The majority of the data that has been acquired concerns parcels themselves. The location at which they have been scanned, the time they have been scanned and other information solely involved with the parcels. Information about the drivers and delivery vans was not retrieved. There are no measurements of human behaviour. There are of course privacy related problems in performance measurement of employees. However, this type of research this could have been highly beneficial. To be able to see how much a delivery van actually drives in the city, what paths they drive, how long does it take for a delivery driver to process parcels at different locations. This type of information can be a necessity for this type of research. Communication within the office could be improved as well. Sometimes it costs too much time to retrieve certain information, since the correct person whom possessed certain information was unsure and forwarded the request to other people. Working in different sectors requires communication between the sectors. For the researcher, this was especially hard for the cost calculation, since the cost calculation that has been made in this research involves all the aspect of last mile delivery. Within PostNL the cost for retail and the costs for normal house delivery are separated. This meant asking different people to be sure about the correct costs.

5.3 Reflection on the research

5.3.1 Reflection on the research (methodology)

Taking a closer and critical look at the creation of this research some aspects need to be addressed. It could have been better to make a clearer distinction between theory and methodology. At this moment, this research has the theory and methodology mixed together. Looking more closely at the methodology and methods used, for example the process of lean could have been more specifically applied. Choosing three different methods to rank and evaluate the delivery models could have some disadvantages. The risk of doing this is the situation that each of the methods have not been used to its fullest capacity. With the CEA method, this method has been used to its fullest capacity and more details would not have improved the research. The MCA could have been better, more specifically the method for the participants to fill in the MCA was misunderstood on several occasions. This lead to scrapping some of the data of the MCA because it was not valuable. Having ten different alternatives in total, including the base alternative, created some confusion amongst participants. This could have been done better. The simulation was of good value for this research. However, to be completely successful the research should have been focussed more on the simulation and less on the MCA and CEA. Since simulation costs a lot of time, at this stage, the simulation used in this research has been used as an addition to the research and not as the main focus, due to time restraints and lack of expertise in the simulation. To improve on this, the simulation should be a part of the research from the start and the research focussed mainly on simulation and not on costs, producing different research questions which have not been examined in this research.

5.3.2 Reflection on the results

Overall the results meet the main goals of the research project. That is making the last mile more cost efficient using parcel lockers. Results show that it is possible to do so. However, in order to do this research, assumptions were made about jurisdictional situations. This was necessary, since this research does not focus on laws and regulations. The research also does not analyse customer behaviour and preferences. Results, especially those from the CEA, are highly positive. Researching the exact costs of last mile delivery taking into account all the different aspects that play a role has not been done before. This means the results cannot be perfect since there is no example to compare it with. The situations that could be compared showed good resemblance, increasing confidence in the cost calculation. Regarding the MCA, results were according to expectation which is that the different alternatives produced similar results. The MCA confirmed that customer values and satisfaction is very important. The results of the simulation could have been better. More specifically adding collection to the simulation and the possibility of halving the numbers of drivers. Unfortunately, the simulation did not perform properly once these factors were added. Therefore, the researcher has chosen to stay with a collection only simulation. This simulation worked according to expectation. Alternatives 2 and 3 were not different in simulation. However, the output of this part of the simulation was then analysed for alternative 2 and 3 separately since the number of parcel lockers was different.

5.3.3 Personal reflection

Reflecting personally on this research several things come to mind. One of the first is the fact that the overall process of getting familiar with PostNL and the way parcel delivery works within the company took too long. The main reason for this was that getting credentials to officially be an intern at the company took more time than was expected and hoped for. Unfortunately, this was something beyond my power and influence. This delay demotivated me a little, since the thing I was mainly working on was theory and things I could find online and in books. When I was granted access to PostNL the research went much faster, which was beneficial. The downside was I was already far along with my thesis, thus in a different setting than normally would be the case when being an intern. Another thing that I learned was making decisions on time was important and that it was not necessary to achieve the perfect solution for every problem. At the beginning of my thesis I wanted to have a perfect solution for every problem there was, but I realised after meetings with my supervisors this was not the best approach for the rest of my thesis. Also, I learned to write down things that are actually important and not to write to make a good story and show the work that has been done. This is still a difficulty for me, even after finishing this thesis, and I hope to improve with time and experience. I enjoyed the cost analysis and seeing how many factors were involved with last mile delivery costs. Literature is different than the actual practice within a company. Which is an important factor for my whole thesis, having the scientific part intertwining with the practical parts and making it one complete piece of research. The multi criteria analysis could possibly have been better conducted. For some people the explanations and criteria were crystal clear, and others had more trouble filling it in. This required eliminating certain aspects from the MCA since they were not useful for the research. Overall at the end it became difficult to finish my thesis. As they would say in The Netherlands “De laatste loodjes wegen het zwaarst”. Which means the last part is the hardest part. Although, overall I am satisfied with the result, I am aware there is much more to be done. However, regarding the time and effort put into it, and considering I was doing a thesis for the first time I think I can be satisfied.

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List of Formulas Appendix

1. *Standard Trans□ortation cost function*: $TC = T \cdot t + D \cdot d + Z$

2. *Stop coefficient*: $\dfrac{TC}{STOP}$

3. *Time window coefficient*: $\dfrac{STOP}{w}$

4. *First time hit rate coefficient*: $STOP \cdot ip$

5. *Collection points coefficient*: $STOP \cdot cp$

6. *Density and area coefficient*: $STOP \cdot ad$

7. *Vehicle type coefficient*: $d \cdot v$

8. *Parcel multipl□cation coefficient*: $STOP \cdot P$

9. *Reverse logisctics coefficient*: $Cost\ per\ parcel \cdot (1 + r) + (C_s + C_d) \cdot r$

10. *Retail costs*: $R_1 \cdot C_{rt}$

11. *Parcel compensation coefficient*: $(R_1 + ip) \cdot C_p$

12. *Last mile cost per parcel shipped*:

$$\frac{(T \cdot t + D \cdot d \cdot v)}{(\frac{STOP}{w} \cdot ip \cdot ad \cdot cp \cdot \mathrm{P})} \cdot (1 + r) + (C_s + C_d) \cdot r + R_1 \cdot C_{rt} + (R_1 + ip) \cdot C_p$$

Appendix I PostNL Parcel Lockers

At this moment (March 2017) PostNL is operating 14 PBA's (Pakket- en briefautomaat) ((Otten, 2017) in this paper referred to as parcel lockers. This started with 4 parcel lockers in October 2016, in November 2016 there were 10 parcel lockers and currently 14 parcel lockers are in operation. The parcel lockers that are used in Almere have several features: pick-up parcels 24/7 (direct from check-out webshop), rerouting of shipments to parcel lockers when not home at first home delivery, C2B return shipments, C2C shipments and an ordinary mailbox for regular mail. The parcel lockers have different sizes and integrated mailboxes. The parcel lockers have been designed in such a way that 96% of all parcels intended to be send to a parcel locker fit (Otten, 2017). Otten (2017) mentions that the key factor to be successful is density. Of the people whom are using the parcel locker up to 50% has no problem walking 500 m to collect their parcels. In Figure 18 below the overview of the placement of the parcel lockers is displayed.

Figure 18 Placement of Parcel lockers in Almere (Otten, 2017)

The parcel lockers as they are right now, are an addition to the current delivery model, these lockers are not replacing the current delivery van. So far, the pilot has been marked as a successful pilot and possible expansion to rural areas in Limburg is in the starting phase at this moment. Results regarding the pilot phase are promising, the usage of the parcel locker at this moment is especially popular with customers whom are ordering more than 2 packages per month. Looking at the parcel locker itself it has 16 parcel lockers which vary in size. As well as a regular mailbox. The parcel lockers consist of 11 Medium sized lockers, three large sized lockers and two extra-large sized lockers of which the dimension can be found in Table 37 below.

Table 37 Parcel Locker Sizes

Size	Medium	Large	Extra-large
Width (mm)	410	410	410
Length (Depth) (mm)	525	525	525
Height (mm)	242	502	758

As can be seen the only things that differs is the height of the lockers the width and length are exactly the same. Giving good prospects of easy changeable lockers, replacing for example one extra-large locker for three medium sized lockers. The current overall dimensions of the complete parcel locker are 1610mm x 525mm x 1758mm. Creating a machine of 1.6 m in width, 52.5 cm in depth and 1.7 m in height. The dimensions stated in Table 37 are the dimensions of the parcel lockers PostNL is placing at this moment in time (end of 2017). The ones placed in Almere a slightly smaller in size. For this research, the updated versions will be used. Below in Figure 19 the parcel machine as PostNL uses it at the moment is displayed.

Figure 19 PBA PostNL (Pakket en briefautomaat) Parcel Machine (PostNL)

The parcel machine has a touchscreen and can be used to draw signatures. A camera is mounted in the locker as well for safety reasons and the machine is reasonably vandalism proof. Consumers will receive an email/text when the parcel is in the locker and can retrieve this with the received code. The machine has a scanner as well, to be able to scan ID's when needed. The maximum storage of this machine is 3 days, where after it will be transported to a retail location.

Consumer Research Parcel Lockers Almere

PostNL has conducted a consumer research in the area of Almere where the parcel lockers are located. This research has asked people whom use the parcel lockers as well as people whom don't use the parcel lockers. Questions have been asked why people are using them or why not, maximum travel distances and locations of parcel lockers. The most important results will be summed up below. The rest of the results can be found in the figures below.

- 70% to 90% of the people receive their parcels at home or via the neighbours, around 50% uses a retail location, usage of the parcel locker and work are limited to around 10%
- Preferences for using a parcel locker (respondents whom have used one before) mostly are not being at home and no set pick up time. Some say to prevention of neighbour delivery or thinking it's easier
- Preferences for not using a parcel locker (respondents whom have used one before) mostly being the fact people are home to receive parcel. Safety is no issue and just 8% prefers personal delivery
- The reasons for not using the parcel locker for receiving shipments for all respondents are mostly the fact people are unfamiliar with the parcel locker or didn't think about it. Being at home or thinking neighbour delivery is just fine is one of the other majority decisions. Reachability to a small extent as well
- Around 90% of the respondents use a retail location for C2B and C2C shipments, just 6% uses the parcel locker
- Reasons for using the parcel locker for these shipments is the easy use of it and not being depended on opening hours from a retail location and not having waiting queues
- Reasons for not using the parcel locker for these shipments is location of the retail location and other options being quicker. Personal contact is not relevant in this question and the majority has the preference for a parcel locker.
- The reasons for not using the parcel locker for shipping parcel by consumers for all respondents of the questionnaire vary a bit. The majority of people didn't know about this option or haven't thought about it. Location of the retail location being closer is a reason as well and in this case safety plays a marginal role also. Another important reason is the fact that at a retail location people are being helped personally. Which in the case of people whom don't use a locker is important.
- Reasons for people not to use the parcel locker in general being the following: distance is too large, being home during delivery, not having the possibility to make your own shipping label, fear about the safety. Just a small part of the respondents prefers the personal contact
- Reasons for people using the parcel locker in general being the following: opening hours of the parcel locker (24/7), if the location is close to home addresses, easy and quick use
- 60% of the respondents prefers the location to be close to a supermarket, the rest of the respondents has the same preferences for schools, stations and shopping malls. 8% Of the respondents doesn't have any preference
- 40% Prefers to go walking to a parcel locker, 22% prefers the bicycle, 19% the car and 19% doesn't have any preferences
- 80% of the respondents is prepared to travel 2 to 10 minutes to a parcel locker

Appendix II “De Pijp” Geographical

This appendix contains all the information related to the research area the district “De Pijp” in Amsterdam concerning items like geographical information about inhabitants, density and how the district is built up. Below in Figure 20 a geographical overview of the district of “De Pijp” is shown together with the smaller districts which are part of the overall district.

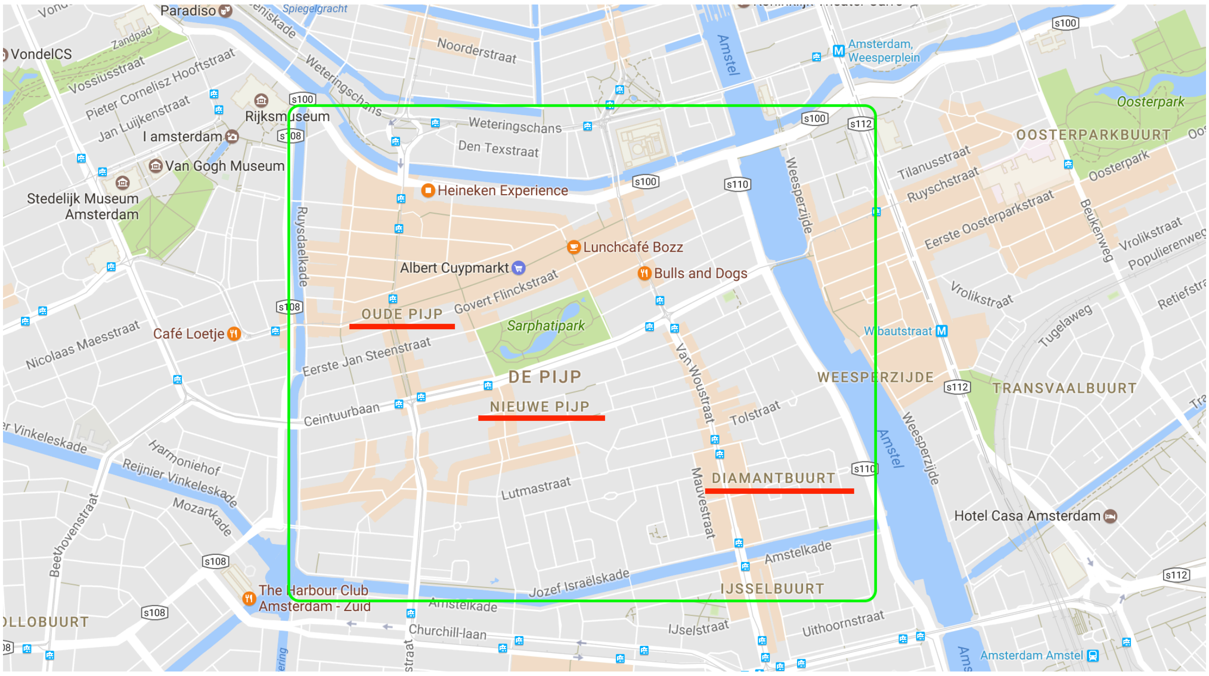


Figure 20 Visualization of “De Pijp” including smaller districts (adjusted from maps.google.com)

Shown in the green square is the district of De Pijp. The smaller districts that are included in the overall districts are underlined in red, being the Oude Pijp, Nieuwe Pijp and Diamantbuurt (from now on referred to as Zuid-Pijp). The smaller districts vary in size and geographic layout, therefore the exact layout is not visualized. The district of De Pijp in Amsterdam is a highly dense area together with a lot of businesses located in the area. This research will focus on the consumers only and will not look into the business side. In Table 38 below an overview of important key figures is listed.

Table 38 Key figures district De Pijp (Centraal Bureau voor de Statistiek, 2017a)

Variable	Amsterdam	De Pijp	Oude Pijp	Nieuwe Pijp	Zuid Pijp
Inhabitants	833624	35525	14850	12400	8275
Population Density (inhabitants/km^2)	5042	23664	23402	24140	23451
Households	456462	22855	9965	7995	4895
Single-Person Households	251828	14675	6660	5150	2865
% 15-65 (age)	72.7%	78.9%	83.0%	79.1%	74.6%
% 65 + (age)	12.0%	10.8%	7.8%	11.0%	13.5%
Daily Busy Index[1]	100	199	243	184	169
Average Income (employee)	€31,700.00	€30,833.00	€33,600.00	€33,200.00	€25,700.00
Average distance to large supermarket (m)	500	233	200	200	300

Looking at the figures that are displayed in Table 38, a lot of information is shown that is of interest. The table has five different columns where the first column are the figures for Amsterdam, the second column the figures for the overall district of De Pijp and the remaining columns are the smaller districts within the overall district of De Pijp. The reasoning for the different variables can be found in the bullet list down below.

- Inhabitants: The number of people can give a good indication of how crowded an area can be and how much market potential there is in a certain area.
- Population density: The number of people living in a certain area can give a good indication for the number of stops a logistics provider needs to make on a certain area. The more people live in an area the less kilometres a logistic provider needs to drive and thus saving on costs.
- Households: The number of households gives a good indication of the total number of houses in a district. This number can be interesting together with the density and the single person households on the number of parcels being delivered in an area. Not only that but the first time hit rate plays a key role as well.
- Single-Person Households: The number of single person households indicates on the number of houses with only one person living in it. This means if this person is not at home a delivery cannot be successful and needs to be addressed to neighbours. Which can be a large disadvantage to some people whom don't like their neighbours or don't trust their neighbours.
- %15-65: This indicator gives the potential market for the delivery of parcels. This is an age group which will order online quite a lot, is working/studying full time and has the ability to walk easily.
- %65+: This indicator mentions the age group of 65 years and older, a group of people whom is retired and will most likely be home to receive their parcels. However, this age group is most likely to be less likely to walk larger distances. Therefore, a higher change they will prefer a home delivery and not only that this age group will order less online.
- Daily busy index: This index cannot be directly related to the delivery of parcels in the area. It can give an indication of how busy a certain district is, which can cause parcels to be delayed due to heavy traffic and possibly a more hostile environment.
- Average income: The average income is a good indicator to see what kind of people are living in the district in relation with the average in Amsterdam as a whole.
- Average distance to large supermarket: This indicator can be of interest to see the average distance people are used to walk on daily basis for their day to day groceries. When selecting a number of parcel lockers this can be a good distance indicator to keep in mind.

[1] Number of residents on an average day per hectare of land, in comparison with the cities average of Amsterdam

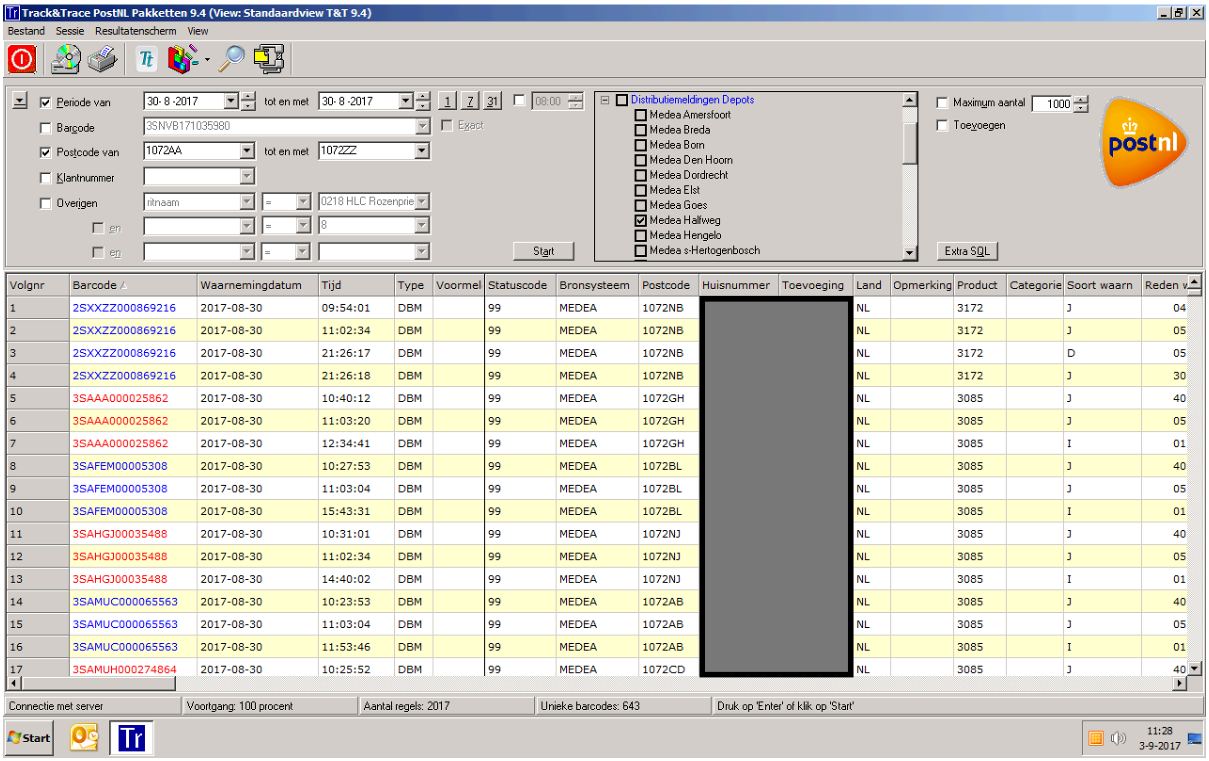
The municipality of Amsterdam has conducted an area analysis in 2016 regarding the area of De Pijp and Rivierenbuurt, this analysis contains interesting information about the district of De Pijp (Gemeente Amsterdam, 2016). Important characteristics will be listed below.

- De Pijp/Rivierenbuurt is a transit area for twenty and thirty year olds.
- De Pijp is a relatively safe district
- Relatively there is a lot of neighbours overload
- Parking problems and rubbish on the streets are irritating factors for inhabitants
- The usage of public space in De Nieuwe Pijp and De Oude Pijp is intense, the density is high and there is a lot of catering industry and there is a market.
- De Pijp is built up from building blocks and narrow streets. Most of the houses are small and more than 60% is a single household.
- 44% Of the inhabitants are between the age of 20 and 39, where 36% is the average in Amsterdam
- A 4% increase of inhabitants is expected between 2015 and 2025
- Due to the lack of space there is relatively a lot of traffic nuisance, parking issues and pollution
- Expectations are that due to the new North-South metro line the district will be more crowded
- De Oude Pijp has the second biggest concentration of bars, restaurants and retail stores, causing a lot of traffic
- De Pijp is a safer district than average

The key figures in Table 38 and the characteristics mentioned above will be used for the design of the future situation, where PostNL will use parcel lockers to deliver their parcels instead of using standard home delivery.

Appendix III “De Pijp” PostNL Data

For this research, it is necessary to know as much as possible about the current delivery by PostNL. This includes as well data about the number of parcels that are being delivered in the area of De Pijp. The area of De Pijp contain the postal codes 1072, 1073 and 1074. Having done the research about the geographical location of De Pijp in Appendix II “De Pijp” Geographical, this Appendix will contain all the information related to delivery of PostNL. How many parcels are being delivered directly to homes, how many parcels are being delivered to a pick-up location, how many parcels are not being delivered? Questions like these are valuable information for this research. To get this information the Track & Trace system of PostNL will be used, this system can retrieve all the data of the parcels and gives great detail about the whereabouts of these parcels. Below in Figure 21 the Track & Trace system is shown.



Volgnr	Barcode	Waarnemingdatum	Tijd	Type	Voormel	Statuscode	Bronsysteem	Postcode	Huisnummer	Toevoeging	Land	Opmerking	Product	Categorie	Soort waarn	Reden v
1	2SXXZZ000869216	2017-08-30	09:54:01	DBM		99	MEDEA	1072NB	[redacted]		NL		3172		J	04
2	2SXXZZ000869216	2017-08-30	11:02:34	DBM		99	MEDEA	1072NB			NL		3172		J	05
3	2SXXZZ000869216	2017-08-30	21:26:17	DBM		99	MEDEA	1072NB			NL		3172		D	05
4	2SXXZZ000869216	2017-08-30	21:26:18	DBM		99	MEDEA	1072NB			NL		3172		J	30
5	3SAAA000025862	2017-08-30	10:40:12	DBM		99	MEDEA	1072GH			NL		3085		J	40
6	3SAAA000025862	2017-08-30	11:03:20	DBM		99	MEDEA	1072GH			NL		3085		J	05
7	3SAAA000025862	2017-08-30	12:34:41	DBM		99	MEDEA	1072GH			NL		3085		I	01
8	3SAFEM00005308	2017-08-30	10:27:53	DBM		99	MEDEA	1072BL			NL		3085		J	40
9	3SAFEM00005308	2017-08-30	11:03:04	DBM		99	MEDEA	1072BL			NL		3085		J	05
10	3SAFEM00005308	2017-08-30	15:43:31	DBM		99	MEDEA	1072BL			NL		3085		I	01
11	3SAHGJ00035488	2017-08-30	10:31:01	DBM		99	MEDEA	1072NJ			NL		3085		J	40
12	3SAHGJ00035488	2017-08-30	11:02:34	DBM		99	MEDEA	1072NJ			NL		3085		J	05
13	3SAHGJ00035488	2017-08-30	14:40:02	DBM		99	MEDEA	1072NJ			NL		3085		I	01
14	3SAMUC000065563	2017-08-30	10:23:53	DBM		99	MEDEA	1072AB			NL		3085		J	40
15	3SAMUC000065563	2017-08-30	11:03:04	DBM		99	MEDEA	1072AB			NL		3085		J	05
16	3SAMUC000065563	2017-08-30	11:53:46	DBM		99	MEDEA	1072AB			NL		3085		I	01
17	3SAMUH000274864	2017-08-30	10:25:52	DBM		99	MEDEA	1072CD			NL		3085		J	40

Figure 21 Track & Trace PostNL

Using this system to retrieve all the data about the number of packages an overview of De Pijp can be made. There has been chosen to select a random week in June from Monday until Saturday for every postal code, this week starts at the 26th of June and ends at the 1st of July. Since PostNL doesn’t deliver parcels on Sunday, Sunday is not taken into account. The data of the Track & Trace system is exported to an excel file and with the use of Pivot Tables the data can be retrieved. Below in Figure 23 such a pivot table is shown.

Description	Value
# of Parcels to be delivered (regular)	372
# of Parcels to be delivered (pick-up location)	62
# of Parcels to be delivered ("postbus")	0
# of Parcels directly delivered	205
# of Parcels neighbour delivery	25
# of Parcels delivered @ pick up location	71
# of Parcels mail box delivery	18
# of Parcels return to DC	115
Return Percentage	26%

Figure 22 Parcel Analysis

Row Labels	Count of Barcode
C	2
1	2
D	1
5	1
I	297
1	205
3	1
8	48
10	25
11	18
J	1125
4	27
5	372
8	80
9	1
10	23
14	1
17	1
21	23
30	123
40	412
55	62
K	71
70	65
72	6
S	9
2	9
Grand Total	1505

Figure 23 Pivot Table

As can be seen in this pivot table a lot of letters and numbers are displayed. Each of the letter together with a number has a special meaning to it. For example, J5 means: parcels that are being set out for delivery (and thus in the delivery van). All other letters and numbers have their own meaning as well and with this a matrix can be made of the number of parcels delivered and not delivered during a selected period. In Figure 22 above the analysis of Monday the 26th of June with postal code 1072 in De Pijp is shown. This analysis will be done for every postal code during the period of the 26th of June until the 1st of July. This overview can be seen in Table 39 below.

Table 39 Data Parcel Delivery De Pijp

Postal Code	Day	Date	Parcels to be delivered (home address)	Parcels to be delivered (pick-up location)	Parcels directly delivered	Parcels delivered at neighbours	Parcels delivered to pick-up location	Parcels delivered to mailbox	Parcels returned to Depot	Percentage delivered personally	Percentage Reimbursement	Percentage Insured	Percentage of returns
1072	Monday	Jun-26	372	62	205	25	71	18	115	55%	1,15%	0,23%	26%
	Tuesday	Jun-27	583	107	469	53	118	3	47	80%	1,01%	0,58%	7%
	Wednesday	Jun-28	696	115	534	73	146	11	47	77%	1,11%	0,62%	6%
	Thursday	Jun-29	629	93	494	60	115	4	49	79%	0,97%	0,42%	7%
	Friday	Jun-30	518	87	406	42	104	11	42	78%	1,82%	1,16%	7%
	Saturday	Jul-01	485	69	362	56	79	3	54	75%	1,44%	0,18%	10%
Total (1072)			3283	533	2470	309	633	50	354	74%	1,25%	0,53%	9%
Average (1072)			547	89	412	52	106	8	59	74%	1,25%	0,53%	9%
1073	Monday	Jun-26	294	25	189	44	41	24	21	64%	0,31%	0,31%	7%
	Tuesday	Jun-27	457	55	329	61	71	24	27	72%	1,17%	0,39%	5%
	Wednesday	Jun-28	591	44	462	62	65	21	25	78%	1,26%	0,63%	4%
	Thursday	Jun-29	502	56	375	74	68	15	26	75%	0,72%	0,18%	5%
	Friday	Jun-30	462	46	357	52	56	14	29	77%	0,20%	0,39%	6%
	Saturday	Jul-01	470	51	351	44	58	20	48	75%	0,19%	0,58%	9%
Total (1073)			2776	277	2063	337	359	118	176	74%	0,64%	0,41%	6%
Average (1073)			463	46	344	56	60	20	29	74%	0,64%	0,41%	6%
1074	Monday	Jun-26	140	1	94	18	4	14	11	67%	1,15%	0,23%	8%
	Tuesday	Jun-27	277	4	209	44	13	7	8	75%	1,01%	0,58%	3%
	Wednesday	Jun-28	324	0	242	53	9	14	6	75%	1,11%	0,62%	2%
	Thursday	Jun-29	312	1	224	44	14	16	15	72%	0,97%	0,42%	5%
	Friday	Jun-30	288	2	219	40	16	14	1	76%	1,82%	1,16%	0%
	Saturday	Jul-01	278	1	218	29	1	11	20	78%	1,44%	0,18%	7%
Total (1074)			1619	9	1206	228	57	76	61	74%	1,25%	0,53%	4%
Average (1074)			270	2	201	38	10	13	10	74%	1,25%	0,53%	4%
Total Overall			7678	819	5739	874	1049	244	591	74%	1,05%	0,49%	6,96%
Total Average			1280	137	957	146	175	41	99	74%	1,05%	0,49%	6,96%

Not only the number of parcels delivered is of importance but the weight, volume, width, length and height as well. The first two variables are less of importance for the parcel lockers itself. However, weight can be an issue when looking at the maximum loading capacity of a delivery van, which cannot be exceeded due to employment rules. Volume can give an indication of the available room in the parcel lockers and the size of the parcels. However, with a long but narrow parcel the volume might indicate the parcel fits in a locker however the length can be too long to fit the locker. Therefore, the width, length and height are factors that are the most important to investigate possibilities for parcel lockers. Below in the Table 40 the width, length and height of all the parcels in postal code 1072 on Tuesday the 27th is displayed. The table is the input for a histogram and consists of several bins, in these bins all the dimensions of the parcels who fit are counted and cumulated creating a histogram which displays the distribution of parcel size.

Table 40 Parcel size and dimensions

Length			Width			Height		
Bin Size (mm)	Frequency	Cumulative %	Bin Size (mm)	Frequency	Cumulative %	Bin Size (mm)	Frequency	Cumulative %
50	1	0,02%	50	4	0,09%	50	367	8,63%
100	0	0,02%	100	33	0,87%	100	1197	36,78%
150	27	0,66%	150	270	7,22%	150	1189	64,75%
200	170	4,66%	200	630	22,04%	200	671	80,53%
250	467	15,64%	250	731	39,23%	250	330	88,29%
300	398	25,00%	300	824	58,61%	300	189	92,73%
350	687	41,16%	350	771	76,74%	350	148	96,21%
400	860	61,38%	400	579	90,36%	400	84	98,19%
450	598	75,45%	450	229	95,74%	450	49	99,34%
500	411	85,11%	500	71	97,41%	500	15	99,69%
550	209	90,03%	550	53	98,66%	550	11	99,95%
600	155	93,67%	600	32	99,41%	600	2	100,00%
650	113	96,33%	650	21	99,91%	650	0	100,00%
700	14	96,66%	700	2	99,95%	700	0	100,00%
750	41	97,62%	750	2	100,00%	750	0	100,00%
800	35	98,45%	800	0	100,00%	800	0	100,00%
850	27	99,08%	850	0	100,00%	850	0	100,00%
900	21	99,58%	900	0	100,00%	900	0	100,00%
950	15	99,93%	950	0	100,00%	950	0	100,00%
1000	3	100,00%	1000	0	100,00%	1000	0	100,00%

As can be seen in Table 40 peaks can be seen for every dimension. For length, the peak is around 400 mm, for width the peak is around 300mm and for height the peak is around 100 and 150mm. This are well within the margins of the parcel locker medium sized locker. Below in Figure 24, Figure 25 and Figure 26 the distribution is shown in a histogram.

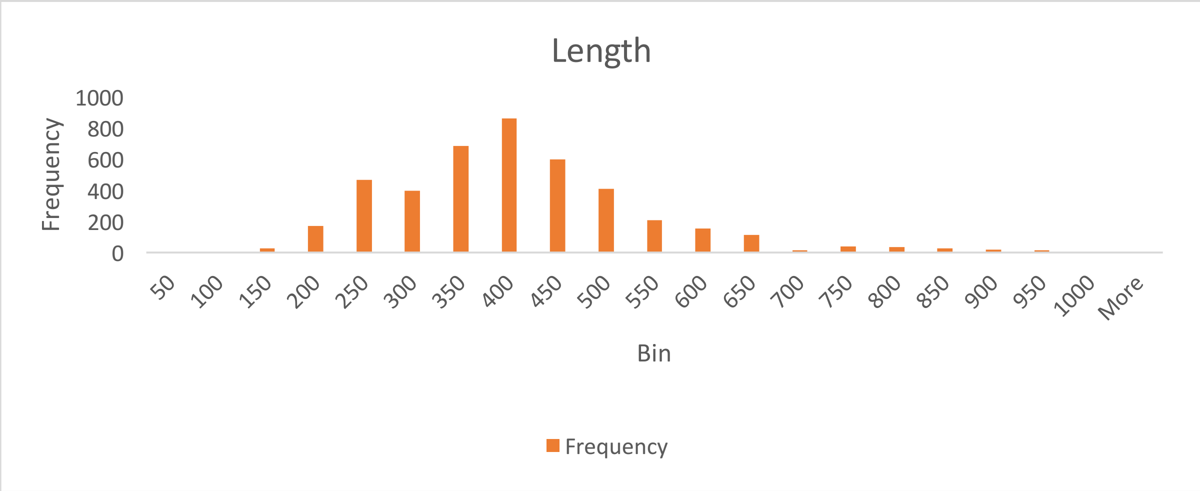


Figure 24 Histogram length parcels postal code 1072

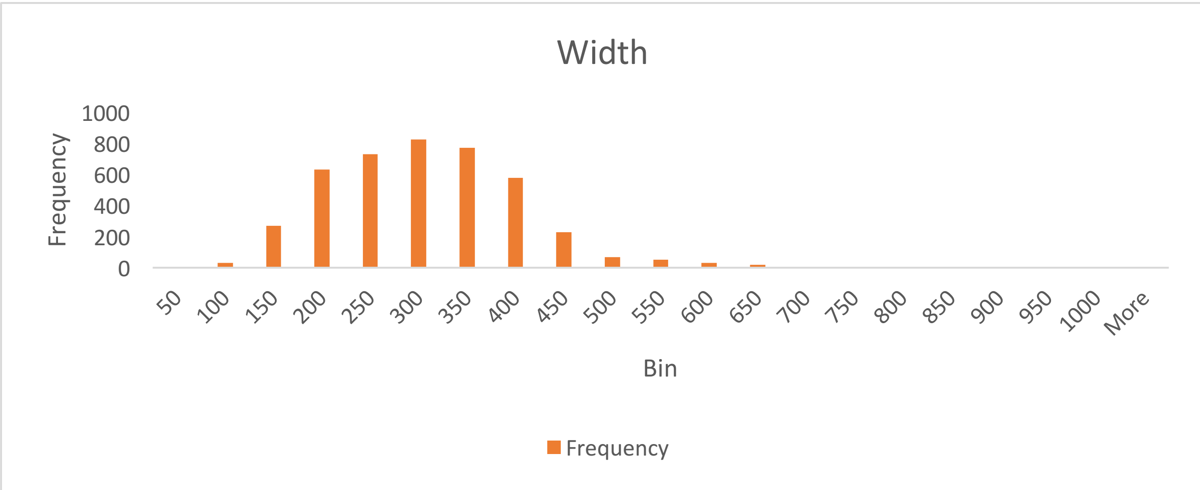


Figure 25 Histogram width parcels postal code 1072

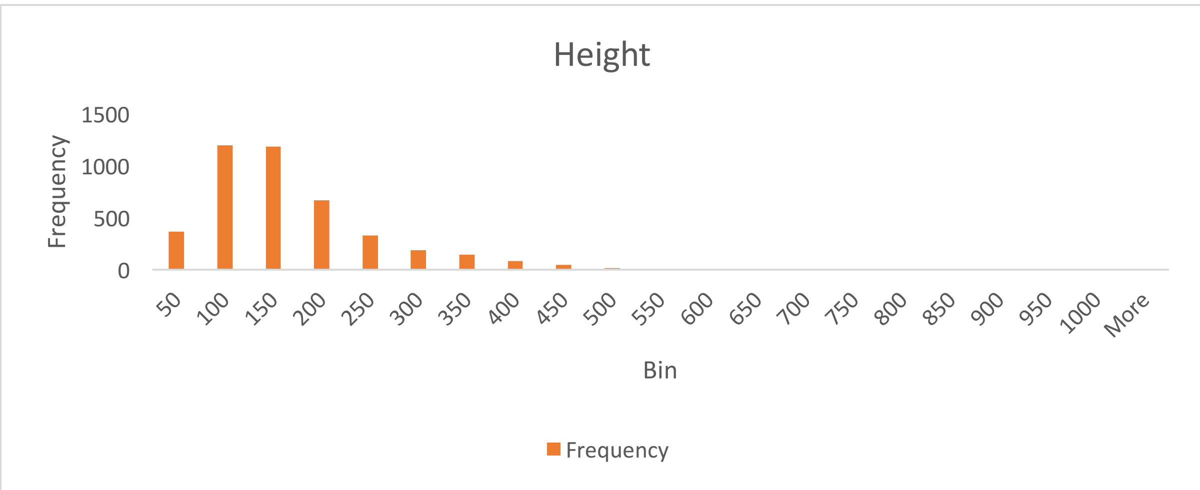


Figure 26 Histogram Height parcels postal code 1072

Mentioned before, not only the dimensions regarding length, width and height play an important role, the weight and volume play a marginal role as well. Below in Table 41 the input for the histograms of Figure 27 and Figure 28.

Table 41 Parcel weight and volume

Weight			Volume		
Bin	Frequency	Cumulative %	Bin	Frequency	Cumulative %
2000	3356	74,64%	15000	2558	59,23%
4000	602	88,03%	30000	980	81,92%
6000	246	93,51%	45000	333	89,63%
8000	104	95,82%	60000	183	93,86%
10000	66	97,29%	75000	89	95,92%
12000	40	98,18%	90000	37	96,78%
14000	21	98,64%	105000	36	97,62%
16000	24	99,18%	120000	17	98,01%
18000	11	99,42%	135000	30	98,70%
20000	7	99,58%	150000	26	99,31%
22000	8	99,76%	165000	10	99,54%
24000	0	99,76%	180000	2	99,58%
26000	3	99,82%	195000	4	99,68%
28000	2	99,87%	210000	6	99,81%
30000	4	99,96%	225000	3	99,88%
32000	0	99,96%	240000	1	99,91%
34000	0	99,96%	255000	2	99,95%
36000	2	100,00%	270000	0	99,95%
38000	0	100,00%	285000	0	99,95%
40000	0	100,00%	300000	2	100,00%

This data will be used to create the designs for the future delivery model. As said before the dimensions will play an important role in this. With the creation of the new designs the dimensions will be used to redesign the size of the lockers when needed. However, the overall dimensions of the parcel machine itself will remain the same as can be found in Appendix I PostNL Parcel Lockers.

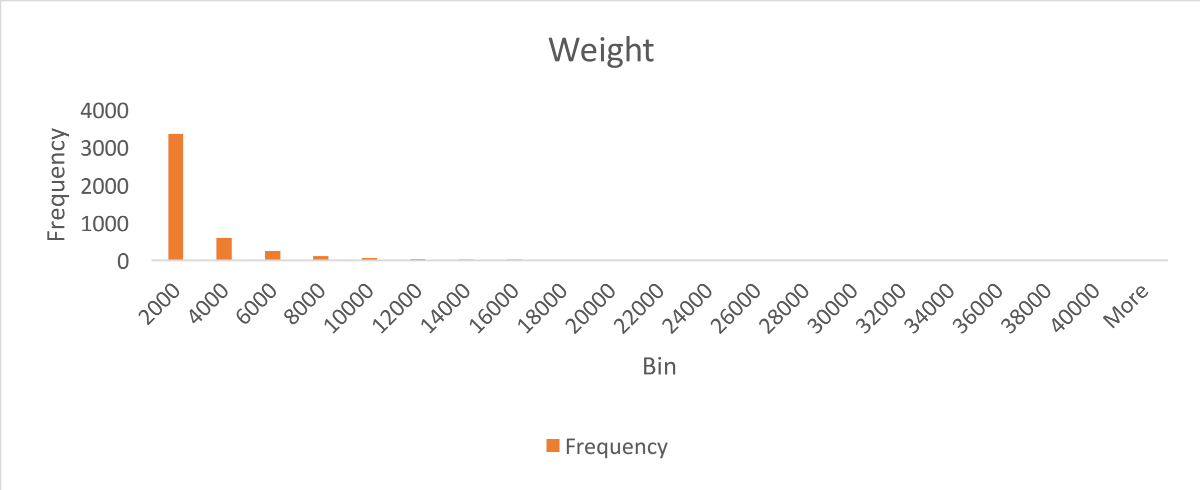


Figure 27 Weight parcels postal code 1072

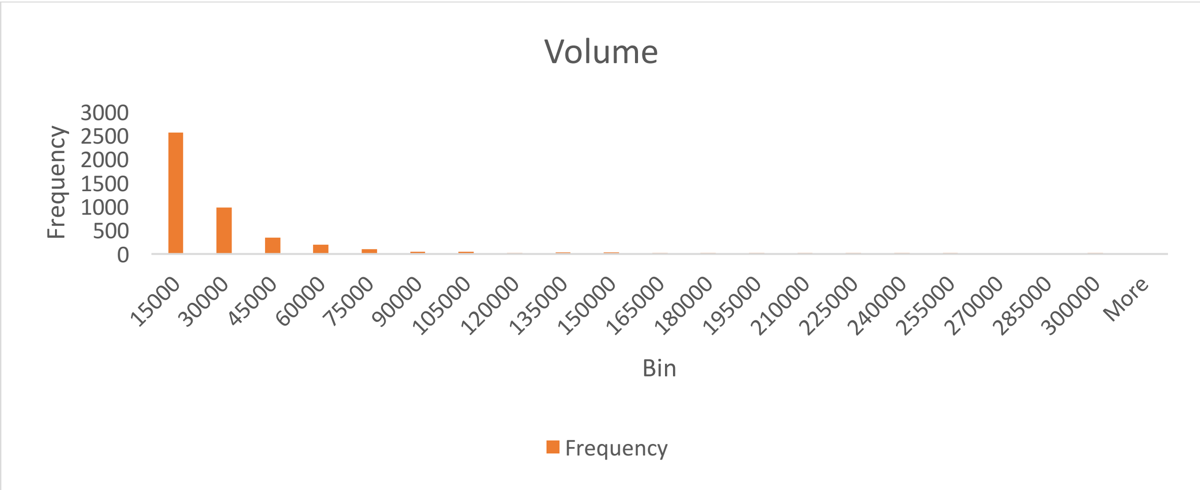


Figure 28 Volume parcels postal code 1072

Other important data is the First Time Hit Rate percentage, the percentage delivered to retail locations and the percentage which failed to deliver and needed to return to the depot. The first time hit rate is around 86%, the percentage of retail locations delivery is around 10% meaning just 4% of all the parcels delivered the same day returns back to the depot. This is for the current parcel delivery situation only. New situations are not known and thus will be based on this information. Regarding yearly growth, taking into account the last 10 years the parcel market grew 10% on yearly basis (PostNL, 2017). This number will be used for the future delivery models, though will be varied with taking 10% as base scenario.

Appendix IV Last Mile subdivided

With last mile delivery, several problems can occur. One of them being the situation where the customer is not home, therefore the logistics provider delivering the parcel needs to go back to the warehouse/distribution centre again. This is one of the largest problems in last mile logistics, having to drive the same route with the same parcel due to recipients not being present at home if a signature is needed. The logistics provider practically never charges extra for a redelivery, causing profits to lower in half due to travelling the same route twice. In Japan for example this number is up to 20% (Yano & Saito, 2016). This redelivery costs up to 420,000 tons of CO2 and 90,000 extra people (on a working staff of 740,000) extra in this Japan case.

A second problem, which can be related to customers not being at home or the reason behind it, can be the delivery window length. Logistics providers will give a certain length of the delivery windows for their customers to be able to let them know when their package will arrive. For the logistics provider, the larger the time window the better it is, since having a small-time window compromises on route efficiency (Gevaers et al., 2011). However, for the recipients a smaller time window is generally more preferable and will be more beneficial for the recipient cost wise, but inefficient when looking at costs for a logistics provider (Boyer et al., 2009).

A third problem is density. More specifically the lack of density in a certain area, whereas a logistics provider needs to travel 30 kilometres to deliver a single parcel the efficiency will be reduced largely (Gevaers et al., 2011). But also in the sense that if a city is densely populated congestion can play an important role as well, causing the driver of the logistics provider to stand still an unnecessary amount of time.

The three mentioned problems can cause extra costs in the process that are unwanted, not only for the logistics provider but for the recipient as well. Not only unwanted costs play an important role but also the environmental aspect. The combination of the costs and the environmental aspect is relatively high in the last mile as well due to the size of delivery vans.

One of the solutions that is present at this moment to overcome the possible extra costs and pollution are the collection points, where parcels can be delivered if a recipient is not present during delivery. However most of the time this will be done after the logistics provider tried to deliver a second time and there is no need for a signature. According to the survey research that has been done by (Yano & Saito, 2016), 70% of the people choose a collection point to be able to receive a parcel at the first try without failing. And 60% choose a parcel locker as option to receive a parcel (people could select more than one answer). Other research that looked at the transport impacts of such collection and delivery points mentioned a positive outcome as well (Cherret et al., 2009). Mentioning a reduction in costs for the logistics provider as well as the recipients when using collection points when having a failed delivery. This comparison was done in relation to the normal manner of trying to go back to the recipient to deliver again the next day and if necessary the next day after that. Nevertheless, research gives good potential to the non-home and unattended deliveries, in the form of collection points in a supermarket or gas station for example. Parcel lockers are just one step further than that, since with parcel lockers the human interference is reduced completely to only the logistics provider bringing parcels to lockers.

The problems of the last mile regarding delivery windows, density and being not at home define a large part of the last mile nature. According to Gevaers et al., (2011) five important fundamentals can be distinguished that define the nature of the last mile. Listed below are those five fundamentals together with a detailed description.

- The level of consumer service
    - Important aspects are the delivery window, delivery lead time, delivery frequency and return flow possibilities. Where delivery window can be of large impact, not only for the customer but for the logistics provider as well. Up to 42% in costs can be saved by using delivery boxes instead of home delivery with a time window (Kämäräinen, 2001).
- Security and delivery type
    - Important aspects are the need of a signature for the parcel. If a signature is not needed, delivery in a reception box or parcel lockers is easier. The cost factor of delivery with and without signature can be up to a factor 2.5 (Punakivi & Saranen, 2001). The first time hit rate will be lower in most of the situations when a signature is needed, couriers need to return more often thus causing higher logistical costs.
- The geographical area and market penetration and density
    - Important aspects are the population density and the average distance between households. Even to what extend goods are pooled. The density of population is an important factor to determine costs per parcel, however living in the city doesn't require the recipient to pay more than someone living in rural areas. Research of (Boyer et al., 2009) showed a marginal decrease in kilometres per customer with increasing density. Where an optimum could be found at 1200 to 2000 customers per square kilometre (original data mentions 3000 to 5000 customers per square mile).
- Vehicle fleet and technology
    - Important aspects are the fuel consumption, vehicle loading capacity, safety, etc. However not only the type of van/truck is important but information sharing as well. To be able to drive optimal routes, a temporary blockage on the road due to construction work can be necessary to know by forehand to avoid extra cost.
- The environmental factor
    - Though the consumers think environmental aspects are important they are not willing to pay for this most of the time. Also, customers are not willing to wait longer due to greener logistics services. The environmental factor combines her importance with the consumer service level, since the smaller the time window the larger the negative environmental factors will be. This balance is very important and can generate a lot of extra cost when not handled correctly.

To substantiate the last mile as much as possible it is important to take a close look at the different aspects that last mile entails. What kind of products are part of last mile transport, what kind of businesses are part of last mile transport and what values do these different flows have? The substantiation can be seen in Figure 29, where the last mile is substantiated from left to right.

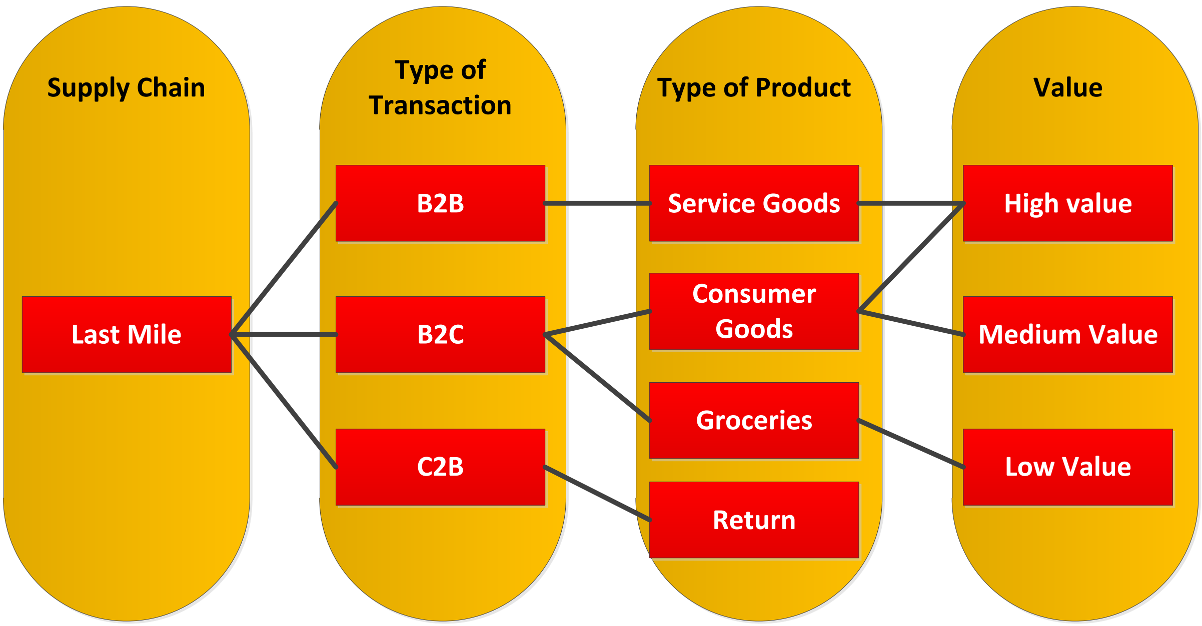


Figure 29 Typology of last mile sub flows (Own work based on (Gevaers et al., 2011)

As can be seen in Figure 29 there are four different columns which are of importance. The fist column being the type of supply chain, is this case the last mile. The second column the type of transaction, is this a business to business (b2b), a business to consumer (b2c) or a consumer to business (c2b)? A choice has been made for these three types since the other types like consumer to consumer (c2c) and business to government aren't so much of a part of last mile logistics as the others are. Consumer to business is in the case of return goods more a first than a last mile supply chain, but it will go through the same process as goods being delivered to someone at their home address.

Subsequently the type of product is categorized in four different categories. With first the service goods, these are goods for companies in the service industry like plumbers, electricians, etc. These goods are mainly in service logistics which is more a b2b network type. Than the consumer goods which is the majority of the parcel industry and a key aspect in this report. Then the groceries, which in the Netherlands are being delivered mostly by companies like Albert Heijn and Picnic, almost none by the large postal carriers. And finally, the return goods, which mostly are consumer goods that will be returned by consumers if they are not satisfied with the products.

These types of product can be divided up in three different value categories. A high value, for laptops for example, a medium value, for books or shoes for example and finally a low value, for products as groceries mostly.

Combining the before mentioned fundamentals with the topology as shown in Figure 29 an analysis can be made. For "The level of customer service" the delivery window, lead time and frequency are important aspects for the low value products such as groceries. Since these are more primary goods the consumer gives a large appreciation to these three aspects. For the higher valued products consumers are willing to wait a bit longer and think the return flow is more important.

For "Security and delivery type" medium and high value products are important, leaving an expensive laptop with a neighbour without signature isn't appreciated. Therefore, the first time hit rate with these products is far more important and often lower than other products. A solution to get a good first time hit rate is are the collection point or parcel lockers. Where only the recipient can access the package and no one else.

Regarding "The geographical area and market penetration and density" the time windows are important again, especially for the lower valued goods. This is important for the geographical locations and penetration and density, whereas people want their primary needs to be on time. For the higher valued products, this doesn't play such a large role and pooling is more of an option, reducing costs of delivery in urban areas.

Looking at "Vehicle fleet and technology" the prices of products do not matter that much and the aspects do not differ that much from each other. For low value products, the technology can be more important due to perishable products, where information about road works is important to divert routes for example.

Finally, "The environmental factor" is important for every value of product. However, it can be more important for the lower valued products due to the willingness to pay for green solutions. If the value of products is low the extra "green charge" can be relatively high in comparison with a higher valued product.

For the different fundamentals input has been asked from PostNL employees to see if there are large differences between the different fundamentals when looking at values of products. In Table 42 below this overview can be found.

Table 42 Overview importance of fundamentals based on (Gevaers et al., 2011)

Fundamentals	Characteristics of the fundamentals	Medium Value (books, accessories) (S.D.)	High Value (laptops, phones, electronics) (S.D.)
Level of customer service	Delivery window, lead time, delivery frequency	8.0 (1.0)	8.6 (0.6)
Security & Delivery type	First time hit rate, collection points, delivery with signature, neighbour delivery	5.6 (1.5)	8.9 (0.7)
Geographical area and market penetration and density	Density and pooling	4.6 (1.5)	4.5 (1.4)
Vehicle fleet and technology	Type of vehicle and information/technology	6.4 (1.4)	6.5 (1.5)
Environmental factor	Sustainability	5.5 (1.5)	5.5 (1.5)

As can be seen only for level of customer service and security and delivery type large differences can be seen. Though with level of customer service this difference is not that large. With security and delivery type there is a difference. Though due to reasons of the low number of insured goods, this difference will be neglected. Since it is impossible for PostNL to see what is inside a parcel.

Appendix V Cost function

This appendix contains the detailed explanation behind the cost function as is shown in paragraph 3.3. The cost function is based on the literature of (Gevears, Van de Voorde, & Vanelslander, 2014) and (Blauwens, De Baere, & Van de Voorde, 2010). The cost function will be designed from a standard general time and distance transport function and contains data from PostNL. When accurate data is not available data from literature will be made or funded assumptions will be used.

The costs are the B2C cost of the last mile as described in paragraph 2.2. This means delivery to a collection point as well. The cost will be per parcel delivered and a return flow is included, averaging the overall cost due to partially returned parcels. To start with the standard layout of a transportation cost function as mentioned in (Blauwens, De Baere, & Van de Voorde, 2010).

$$TC = T \cdot t + D \cdot d + Z \qquad \text{(V1)}$$

With:

- TC = total transportation costs [€]
- T = time/duration of the transport [hour]
- t = time/hour coefficient [€/hour]
- D = distance driven/travel for transport [km]
- d = distance coefficient [€/km]
- Z = extra costs not related to distance/time [€]

The total time costs consist of the multiplication of the total time driven by the driver with the time coefficient and the total distance costs consists of the multiplication of the total distance driven with the distance coefficient. Together with possible additional costs this will give the total transportation costs of the last mile. The important factors in this function are the two different coefficients. PostNL uses subcontractors for 80% of their parcel routes, these subcontractors are getting paid a variable amount per hour. This changes with distance the driver drive per route. And can differ on the type of subcontractor as well. Assumption will be made that only one type of subcontractor will be used, the so called ZZP'r. An independent employee whom works for himself without any other staff. The minimum hour tariff including kilometre cost is €25.00. Therefore, the kilometre cost needs to be multiplied with a minimum of 56 if the number of kilometres is below 56 per day. The reasoning behind the coefficients can be found in Table 43 and Table 44 below.

Table 43 Hour costs calculation in € per hr

1	**Road tax, Euro-vignette, contributions, dues**	[redacted]
2	Driver's wages (incl. all charges and premiums)	[redacted]
Total:	Hour coefficient (t)	[redacted]

Table 44 Kilometre cost calculation in € per km

1	**Fuel (€1.20 excl taxes p litre, usage 1:8)**	[redacted]
Total:	Distance coefficient (d)	[redacted]

The time and distance coefficient can vary amongst the size and payload of the trucks or vans being used for last mile delivery. In this case, there will be chosen for just one size delivery van which will be mostly used in the researched area. Therefore, no further calculation to other truck and van sizes regarding the time and distance coefficient will be conducted. In the following steps the total cost function will be designed based on sub-characteristics that are most logical for last mile parcel delivery and have a substantial impact on urban environments.

Number of stops (stop coefficient) [STOP]

The number of stops is an important characteristic for last mile parcel delivery. The more stops you have on a certain route the lower the cost per parcel will be, with just one stop per route the costs of delivering a parcel will be high. This will result in the following extension to the total cost function:

$$\frac{TC}{STOP} \qquad (V2)$$

Time window (time window coefficient) [w]

Time windows can play a critical role in parcel delivery, not only for the customer but for the logistics provider as well. Regarding the routes when having a time window the number of parcels which can be delivered will be reduced when the time window gets smaller. When a driver can deliver less parcels the costs per parcel will increase. The time window is linked to the amount of stops a driver can make, the smaller the time window the smaller the number of stops. This will result in the following extension to the total cost function:

$$\frac{STOP}{w} \qquad \text{(V3)}$$

If there is no time window w = 1. However, if there is a time window w needs to be larger than 1 to reduce the number of possible stops. Below in Table 45 the time window coefficient can be found from 1 to 9 hours, where 9 hours is a complete working day. The numbers are based on the research of (Boyer, Chung, & Prud'homme, 2009).

Table 45 Time window coefficients

Window Length (hours)	Time window coefficient (w)
1	2,1
2	1,8
3	1,6
4	1,4
5	1,3
6	1,2
7	1,1
8	1,1
9	1

Recipient at home (first time hit rate coefficient) [ip]

The *ip* coefficient is based on the so called “first time hit rate” (FTHR) percentage. Which indicates how much of the delivery succeed at the first try of delivery. The lower this number gets the lower the effective number of stops will be. This means that including the number of stops is a necessary aspect as well. The first time hit rate is a percentage between 0% and a 100%, where a 100% indicates that all the parcels delivered are successful at their first delivery attempt. This will result in the following extension to the total cost function:

$$STOP \cdot ip \qquad (V4)$$

Alternative delivery point (collection points coefficient) [cp]

The usage of collection points will increase the number of parcels that are being delivered at a drop. Not only that the FTHR will increase as well. However, the assumption will be made that this will not change and therefore it will be incorporated in the cp coefficient. If a logistics provider makes us of only collection points or parcel lockers the FTHR will be 100%, although multiple parcels will be delivered in that same drop a van has a maximum loading capacity and therefore the cp coefficient needs to be 1 and not higher, since a double counted effect could be possible. This will result in the following extension to the total cost function:

$$STOP \cdot cp \qquad (\text{V5})$$

Table 46 Collection point coefficient

Coefficient	Symbol	Analysis
Collection point	cp	If none => cp = 1, if yes => cp => 1

Population density and geographical area (density and area coefficient) [ad]

The population density can influence parcel delivery to a great extent. In rural areas, more kilometres per parcel delivery need to be made than delivering parcels in an urban area. The goal of the coefficient is to correct the amount of parcel delivered for the number of kilometres driven. With urban areas for the same number of kilometres driven the number of stops will increase in relation to a rural area for example. The *ad* coefficient will compensate for this effect by taking into account the population density in relation to the number of stops. This will result in the following extension to the total cost function:

$$STOP \cdot ad \qquad (V6)$$

To be able to determine the values for the coefficient the average population density of the Netherlands should be taken into account, which is 502 (people/km^2) (Centraal Bureau voor de Statistiek, 2017) and the figures of (Boyer, Chung, & Prud'homme, 2009).

Table 47 Density and area coefficient

Number of inhabitants per square km	Coefficient ad (calculated assumption)
0-100	0,71
101-400	0,89
502 (Density/km in the Netherlands)	1,00
401-700	1,02
701-1000	1,10
1001-1300	1,17
1301-1600	1,23
1601-1900	1,28
>1900	1,31

If for example a city with 1700 inhabitants per square kilometre is taken into account the coefficient of 1,28 indicates that the possible number of stops increases with 28% taken the same number of kilometres in consideration.

Vehicle (vehicle type coefficient) [v]

Another important factor to take into account is the type of vehicle that is doing the delivery. Since vehicle type is directly related to the cost of driving, fuel usage for example or speed of the delivery van. The coefficient will be used to indicate if the type of vehicle used has different characteristics than the average delivery van, this can be better or worse. When being worse costs will increase. Where the *d* coefficient that is mentioned above sets the average level and any vehicle that is different gets a different coefficient. This will result in the following extension to the cost function:

$$d \cdot v \qquad \text{(V7)}$$

In Table 48 below the interpretation of the coefficient can be seen.

Table 48 Vehicle type coefficient interpretation

Vehicle type	Relation
If v = 100%	The vehicle type has the same “d” coefficient as assumed
If v < 100%	The vehicle type has a lower than market operating cost
If v > 100%	The vehicle type has a higher than market operating cost

Parcel multiplication coefficient [P]

This coefficient will be used to multiply the number of STOPS to create the number of parcels that will tried to be delivered. This number will be based on the average number of stops and parcels that can be found in the urban area of De Pijp. For De Pijp this coefficient is 1.2.

$$STOP \cdot P \qquad \text{(V8)}$$

To be delivered parcel quantity [Q]

To be able to determine costs as good as possible the number of parcels that will be delivered. Since in this cost function the number of *STOP*s is being used already and the *cp* coefficient there are variables to indicate the number of parcels. Since multiplying the number of *STOP*s with the *cp* coefficient the parcel quantity can be determined. However, when using only collection points things will change a bit. The table below will indicate how to use the coefficient *Q.*

Table 49 Parcel Quantity

Coefficient	Symbol	Analysis
Parcel Quantity	Q	If cp = 1, *Q* = *STOP* ·P and if cp > 1, *Q* = *cp* ·*STOP* ·P

Return logistics (reverse logistics coefficient) [r, Cs, Cd]

Since returning parcels due to failed delivery is an important part as well this cannot be neglected. The returning part is a part of the total costs as well, being the fact that the driver needs to drive his van back with the parcel and bring it back to the distribution centre again, delivering the parcel again the next day. Causing extra costs for time and distance in manual labour for example. In the total cost function, the return part will be represented by *r*. This value is based on the “first time hit rate”, if the first time hit rate (*ip)* is 80% it means that 20% of the parcels could not be delivered and are part of the return logistics, giving *r* a value of 0,20, *r* = 1 – *ip.* The formula consists of two parts, where the first parts represents the part of the total amount of return logistics and the second part represents the processing part at the distribution centre, such as sorting costs C_s and the debrief costs C_d. This will result in the following extension to the total cost function:

$$Cost\ per\ parcel \cdot (1 + r) + (C_s + C_d) \cdot r \qquad \text{(V9)}$$

Retail Costs [Crt]

A certain percentage of parcels needs to be delivered to a retail location, this causes extra costs for the shipper. The number of parcels that will be delivered to a retail location can vary quite a bit. Therefore, it will be averaged alongside the normal price of delivery. Taking into account the price of delivering to a retail locationand the percentage of parcels delivered to such a retail location.

$$r_1 \cdot C_{rt} \qquad (V10)$$

Parcel compensation coefficient

Every delivery driver will get a fixed compensation for every parcel that he successfully delivers. This means that if the parcel couldn't be delivered the driver doesn't get paid for this parcel, savings costs for PostNL as well. This fee will be depending on two different aspects, being the first time hit rate and the percentage sent to retailers to determine the exact cost per parcel (on average). This will create the following extension to the formula.

$$(r_1 + ip) \cdot C_p \qquad \text{(V11)}$$

Integration of all the coefficients in the total cost function

All the additions to the cost function will make the following function:

Last Mile Cost per parcel shipped:

$$\frac{(T \cdot t + D \cdot d \cdot v)}{(\frac{STOP}{w} \cdot ip \cdot ad \cdot cp \cdot \mathrm{P})} \cdot (1 + r) + (C_s + C_d) \cdot r + r_1 \cdot C_{rt} + (r_1 + ip) \cdot C_p \qquad \text{(V12)}$$

Table 50 below will give an overview of all the used variables with their symbols in the equation.

Table 50 Used Symbols

Symbol	Variable	Symbol	Variable
T	Duration of route in hours	ad	Area density coefficient
t	Time coefficient	cp	Collection point coefficient
D	Distance of route in kilometre	R_1	Percentage sent to retailers
d	Distance coefficient	r	Return logistics coefficient
v	Vehicle type coefficient	Cs	Evening sorting costs per parcel
P	Parcel multiplication coefficient	Cd	Debrief costs per parcel
STOP	Average number of stops per delivery route per driver	Cp	Parcel compensation cost
w	Time window coefficient	Crt	Retailer costs per parcel
ip	First time hit rate coefficient		

Appendix VI Design Methodology

In literature, a lot of books and articles can be found that are discussing different methodology for a design. For engineering these are quite often specialized in mechanical engineering parts or chemical engineering parts. Though these can be beneficial as well they can be quite specific sometimes. Researching different articles a lot of references and citations are being made to two books. One being the book the Engineering Design: A Systematic Approach (Beitz et al., 2007). Below in Figure 30 the steps for the design process according to Beitz et al (2007) is displayed.

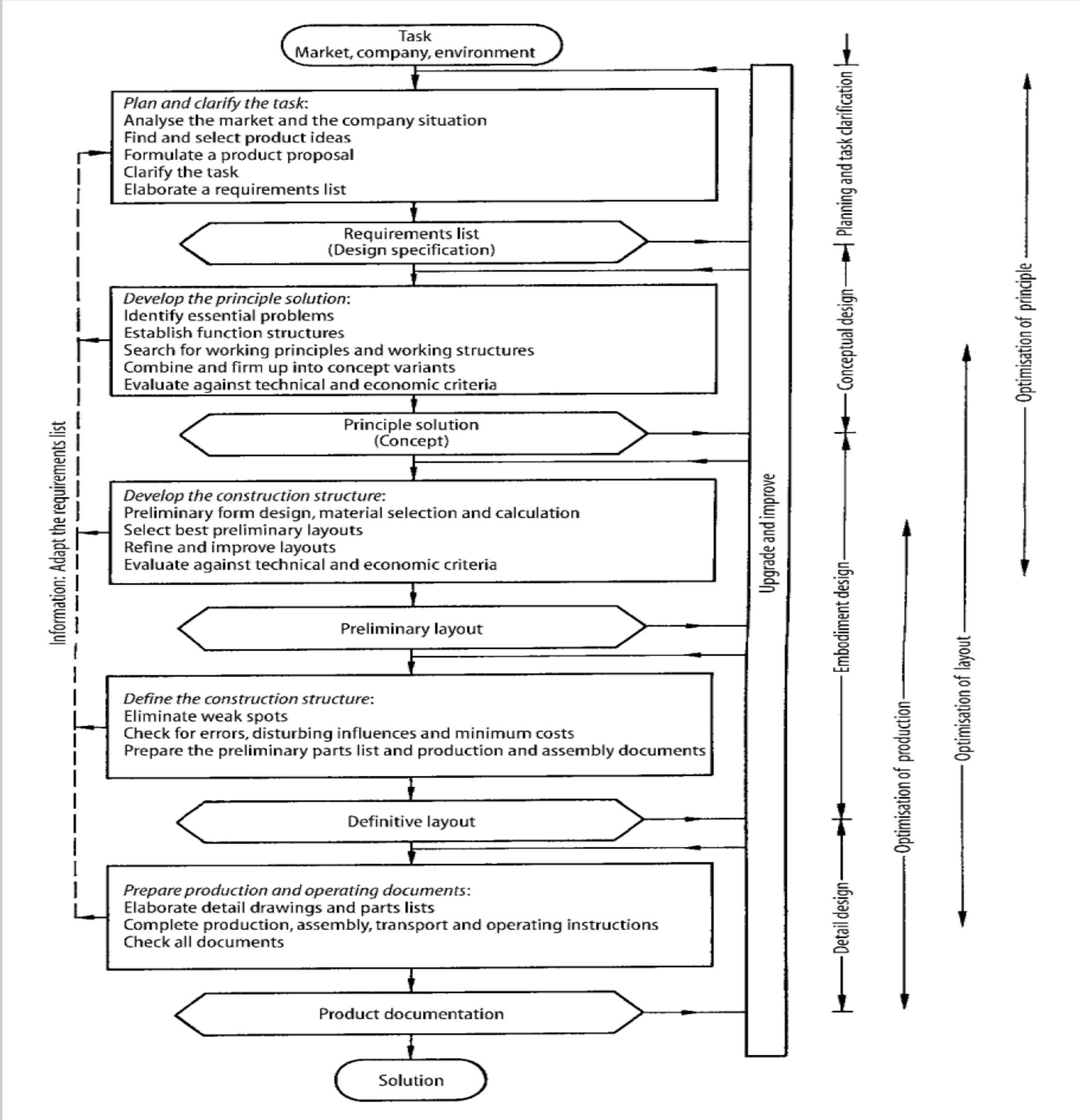


Figure 30 Steps in the planning and design process (Beitz et al., 2007)

The other being the book Engineering Design: A project-based introduction (Dym et al., 2014). This book also describes the different steps required in the overall process of problem definition and design. Below in Figure 31 the model of the design process according to the before mentioned authors is displayed.

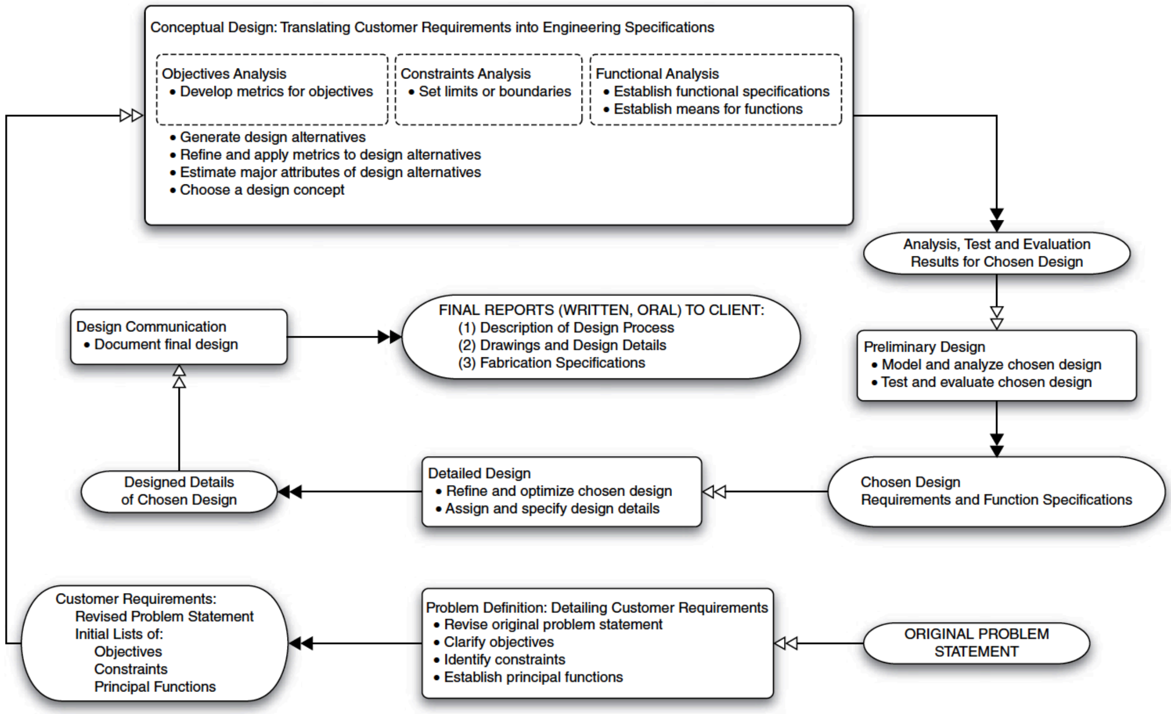


Figure 31 Five step design model, output in ovals, stages in rectangles (Dym, Little, & Orwin, 2014)

Where in Figure 30 the design process is modelled as a linear sequence of steps it does have feedback loops on the left and right, Figure 31 shows a spiral, without any feedback loops, with the idea behind it that design isn't just a linear sequence of performing steps. Both models begin with clarifying the original task or problem, in this research this will be the set-up of a clear problem statement and the objectives to reach that problem statement. In this research, the problem statement has been clarified in the Introduction and after that in the following chapter the Last Mile Delivery: current delivery model and future model(s) has been elaborated. Where the last mile as it is right now being researched and a system analysis has been made, to define the different constraints and objectives to support a future design further on in the research.

Next in the process will be the first start towards the design, which will be the requirements for the design. These requirements can be based on the current situation and the system analysis but can also be related to different characteristics the problem owner requires to have for a design. What are the objectives for this design and related to the problem statement what are the requirements that it should fulfil?

Hereafter the designs can be created, though this will be a concept design and not the full design yet. The requirements which have been made before will be converted into engineering specifications and with that made into a design. An analysis of the constraints, objectives and functions have to be made to come up with one or more conceptual designs.

Subsequently the conceptual design or designs need to be evaluated and the final design will be selected. This can be done with various methods to determine which of the design or designs is best qualified for the chosen purposes, which have been made clear in the problem statement and requirements chapter. After selecting a design with the usage of simulation the design will be further evaluated. The book of Banks (1998) mentions the following definition for simulation: “Simulation is the imitation of the operation of a real-world process or system over time. Simulation involves the generation of an artificial history of the system and the observation of that artificial history to draw inferences concerning the operating characteristics of the real system that is represented”. Simulation can come in handy when looking at the future delivery model and simulating a week worth of delivery to see how the delivery model operates and where possible bottlenecks can be identified. The book of Banks (1998) mentions several steps in the modelling approach of which some can be fit in with the design approach of (Beitz et al., 2007) and (Dym et al., 2014). The two latter will be used as main resource for the design of a future delivery model where Banks (1998) will be used more in the aspect of the simulation part later down the design cycle. The steps Banks (1998) describes are the following: (1) problem formulation, (2) setting of objectives and overall project plan, (3) model conceptualization, (4) data collection, (5) model translation, (6) verification, (7) validation, (8) experimental design, (9) production runs and analysis, (10) more runs, (11) documentation and reporting and finally (12) implementation. A lot of the steps can be interwoven with the design shown in Figure 32, such as (1), (2), (3), (4), (6), (7), (11) and (12). Steps (5), (8), (9) and (10) require a more specific explanation and will be further elaborated on further in the report.

Finally, the best design or designs will be made in more detail (where necessary) and validated by usage of simulation and a financial cost model. This final design will be used for the research to analyse further. With this design, it should be possible to answer the research question with the best possible outcome. With this a sensitivity analysis can be performed for example to see how rigid the design performs and maybe a new design needs to be considered when the chosen design isn't validated according to the set standards.

The complete design cycle can be found in Figure 32. This design cycle includes feedback loops as well, since a design is an iterative process.

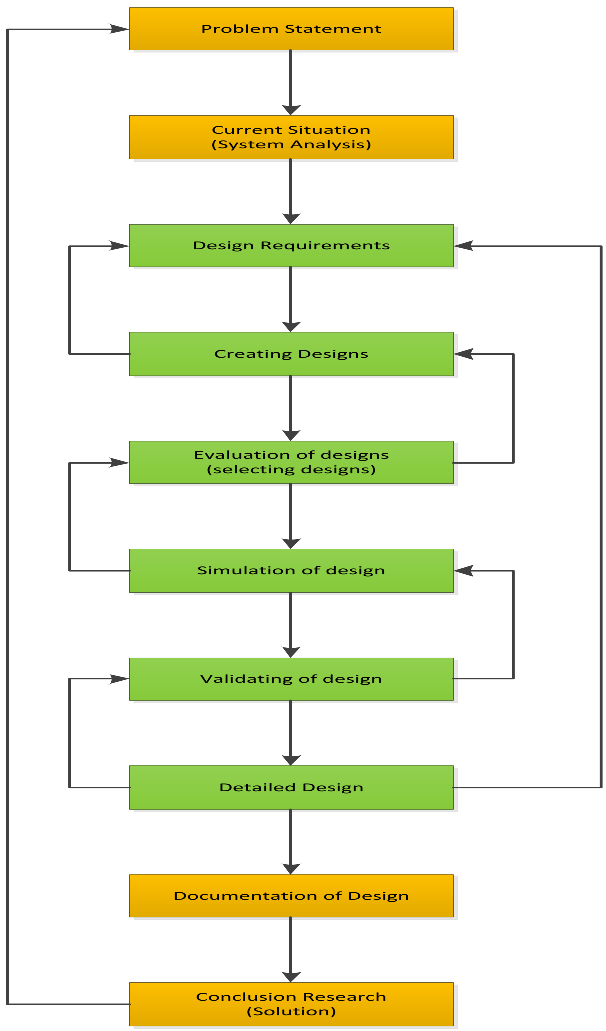


Figure 32 Methodology (Design Cycle)

Appendix VII Design Requirements

Finding requirements to design a system or a product isn't such an easy task. Lots of books and articles have been published discussing the importance of having good requirements. The so-called requirements engineering even is a separate part in science. Requirements can be divided in several types of requirements. Robertson and Robertson (2006) are mentioning the functional, non-functional and constraints as the three types of requirements that are the main focus point. These three types of requirements will be elaborated down below.

Requirement

"A requirement is something the product must do or a quality it must have. A requirement exists either because the type of product demands certain functions or qualities or because the client wants that requirement to be part of the delivered product" (Roberston & Robertson, 2006).

Functional Requirements

Functional requirements can be defined as follows: "A functional requirement is an action that the product must take if it is to be useful to its users. Functional requirements arise from the work that your stakeholders need to do" (Roberston & Robertson, 2006).
Important is that the functional requirements are not mentioned with technological issues, they should be independent from design and implementation impacts. And leave a solution space as broad as possible. According to Fernandes & Machado (2016) the set of functional requirements must be complete and coherent. The set is complete if the requirements consider all the wishes of the stakeholder satisfied. The set is coherent if there are no contradictions amongst its elements. It is hard to ensure these mentioned characteristics, especially to satisfy all the needs of the most important stakeholder. The most obvious requirements can sometimes be forgotten and not asked for by the stakeholders, for example an entrance door when building a house, in some cases it is a necessity that these requirements are documented, they are called implicit requirements (Fernandes & Machado, 2016). The same for the requirements that are asked by the stakeholders, in the case of the house a stakeholder whom doesn't want an entrance door but a hole in the wall for example, these requirements are referred to as explicit requirements.

Non-Functional Requirements

Non-functional requirements can be defined as follows: "Non-functional requirements are properties, or qualities, that the product must have. In some cases, these can be critical to the product's success" (Roberston & Robertson, 2006). The non-functional requirements are more of a technical nature most of the time. It is important that these requirements are discussed and agreed upon with the stakeholders before constructing a design. The essence of the system functionality is not affected by a non-functional requirement (Fernandes & Machado, 2016). A black car doesn't change the functionality of the car itself. However, in a warm environment it is not pleasurable to have a black car. The functional requirements will not be influenced by the non-functional requirements. Due to this nature, it is common that project have their origin more in the non-functional requirements. In the case that the current system is to slow and unreliable, the non-functional requirements ask for improvement. Though the functional requirements remain the same since the system itself isn't going to change its functionality it only improves it. Non-functional requirements are applicable for the whole of the system and not just some of it parts. When a system needs to be inexpensive this entails the whole system, though it needs to be quantified in a numerical form like euro's. Looking at that the non-functional requirements can be seen as emergent properties. Where an emergent property is a property that can be seen with the system as a whole but not individually to each of its components (Fernandes & Machado, 2016). Speed can be such an emergent property of a system. Not all the components can be that fast and some need their time for example but as a whole for the system it can be. Non-functional requirements are key in the system architecture, the system needs to have some kind of structure to engineer a system. Non-functional requirements are not isolated on their own and one requirement can affect the other. In the case one requirement is the price of parts, the requirement of durability can be affected by the cheaper parts for example. Several resources have tried to classify the non-functional requirements. The classification of Somerville (2010) is shown below:

- Product Requirements
  - Specify the constraints and behaviour of the design. Such as reliability, performance, efficiency, security and usability
- Organizational Requirements
  - Broad system requirements derived from policies and procedures in the stakeholders and system organization. Such as operational process requirements and implementation requirements, such as use of certain safety standards for personnel.
- External Requirements
  - Factors derived from external aspects in the system and its developments process. Such as regulations by law and ethical requirements.

Robertson and Robertson (2006) have a classification for non-functional requirements as well, which defines eight types of non-functional requirements and is more related to the software and information systems domain:

- Appearance
  - How does the system look like regarding aesthetics?
- Usability
  - The ease of use of the product, and special considerations to have a better user experience
- Performance
  - The speed, the quantity, the accuracy of the design
- Operational
  - The characteristics of how the system should cope with its environment
- Maintainability and support
  - Allowance of the system to be repaired and added with new functionalities
- Security
  - How secure and confidential a product must be
- Cultural and Political
  - Any requirements related to the stakeholders' culture and habits
- Legal
  - Special laws and standards that are of influence on the product

Looking at the classifications of Somerville (2010) and Robertson and Robertson (2006) certain similarities can be found but differences as well. Somervile (2010) has more of a global overview whereas Robertson and Robertson (2006) are more into detail about the differences in non-functional requirements. These two can be combined together with the five last mile fundamentals mentioned in Appendix IV Last Mile subdivided. The combination of the two classifications with the fundamentals can give an overview and classification that is specially designed for the purpose of this research. This classification can be found below.

- Consumer requirements
  - These are the non-functional requirements related to the consumer and their service level. This can be the appearance, usability, performance and certain consumer related product requirements.
- Security & Safety requirements
  - These are the non-functional requirements related to everything regarding the security and safety of the design. How safe is the design to use and how secure is it related to violence or hacking of the system?
- Environmental requirements
  - These are the non-functional requirements related to the environmental aspects of the design. This can be the sustainability of the design, related to different cultural and political demands. Legal issue related to sustainability as well, but as well how does the design relates to the street view?

- Geographical requirements
    - These are the non-functional requirements related to the geographical locations of the design. Where can the design be placed and where not? How large should the perimeter be of a certain amount of people living in the area?
- Product technical requirements
    - These are the non-functional requirements related to the product technical aspects of the design. For example, the design cannot weigh more than a certain amount. The interface of the design should be open-source software. The design can only be built with steel and not with aluminium.

The five types of classifications of non-functional requirements stated above can have some overlap of different aspects. The classification is made to get more structure in the non-functional requirements but doesn't need to be leading. At the end the requirement itself is most important.

Constraints

Constraints can be defined as follows: "Constraints are global requirements. They can be constraints on the project itself or restrictions on the eventual design of the product" (Roberston & Robertson, 2006).

Appendix VIII Creating Designs

Brainstorming: Brainstorming is not only good for coming up with requirements for the design is can come in handy as well when generating alternatives. Kosky et al., (2010) mention one important role that needs to be taken into account when induced in a brainstorm session: “Criticism of ideas is not allowed”. Giving each team member that is involved in the brainstorm session the confidence to express their ideas and no idea will be rejected right away, creating a pool of ideas which eventually can be combined into one perfect idea. During brainstorm session with experts the majority of the ideas are funded ideas and ideas with reasoning from experience. But it is a good idea to come up with ideas that are bold and unconventional, especially in the case of creating ideas that are not yet existing, this to expand visions and think out of the box. Only when the brainstorm session is completed the concepts should undergo the elimination process, which ones are not feasible, which ones are alike and for example which ones are not legal to make. Important to keep in mind is that brainstorming is not the only option to create design alternatives, it should be seen as one of several tools that will be part of a larger entirety.

Concept sketching: Writing ideas down on a piece of paper is in existence for a long time already and has been proven to work for a lot of people. One of the most used forms of writing down ideas is the use of a “Mind Map” a popular tool and suitable for collaboration (Kremen et al., 2012). For this research, a mind map will not be used but the principal of sketching something on paper will be used. Kosky et al., (2010) gives the following definition of the reason for making a sketch: “The goal in producing a concept drawing is to convey what the design is and how it works in the clearest possible terms”. Important to keep in mind is the fact that this is not a detailed design, meaning that dimensions, pricing and for example colour is not important at this stage. The sketching phase consists of two phases, the first phase is the creative phase, where the idea is made visual and can be used further. The second phase is the documentation phase where the sketch is made in such a fashion that it is clear and understandable for other project engineers. The outcome of this final sketch according to Kosky et al., (2010) should fulfil the following requirements: hand sketched or computer generated, no extensive details, labelling of main futures and if needed provides multiple views to see how the design works. The looks of the sketch are not of large importance, the most important thing is whether the sketch is clear enough to be understandable. In the case of a future delivery model a sketch can be really important and is almost a necessity in the design phase this sketch will be detailed to a larger level to indicate a real design and not an idea as it is at this moment.

Research-based strategies: Most ideas and designs that have been made are based on previous designs, just a handful of ideas and designs is truly original. This concept is there to make use of those old designs and help to create new designs. Kosky et al., (2010) are mentioning three different methods to do so. The first method is that of *Analogies*, with this method the idea is to look for analogous design situations in other unrelated fields. This method will be less suited for the purposes of this paper and will therefore not be used. The second method is *Reverse Engineering.* With this method, the idea is to acquire a certain product that is similar to the design you have in mind, take it apart, figure out how it works and then use this to improve this product or use it for you own design. This method as well is not suited for the design of a delivery method, it’s more suited for physical products. The third and last method is *Literature Search*. This method is used to find ideas in literature and use that for the design. The method of literature search is being applied throughout this research and is not used in particular as a standalone solution.

Functional Decomposition: Complex problems can be solved easier when breaking it down to smaller, simpler and more manageable parts. “In the case of design, those smaller parts usually correspond to the individual functions (or tasks) that must be performed in order to achieve the overall design objective” (Kosky et al., 2010). This approach consists of four different steps. The first step is *Decomposing*: the goal is to decompose the main function into several sub functions and when needed decompose these sub functions even further. The most common way of representing such a decomposition is a tree diagram. Since it can be hard sometimes to think of sub functions it can be helpful to use a sequential. Important side note with using this functional decomposition is to keep it as general as possible and avoid making the decomposition to biased. The second step is *Brainstorming for alternative concepts for each function*: This by using a so-called classification scheme, where the functions of step 1 will be used together with corresponding design solutions that have been brainstormed. Step three is *Combining function concepts to form alternative design concepts*: this step uses the classification scheme of step 2 to combine the different design solutions of the different functions to create a new design. Important is that the designs shouldn't be alike and that the combinations that are being used are viable to work. The fourth and last step is *Sketching the most promising combinations*: this step uses all the aspect from the before mentioned method of sketching concepts. This method can be helpful when designing a delivery model to deliver parcels into a parcel locker but to a certain extent. The method is originally designed for creating new products and not for creating methods, which requires a bit of a different approach.

Appendix IX MCA Model

Making a decision which design to choose is an important but difficult decision. Several methods have been found in literature which are explaining the best way to do this. One of these methods is the method of Saaty (2008). The analytical hierarchy process, this process is designed to compare different criteria, products or other things relative to each other. It is based on a comparison with the goal to create an overall analysis of complex situations. Comparing different criteria with each other without making it to subjectively but taking into account all the criteria and making it a whole. But to be able make comparisons a set of numbers is required to do so, this to indicate how much more important one aspect is above another aspect (Saaty, 2008). Below in Figure 33 the overview of the weights used by Saaty (2008) is shown, the range of numbers will be used in this research as well.

Intensity of Importance	*Definition*	*Explanation*
1	Equal Importance	Two activities contribute equally to the objective
2	Weak or slight	
3	Moderate importance	Experience and judgement slightly favour one activity over another
4	Moderate plus	
5	Strong importance	Experience and judgement strongly favour one activity over another
6	Strong plus	
7	Very strong or demonstrated importance	An activity is favoured very strongly over another; its dominance demonstrated in practice
8	Very, very strong	
9	Extreme importance	The evidence favouring one activity over another is of the highest possible order of affirmation
Reciprocals of above	If activity i has one of the above non-zero numbers assigned to it when compared with activity j, then j has the reciprocal value when compared with i	A reasonable assumption
1.1–1.9	If the activities are very close	May be difficult to assign the best value but when compared with other contrasting activities the size of the small numbers would not be too noticeable, yet they can still indicate the relative importance of the activities.

Figure 33 The fundamental scale of absolute numbers (Saaty, 2008)

As can be seen giving a number of 1 means that the criterion that is being compared is equally important as the other criterion. Or in the case of the example in Figure 34 below, giving a 1 would mean that coffee is being consumed as much as wine. Giving a number of 9 means that the criterion is 9 times more important than the criterion it is being compared with. Making this matrix with the input of more than one person eliminates the subjective nature and gives a better overview of a more objective comparison. In Figure 34 below Saaty (2008) has made an example of drink consumption in the USA based on judgements of different people. As can be seen the values from the judgements are really close to the actual numbers from the statistical sources. Meaning that this method has great potential.

Which drink is consumed more in the USA?							
An example of examination using judgements							
Drink consumption in US	*Coffee*	*Wine*	*Tea*	*Beer*	*Sodas*	*Milk*	*Water*
Coffee	1	9	5	2	1	1	1/2
Wine	1/9	1	1/3	1/9	1/9	1/9	1/9
Tea	1/5	2	1	1/3	1/4	1/3	1/9
Beer	1/2	9	3	1	1/2	1	1/3
Soda	1	9	4	2	1	2	1/2
Milk	1	9	3	1	1/2	1	1/3
Water	2	9	9	3	2	3	1

Note: The derived scale based on the judgements in the matrix is:
0.177 0.019 0.042 0.116 0.190 0.129 0.327
With a consistency ratio of 0.022.
the actual consumption (from statistical sources) is:
0.180 0.010 0.040 0.120 0.180 0.140 0.330

Figure 34 Relative consumption of drinks (Saaty, 2008)

The example is being used with actual products not with criteria. To make use of this principle with criteria and designs a step further needs to be addressed. The first step is that the same comparison needs to be made this time between different criteria. This is shown below in Table 51. The second step is that the different designs need to be valued in comparison with the current situation. The current situation which for this method will be called the status quo will be valued at a 5 on every criterion, since this is the benchmark design. The other designs will be given values in relation to this benchmark design, where higher than a 5 is better on that criterion and lower is worse. This is shown in Table 52. For every design a table will be made with the values for each criterion with the reasoning behind it, this can be seen in Table 53. After the first two steps the third step will combine the first two steps by multiplying the normalized values of the first step with the values of the second step creating the decision matrix. This matrix will show which design is the best based on those criteria. This is shown in Table 54.

Table 51 Criteria Weights

Criteria	Criterion 1	Criterion 2	Criterion 3	Normalized
Criterion 1	1	8	6	0.696
Criterion 2	1/8	1	1/4	0.064
Criterion 3	1/6	4	1	0.240

Table 52 Alternative Scores

Criteria	Status Quo	Design 1	Design 2	Design 3
Criterion 1	5	8	9	3
Criterion 2	5	3	7	5
Criterion 3	5	5	5	1

Table 53 Design 1 Scores

Criteria	Design 1	Reason
Criterion 1	8	Better
Criterion 2	3	Worse
Criterion 3	5	Same as status Quo

Table 54 Weighted scores per alternative

Criteria	Weights	Status Quo	Design 1	Design 2	Design 3
Criterion 1	0.696	3.48	5.568	6.264	2.088
Criterion 2	0.064	0.32	0.192	0.448	0.32
Criterion 3	0.240	1.2	1.2	1.2	0.240
Total		5	6.96	7.912	2.648
Relative Importance		63.20%	87.97%	100%	33.47%

As can be seen in Table 54 the best scoring alternative in this case is Design 2, important to take into account is that design 1 is close to design 2 when it comes to relative importance. Meaning that these designs can be alike and should looked more closely to. It is clear that design 3 is the worst design, even worse than the status quo. By using the relative importance, the goal is to see how well the designs perform amongst each other and the status quo.

Appendix X Simulation Study

To conduct a simulation-study a number of essential steps needs to be taken in order to perform a successful simulation. Several sources are mentioning the steps to take for a simulation analysis, this research will use the steps described by Banks (1999). The steps of Banks (1999) are shown in Figure 35 below.

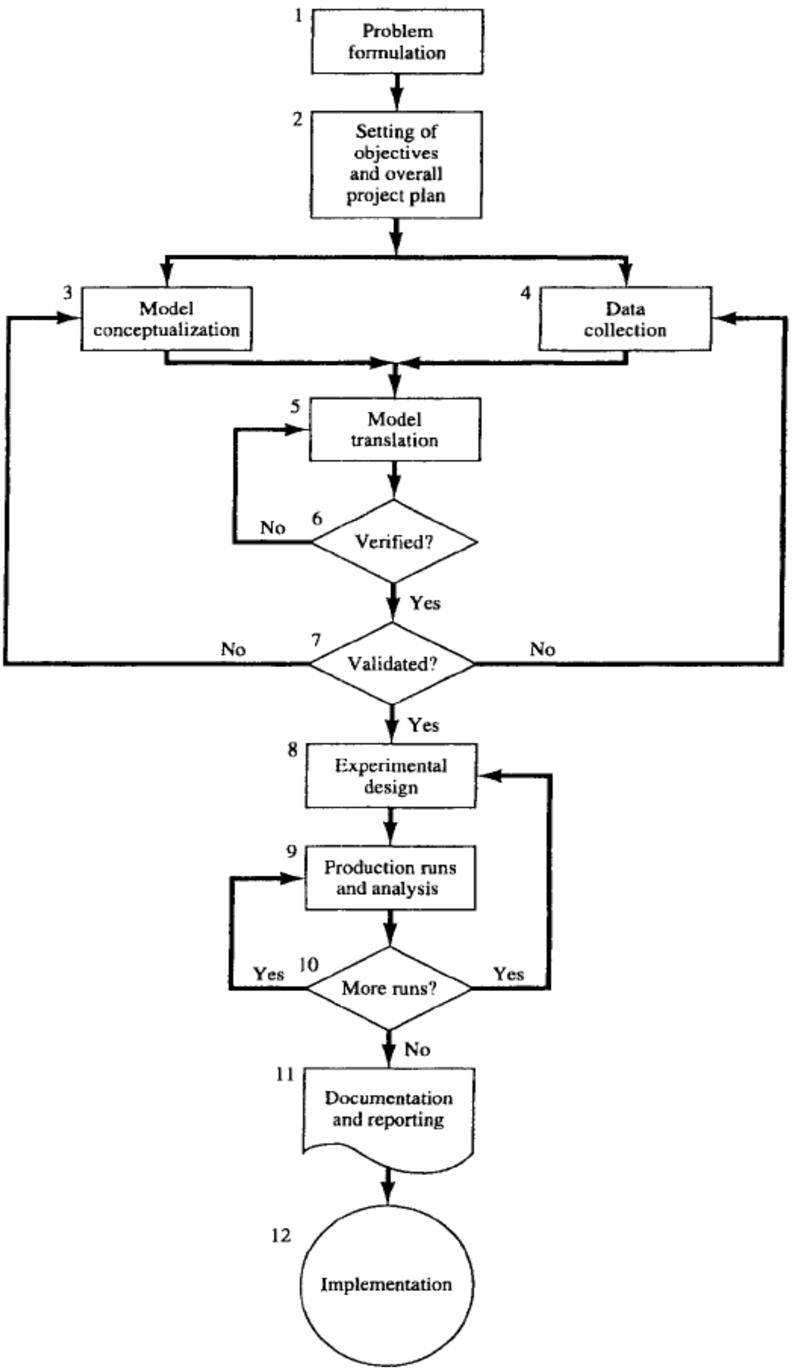


Figure 35 Simulation Steps

As can be seen in the figure twelve different steps can be differentiated. Where for some steps a feedback-loops can be seen, to check whether the model is validated or verified for example. Perhaps the model needs more runs or the model can be documented and reported. For each of the twelve steps the explanation can be found below. The majority of these steps is researched in other chapters of this report than the simulation chapters.

1. Problem Formulation: The first step that every simulation study needs, is a proper problem statement. Both the client and the one performing the simulation need to agree on the clarity of the problem. Possible reformulation can be needed further along the research. The problem formulation in this research is conducted in paragraph 1.2.
2. Setting of objectives and overall project plan: Banks (1999) refers to this step as “prepare a proposal”. Objectives indicate the questions that need to be answered by the simulation study and the project plan should indicate a statement of the different scenarios that will be investigated. This plan needs requirements, time, personnel, software and many other. This step is conducted in paragraph 4.1.
3. Model conceptualization: “The real-world system under investigation is abstracted by a conceptual model, a series of mathematical and logical relationships concerning the components and structure of the system” Banks (1999, p15-17). The goal of this model conceptualization is to do this step by step, start with the small things and slowly add more and more things to the model. This step is conducted throughout chapters 4.1, 4.2 and 4.3.
4. Data collection: This step can be performed simultaneously with the model conceptualization, this will be the case in this report as well. The data collection phase is the step where all the necessary data for the simulation model will be gathered. Preferably this will be individual data samples and not summaries of data such as averages, which sometimes can give a distorted image. The data collection is mostly done in chapter 4.2.
5. Model translation: In this step, the conceptual modal together with the collected data will be coded into a computer-recognizable model. With this model software is required which in this report will be Simio. This will be explained further down below. The model translation is conducted in paragraph 4.3.3
6. Verification: The verification is for the computerized model, the most important question to be asked if the model operates correctly? Even smaller models have possibilities for flaws, if it’s 50 lines of codes or 2000 lines of codes mistakes can be made easily. Banks (1999) recommends the simulation analyst to verify the model continuously and not wait until the last moment in time to do so. Making use of some form of a debugger is highly recommended. The verification is conducted in the same paragraph as the model translation, paragraph 4.3.3
7. Validation: Validation looks into the conceptual model and its resemblance to the real system. Is it possible to substitute the model with the real system? And if possible is there a real system to compare the model with? Most of the time with new models this is not possible and other methods are suited for this. These methods are elaborated on in paragraph 3.4 and the validation is conducted in paragraph 4.4.
8. Experimental design: For each design conditions need to be set regarding number of runs, time and so on. These conditions will be formulated in the simulation paragraph 4.3.3.
9. Production runs and analysis: “Production runs, and their subsequent analysis, are used to estimate measures of performance for the scenario’s that are being simulated” Banks (1999, p18). This step is conducted partially in paragraph 4.3.3and 4.5.
10. More runs?: Is the model accurate enough, are the scenario’s clear or are there more runs needed to make more simulations and improve the outcomes? This step is conducted in paragraph 4.5.
11. Documentation and reporting: Documentation is a step that can be necessary for different things. When the model will be used again, it is important to document properly how the model works and what it does. The same goes for potential modification. Documenting can be necessary as well to clarify the analysis of the model. Especially the analysis needs to be reported adequately. The results of the simulation are important in this research to determine the final design and give an answer to the research question. This step is conducted in paragraph 4.5.
12. Implementation: This step in the simulation study will not be used, since the model that will be designed is a new model and too many assumptions need to be taken to be able to implement it in a real system. The output of the model will be used though to be able to answer the research question.

These twelve steps are the steps to make a simulation according to Banks (1999). Many of these steps are part of other chapters in this research and will therefore not be elaborated on in detail. One of the most important steps that will be explained further in depth is the fifth step, the step of model translation. This step will explain what type of simulation will be used, the type of program that will be used and the reasoning behind it.

Model Translation

The type of simulation that will be used is discrete-event simulation. This method is preferred over the use of continuous simulation. The reason for this being the fact that with discrete event systems, things will change at discrete moments in time rather than continuously (Fishman, 2001). This example is illustrated in the book of Fishman (2001) with a bus travelling a certain route with passengers. The bus moves continuously, however the passengers move in and out at certain times in the process more specifically at bus stop. The changing aspects are the waiting time of the passengers for example and how many passengers hop on and off. This type of event is typical for discrete-event simulate. The performance of the systems of mostly measured in four different terms. Delay, number waiting, throughput and resource utilization (Fishman, 2001).

Delay: indicates time spent waiting for resources
Number waiting: denotes number of items, jobs, or individuals for resources
Throughput: number of finished units emerging from the system per unit time
Resource utilization: proportion of time that resources are busy relative to total time

Fishman (2001) identifies seven different concepts for discrete-event systems, which relate to the conditions that for example buffer times are not infinite but have a maximum capacity based on the room available. The seven concepts are: work, resources, routing, buffers, scheduling, sequencing and performance.

Work: denotes the items, jobs, customers, etc. that enter the system seeking service.
Resources: include everything that can provide services, such as a train in a public transport network.
Routing: together with each unit or batch of work the route will feature the collection of services, resources and the order of these services. In a train network, this will be the movement of the train from station to station where passenger can hop on and off.
Buffers: these are waiting areas that hold work while waiting for services. This can be indefinite, for example when there is more space than people will come, but can be definite as well, for example the capacity of a parking lot in the city centre.
Scheduling: denotes the pattern for availability of resources. For a train network, this will be the deployment of trains in the peak periods.
Sequencing: denotes the order in which resources provide services to their waiting work. This can vary from first in, first out to demand and supply.

Though with these different concepts and performance measures a type of software needs to be chosen as well to be able to convert all the different steps mentioned before into a proper simulation. Selecting simulation software can be quite a burden. It can be hard and time consuming and requires multi-criteria decision making (Nikoukaran et al., 1999). Among other things due to lack of time the software of choice will be Simio, one of the main reasons for doing so is the experience of the researcher with this type of software. Other reasons are the benefit of making the simulation visual instead of using lines of codes which is the case with MatLab, SIMSCRIPT, SLAM and SIMAN (Kelton et al., 2011). Simio is a relatively new and modern simulation software, which has been developed by the same people whom developed programs such as Arena and SIMAN, meaning Simio has quite a lot of experience (Kelton et al., 2011). Simio is a type of software that is a more object based paradigm. Using Simio, graphical process flows are being used requiring no programming. This enables easier built up of own models, such as future delivery models that do not exist yet.

According to Sargent (2011) with simulation language there are four aspects concerning the verification. First being the creation of an error free simulation language. The second the situation that the simulation language has been properly implemented on the computer. The third being that a tested pseudo random number generator is implemented properly. Finally, the fourth which is that the model is programmed correctly in the simulation language. Structured walkthroughs and traces being the techniques to check the correct programming of the model. To test simulation software Sargent (2011) mentions two different approaches: static testing and dynamic testing. With static testing the computer program is merely checked by walkthroughs, correctness proof and close examination of the programs structure. Dynamic testing is a bit more elaborate than that. With dynamic testing the computer program will be executed with different conditions and the obtained values will be checked to see if implementation is correct. Techniques to do dynamic testing are amongst other things, traces, internal consistency checks, reprogramming certain components to see correct results and investigating input-output relations using different validation techniques. Important not to forget is that errors may be found in the incorrectness of data, conceptual model, the computer program itself or computer implementation.

Appendix XI Ranking evaluated alternatives

Since this research will use three methods to evaluate the different alternatives, it will be possible that every method will get a different ranking on the alternatives. This doesn't need to happen though, it can be the case that for every method the alternatives score equally good or bad. However, to prevent any mistakes from happening or have any discomfort with the alternatives, the three methods will get an equal ranking from 1 to 10. Since there are 10 types of alternatives. The three methods will score individually per alternative and the sum of the three-different alternative will determine the overall score. The alternative with the lowest overall score is the best alternative. Below in Table 55 an example of such a ranking can be found.

Table 55 Ranking for the three methods

Alternative	CEA	MCA	Simulation	Overall Score	Overall Ranking
Alternative 0	6	1	10	17	6
Alternative 1 M, L, XL lockers	3	2	1	6	1
Alternative 1 S lockers	1	3	9	13	3
Alternative 1 XS lockers	2	4	2	8	2
Alternative 2 M, L, XL lockers	5	6	7	18	7
Alternative 2 S lockers	4	8	4	16	5
Alternative 2 XS lockers	9	10	5	24	10
Alternative 3 M, L, XL lockers	7	7	6	20	8
Alternative 3 S lockers	8	4	3	15	4
Alternative 3 XS lockers	10	5	8	23	9

Appendix XII Day of parcel delivery

Working a day with a (parcel) delivery man

Friday the 8th of September, Delivery man: Peter Bosman, Interviewer: Yorick van Amstel

There are two types of delivery men. The PostNL employees and the subcontractors. The PostNL employees have a full-time contract with PostNL and the subcontractors are being paid for every stop they make.

Steps before delivery

- Registration at planning desk and reception of delivery van keys
- Driving the van to the designated dock and connecting it to the dock. Where after the driver stands at the end of the gutter.
- The parcels come down the gutter one by one and will be placed by the driver in the delivery van sorted on street or neighbourhood, these parcels do not need to be scanned.
- The parcels that need to be scanned are the parcels that could not be sorted with the machines. These parcels will be sorted in the van the same way as the regular parcels.
- After approximately 45 minutes the loading process is completed, the driver will undock his van and will start with his delivery run.

Steps during delivery

During Friday, the 13th the researcher was driving together with a PostNL employee whom was working on this specific route for four years already. Meaning he knew the route by heart and knew how to drive around for optimal parcel delivery. This meant for example to start in a street with stores as well as regular customers. In the morning delivering the parcels to regular customers and later in the day the stores, seeing this and experiencing this, the efficiency of this operation came forward really good. Three types of parcels have been delivered this day, within these three types a specification can be made as well, but this will not be done due to time and complexity issues.

- Normal parcels: This type of parcel can be delivered without signing, meaning this type of parcel can be delivered with neighbours as well.
- Parcels with signature: This type of parcel can only be delivered when a signature is given. Sometimes parcels of this type can only be delivered to the recipient on the address label, if this is not the case a neighbour can sign for this parcel as well when necessary.
- Parcels with reimbursement: This type of parcel needs a payment from the recipient. This payment needs to be paid in cash and with the exact amount. Reasoning for these costs can vary from taxes to shipping costs.

Every parcel that will be delivered needs to be offered to the recipient twice. If the first delivery fails, the driver needs to put this in his hand terminal. Put a note of notification in the mailbox of the recipient, stating PostNL tried to deliver a parcel and the customer wasn't home at the time of delivery. The customer can than select the option for delivery next day at their home address, or divert it to a postal office. The driver takes the parcels back in the van and puts a sticker on it with the date of first delivery. Indicating a failed 1st attempt for the driver whom is delivering this parcel the next day. The parcels will be taken back to the depot and the end of his shift. For parcels that have a second attempt and cannot be delivered the parcels will go if possible straight towards the postal office at the end of the shift. The driver puts this in his hand terminal as well and places a notification in the mailbox of the recipient stating the parcel is available at the postal office. At the end of his shift the driver, drives to the postal office to bring away the parcels that need to go to the postal office and he will pick up when possible the parcels that customers want to send themselves. This can be return shipment but also C2C shipments. After the driver is finished with his last stop he will drive back to the depot to start the debriefing process.

Debriefing Process
The debrief process consists of several steps and has several types of parcels.

- The driver waits in line (if necessary) until one of the debrief docks is free
- He parks the car at the dock
- The driver will take out all the parcels left in his van and hands them over to a debrief employee
- The debrief employee scans all the parcels to check if all the parcels that needed to come back are present at the depot.
- If everything is okay, the driver is finished for today. If things are not okay the driver needs to explain the reasons why things are different than they were supposed to be.
- After finishing the debrief process the driver parks his van and hands in the keys. After this he is done and go home or drink some coffee.

The debrief process has several types of parcels, however for this research the type of parcels are not relevant and will therefore not be discussed further.

Remarks

- Working ICT infrastructure is one of the most important things. The driver that was delivering parcels Friday the 8th of September mentioned several times that the hand terminal would stop working half way in the process. This required him to log back on once in a while causing a delay in the process.
- Sorting out parcels properly is key. Not only before the van leaves the depot but when possible also during delivery, in between stops. This will save a lot of time, since the need to look for parcels is gone.
- With heavier parcels, it is better to see if people are home during delivery to prevent carrying around these parcels and causing physical discomfort.
- The reimbursement can be quite a burden for drivers, since this need to be paid in cash and most of the time people don’t have cash in their homes or didn’t expect the costs.
- Some drivers prefer to have less stops due to the heavy loads they sometimes need to carry around, having less stops creates less need to carry heavy parcels around.
- Contact with people is one of the things that driver really appreciates, taking this away creates a need for alternative social contacts.

Appendix XIII Logistic Vision PostNL

The document of Logistieke Strategie PNP (2016) mentions a number of fundamental rules that the logistics of PostNL is built upon. Future changes in logistics cannot be in conflict with these rules, though when absolutely necessary expectations can be made. Some of these rules are used for requirements in this research and some of these rules do not apply for this research. All of the fundamental rules will be listed below, where after the most important ones will be further elaborated on.

1. The processing of parcels and registered letters needs to take have costs as low as possible taking into consideration the service cadres and formulated policy. Cost as low as possible means that there are no wastes in the logistic chain and the processes are drawn up by the LEAN-concept.
2. Design is in such a way that damaged goods and missing items are reduced to a minimum.
3. The full chain from customer to addressee is closed from a security point of view.
4. PostNL parcels has the direction over all the parts in the chain, as well as the outsourced processes. PostNL controls the processes, not only with own staff, but PostNL stays in charge and holds the final responsibility.
5. The regular NLI network is a bulk network. This network only holds standard products and standard processes. For specials, demand related or niche products other PostNL networks will be used.
6. The logistic infrastructure is designed in such a way that 11 months per year operations can be done in a standard way. For the SKNJ (Sinterklaas, Christmas and New Year) special measures will be taken.
7. The goal is to overcome any necessary complexity in de ICT and tools and not in the procedures for employees (at reasonable costs)
8. The logistics facilitates excellent information provision towards receiver and sender. Meaning that from the processes real-time, interactive information provision can occur toward the receiver and sender.
9. The NLI network functions as a pump and isn't' designed for storage. Meaning that parcels need to leave the network as fast as possible.
10. The process needs to be conducted in such a way that all the demands of the ARBO are fulfilled.
11. PostNL parcels is a Benelux network. All the fundamental rules apply to all the activities in the Benelux.

Two fundamental rules require some more explanation and are one of the most important rules. The first rule and the sixth rule are the ones whom require extra details. For the first rule of keeping the costs as low as possible some terms need to be set up. Summarizing these rules the most important rule is uniformity, at every depot the same rules need to be fulfilled and delivery needs to be as simple as possible. For the sixth rule of designing the infrastructure in such a way that 11 months per year operations can be fulfilled. The most important aspect of this rule is the fact that the infrastructure needs to be designed for those 11 months in the year, for the peak month separate plans will be made based on commercial expectations.
The logistics vision PostNL wants to pursue has three important starting points. Volume growth, volume distribution and the dm3 and kg per parcels. In this research, the design that will be created will be a future design, therefore the volume growth is one of the most important factors to take into consideration. Together with the volume distribution these two starting points are valuable input for the simulation analysis. Logistieke Strategie PNP (2016) mentions several expected growth scenarios', varying from 2.8% to 17%. Looking at the financial year report of 2016, the growth between 2015 and 1016 has been 13.3% (PostNL, 2017). The different scenarios differ quite a lot, this is an important thing to keep in mind when performing a simulation analysis. However, the different inputs can be used to investigate the robustness of the model, in the sense of a sensitivity analysis.

Volume distribution is an important factor as well, since the Tuesday is the busiest day for PostNL and the volumes differ relatively a lot between Tuesdays and Wednesdays until Saturdays. The goal for

PostNL is to distribute these volumes more evenly over the week, causing less stress on the capacity off the network. Looking at the figures for this volume distribution the Mondays have 5% of the parcels, the Tuesday 23% and the rest of the days (Sunday is no delivery day) averaging 18% (Logistieke Strategie PNP, 2016). Meaning that capacity for the parcel lockers should be sufficient enough to withstand the Tuesday peaks. Looking at the third starting point of volume and weight, the expectations are the average parcel size will grow in volume and weight. However due to efficient packing less waste will occur in packaging, creating smaller parcels. Creating at the end just a small growth in volume and weight. Where the average parcels are 2.5 kg in weight and 21,489 cm^3. For the new delivery model with parcel lockers some assumptions need to be made to comply to the parcel locker formats. Since garden furniture is part of the average weight and volume of the parcels, though will less likely to be delivered in lockers due to lack of space. Therefore, the goal is to take a close look at the parcel size and the number of parcels linked with a certain band with.

Another important aspect to take into consideration are the registered letters. These letters cannot be delivered in a mailbox since a signature is required from the recipient. A letter is relatively small and thus placing it in a locker would generate a lot of useless space. A consideration should be made regarding this aspect to see if these letters are large in volume and maybe necessary to deliver differently. Though now they are sorted in the normal parcel distribution process.

Drivers are in charge of determining their own route and order in which the parcels are being delivered. They need to deliver within a certain time window but for the rest they are free to go where they want to. Together with the delivery route the hand terminal plays an important role, in this terminal the driver can give all the status updates necessary. From delivered to not at home and even reimbursements approvals. Driving according to a certain route is done with the Sunday network and “Postbus” network. This due to the lack of stops and large distances between the stops, making a pre-determined route more efficient at the end.

The government has the idea to deliver emission free by 2025 in the city centres. For PostNL this is an important aspect to take into account, with the delivery towards parcel lockers this can contribute significantly (Logistieke Strategie PNP, 2016).

Appendix XIV Expert Meetings

1. Brainstorm session(s) design requirements

Interviewee: Corstiaan Smit
Interviewer: Yorick van Amstel
Date: 15th of September 2017
Location: Hoofddorp PostNL Pakketten (Phone conversation)

- Benefits parcel locker: not at home, close by, opening hours
- Downsides parcel locker, actually being at home during delivery
- Parcel lockers works the same way as “Pakjegemak” people need to have an email/phone number available to be able to receive a code to open the locker
- Maximum travel time for parcel lockers is five minutes
- Customer satisfaction is quite high but sometimes debatable
- Products with an increased liability are of concern not to put in the parcel lockers.
- Parcel lockers do have a touch screen making it possible to place signatures on the screen. At this moment, this is not done however, the adjustment isn’t’ that hard.
- Price of a parcel locker is around €10,000.00

Interviewee: Chris Scholtens
Interviewer: Yorick van Amstel
Date: 28th of September 2017
Location: Hoofddorp PostNL Pakketten

- TVI (Tijdvakindicatie) is an important focus point when it comes to delivery. Time window indication is important to communicate with customers and having 150 stops on a route means 150 possibilities to disturb this time window. With lesser stops, lesser disturbance can be created.
- Communication is key. Communication to customers about their products is incredibly important, false information is not done. Especially related to time windows. For example, if a customer receives notice that the parcel is located in locker 20 and ready to pick up at 13.00, it should be there at 13.30 in that locker. If this is not the case something goes wrong.
- Capacity of parcel lockers and delivery vans are important. These have set boundaries and cannot be adjusted, for a parcel locker the layout can be adjusted slightly.
- At this moment parcel delivery men are able to deliver 14/20 parcels every hour. New delivery models should at least be able to deliver these amounts.
- Changing the delivery model can change the loading process of the van as well
- Having a higher hit rate causes less parcels to come back to the depot for second distribution, this creates added value in the depot itself. Which will influence the sorting process again. Since the sending is the bottleneck process.
- Requirements do not only affect the distribution process but can affect other processes in the depot as well.

Interviewee: Sebastiaan van Oostrum
Interviewer: Yorick van Amstel
Date: 28th of September 2017
Location: Hoofddorp PostNL Pakketten

- If after three days a parcel has not been picked up the driver will bring the parcel to a retail location. Indicating a three-day storage maximum.
- One parcel per locker is the maximum capacity.
- When system is offline, parcels are still available for pick up.
- Drivers are still important factors, they are feeding the lockers with parcels and most of the issues can be related to drivers.
- Future adjustments make it possible for the driver to select the locker himself, normally the system automatically assigns a locker.
- Subcontractors were quite hesitant at first, since they are being paid per stop and per parcel. Having parcel lockers reduces the number of stops significantly and thus reducing the income of the subcontractors.
- Due to the “Postal Law” in The Netherlands placing a mail box on the street is free of charge, meaning that if a parcel locker has a mail box it can be placed on the street for free.
- Taking scanning into account a delivery man can fill one locker within ten seconds

Interviewee: Delivery Driver
Interviewer: Yorick van Amstel
Date: 4th of October 2017
Location: Delft

- Volumes in the van keep on increasing more and more without any consultation of drivers
- Subcontractors get paid per stop and per parcel, however the fee per stop is the full fee and the fee per parcel is just marginal
- Physical problems become more and more an issue, however if you don’t want to do the work somebody else will do the work just as easily
- Average allowed weight per parcel has increased from 15kg to 30kg since several years ago
- Sorting of the parcels is really important and knowing the neighbourhood as well
- The social aspect of the work is still valued highly by delivery drivers, having contact with the customers is one of the best things of the job.

Appendix XV Lean design improving

This appendix will take a closer look to the designs and how they can perform or should perform according to the lean principle. First taking a look again to what lean exactly is. The goal with lean is to reduce or eliminate wastes as much as possible and increasing the speed and flow. In the case of the new delivery model, the reduction of waste can relate to the increase of the first time hit rate, meaning less need to take parcels back to the depot again and do a new distribution. Less stops can be a solution to increase a better flow, and more parcels per stop is creating better value as well. In Table 56 below the current parcel delivery process is displayed together with possible wastes and the type of wastes.

Table 56 Current delivery model lean evaluated

Process Step	Activity	Person performing activity	NVA/NNVA/VA	Type of waste
1. Sorting	Taking parcels from chute to delivery van	Delivery driver	NNVA	Motion
	Sorting parcels on neighbourhood	Delivery driver	VA	
	Waiting for the shift to end	Delivery driver	NVA	Waiting
2. Driving	Driving out of the dock and depot area	Delivery driver	NNVA	Transport
	Driving towards the area of delivery	Delivery driver	NNVA	Transport
3. Delivering	Unloading parcel from delivery van	Delivery driver	NNVA	Motion
	Carrying parcel to delivery location	Delivery driver	NNVA	Motion
	Checking recipients' presence	Delivery driver	VA	
	Scanning parcel(s)	Delivery driver	VA	
	Signing with signature	Consumer or Retail employee	NNVA	Waiting
	Scanning not home notification	Delivery driver	VA	
	Posting notification	Delivery driver	VA	
	Walking back to delivery van (with parcel)	Delivery driver	NVA	Motion
	Driving to next stop	Delivery driver	NNVA	Motion
4. Driving	Driving back to the depot	Delivery driver	NNVA	Transport
	Driving to docking area	Delivery driver	NNVA	Transport
5. Debrief	Unloading parcels	Delivery driver	NNVA	Motion
	Scanning parcels	Intake employee	VA	
	Handling planning desk tasks	Delivery driver & Planning desk employee	NNVA	Over-Processing

As can be seen in Table 56 the most important wastes that can be identified are transport, motion, waiting and over-processing. The first two transport and motion are quite common in transport related processes, the same as waiting. Over-processing is less common with transport related processes. Though it is still important to take notice with the new design alternatives that transport and motion need to be reduced as much as possible, since efficiency can be won in these aspects. The value-added aspects are important as well, maybe even more important. Since these are crucial aspects that are absolutely necessary and create value, not only monetary but in flow optimization as well. Taking a closer look to the three new alternatives for every alternative some important factors can be noted to take into account with the detailed design and the evaluation. What aspects value can be won and what aspects value can be lost.

Alternative 1: Substitution of retail location with parcel lockers

With this alternative, the most important thing is that the retail location will be replaced by parcel lockers. The goal is to have an as low as possible amount of parcel lockers, creating no excess motion in transport. Having no retail locations saves time waiting for the retail employee to scan the parcels, this adds value in the end. Important with this design as well is the choice to deliver all the undelivered parcels at the end of the route as normal with the retail locations or in between delivery. Efficiency is key in this aspect, having a lot of parcel lockers creates more transport obviously, delivering parcels during the route to these lockers eliminates extra kilometres at the end of the route. Though when collecting parcels, it can be more efficient to do this at the end of the route due to van capacity. These aspects can be evaluated better after using simulation and a MCA, looking whether certain variants of an alternative perform better than others.

Alternative 2: Parcel lockers as substitution for current parcel delivery model

With this alternative, the current delivery model will be replaced with parcel lockers as much as possible. If the parcels do not fit in a parcel locker the parcel will be delivered according to the standard delivery model. This creates an extra step in the delivery process. Meaning both of the steps need to be as efficient as possible and limited to a minimum number of wastes. More important the duration of the wastes to be precise. A lot of wastes can be saved by increasing the first time hit rate and thus less need to take parcels back to the depot. Having parcel lockers instead of house addresses saves wastes as well regarding transport, less need to make a lot of stop and go motions. Important to take into consideration are to limit or reduce all the NNVA where possible. Regarding transport to and from the depot this will be hard, since this is a standard route which will not change. Though having a higher hit rate will reduce the unloading of parcels at the depot, this will be highly beneficial. Looking at the retail location there will be less parcels brought to the retail location and thus less waiting for a retail employee to scan all the parcels, this will save time as well. Depending on the different variants this can and will save a lot of time. With a parcel locker close to the streets, the number of meters a driver needs to walk will be less. Since all the parcels can be dropped in one location, therefore time will be saved here as well. Unloading the parcel lockers for collection parcels at the same parcel locker stop will save a lot of time at the end with driving the same route again to collect parcels, this means work can be conducted more efficiently.

Alternative 3: Distribution only delivery model

With this alternative only distribution will take place. There will be no collection, the collection will take place with the collection routes as they are present right now. This can create a highly efficient route with delivering parcels. Transport wastes can be limited to a certain number and due to the fact that all parcels will be dropped off. The delivery van will drive back empty to the depot, therefore there is no need to unload parcels anymore and the planning desks tasks can be reduced to a minimum as well. This creates a lot of reduction in wastes in the process. The goal is with the different variants to try and keep wastes as low as possible. Limiting the number of parcels to a retail location for example since this will cost a lot of time.

Appendix XVI Design Alternatives

The designs that are generated can be distinguished in three categories based on where parcels are being delivered. Below in Table 57 this is displayed in more detail. The first category is home delivery, the second category is the delivery to retail locations and the third category is the delivery to lockers. Each of the three categories has a separation between distribution and collection of parcels. In total, there is one base alternative and three new alternatives. Table 57 displays the categories on which the alternatives can be distinguished, with a Yes or No will be indicated what the alternatives do regarding to the type of delivery location and if there is distribution or collection. The separation between distribution and collection will not change within the alternatives. What can change is the number of parcels that fit in a locker or the number of drivers that will be used for example.

Table 57 Design alternatives future delivery model

Alternative		Home	Retail	Parcel Locker
Alternative 0: Current parcel delivery	Distribution	Yes	Yes	No
	Collection	No	Yes	No
Alternative 1: Substitution of retail location with parcel lockers	Distribution	Yes	No	Yes
	Collection	No	No	Yes
Alternative 2: Parcel lockers as substitution for current parcel delivery model	Distribution	Yes	Yes	Yes
	Collection	No	Yes	Yes
Alternative 3: Distribution only delivery model	Distribution	Yes	Yes	Yes
	Collection	No	No	No

Alternative 0: Current parcel delivery

To design the future delivery models first the current delivery in De Pijp will be discussed briefly. De Pijp is being delivered with eight routes every day. The delivery vans will be loaded at the depot by the driver at the start of each shift. After loading the delivery van, the driver will drive towards the delivery area and will deliver the parcels. In this alternative, all the parcels will be delivered at home addresses, if people are not home neighbour delivery will be attempted. If this is not possible the parcels will be brought back to the depot or will be brought to a retail location. All the parcels that will be brought at the retail location, have failed delivery attempts or have been selected to be delivered by a customer. At the retail location, the delivery driver will pick up the collection parcels, these are C2C and C2B parcels. After dropping off and picking up the parcels the delivery driver will drive back to the depot. At the depot, the delivery driver will drop off the parcels in the van and will do a debrief. After the debrief the delivery driver is done for the day and the delivery process as well.

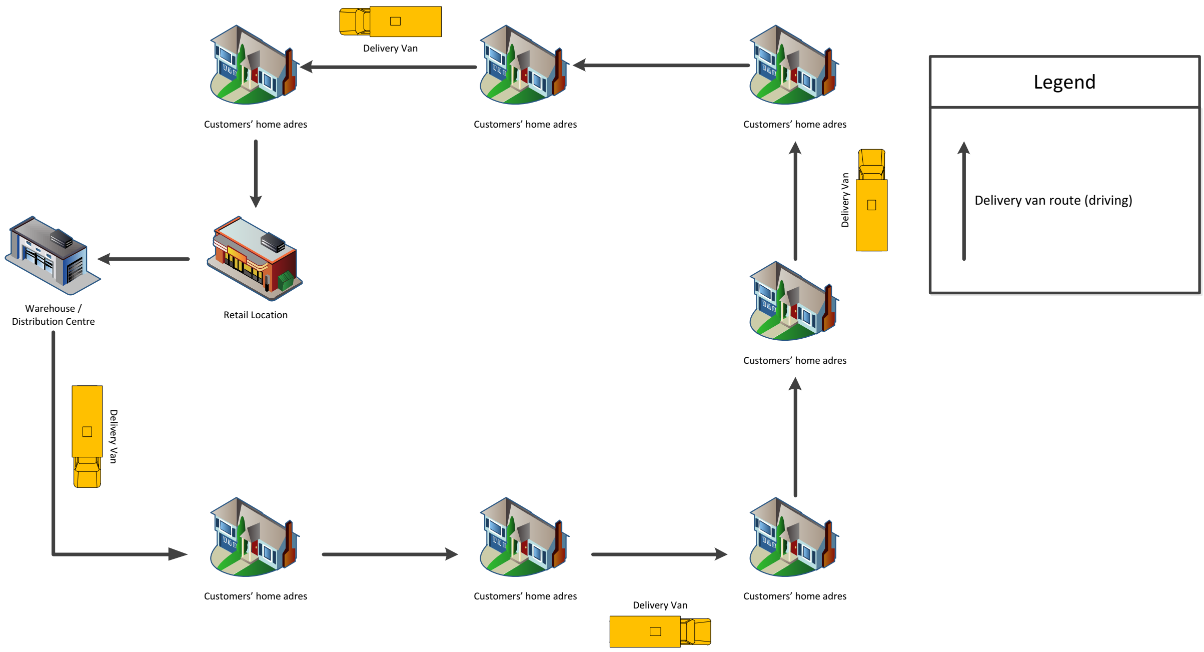


Figure 36 Alternative 0: Current parcel delivery

Alternative 1: Substitution of retail location with parcel lockers

This alternative will substitute the retail location with parcel lockers. The goal is to deliver all failed delivery attempts to house addresses in parcel lockers, the same day of attempting the delivery. With collection of parcels at the retail location, this will be replaced with collection at parcel lockers. The delivery process as explained in alternative 0 will remain largely the same. The aspect that differs is the fact that instead of delivering to a retail location the parcel lockers will be used. If a delivery fails at a home address the parcel will be delivered the same day to a parcel locker at the end of the delivery route. Together with delivering the parcels to the parcel locker the parcels destined for C2C and C2B will be collected from the lockers as well. After this the delivery driver will drive back to the depot and do the same debrief process as alternative 0.

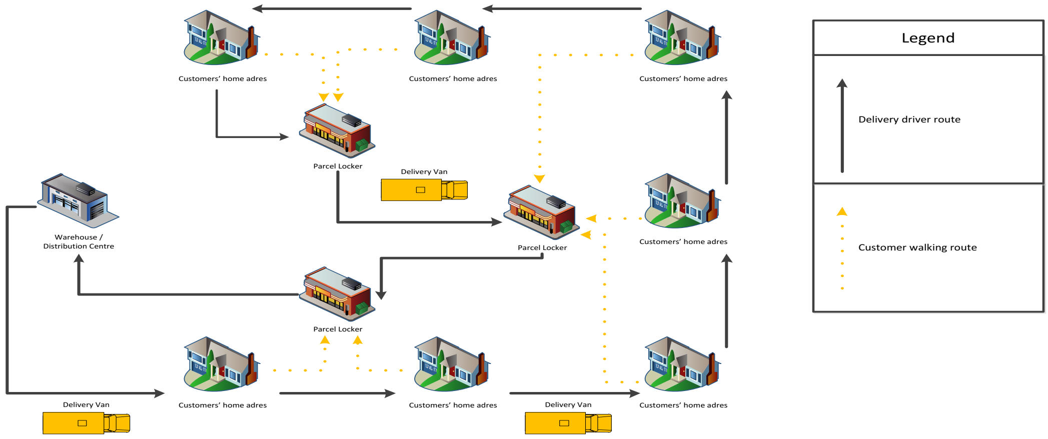


Figure 37 Alternative 1: Substitution of retail location with parcel lockers

Alternative 2: Parcel lockers as substitution for current parcel delivery model

This alternative will use the parcel lockers as first option for delivery. Instead of delivering all the parcels immediately to house addresses this alternative will use the parcel lockers as first option. The parcels that will not fit in the parcel locker will be sorted out in the depot by the driver and will be delivered with a standard delivery route. The parcel locker delivery model will have the same characteristics as the current parcel delivery model. However instead of delivering to home addresses, the delivery will take place to parcel lockers. The delivery drivers will collect parcels from the lockers as well when there are collections available. After delivering to all the parcel lockers the driver will drive straight back to the depot and will do the same debrief as alternative 0. The delivery route that will take the parcels that do not fit in the lockers will go to house addresses to deliver and will go to the retail location as well to pick up parcels and deliver parcels. After this the driver will drive back to the depot and will do the same debrief process as alternative 0.

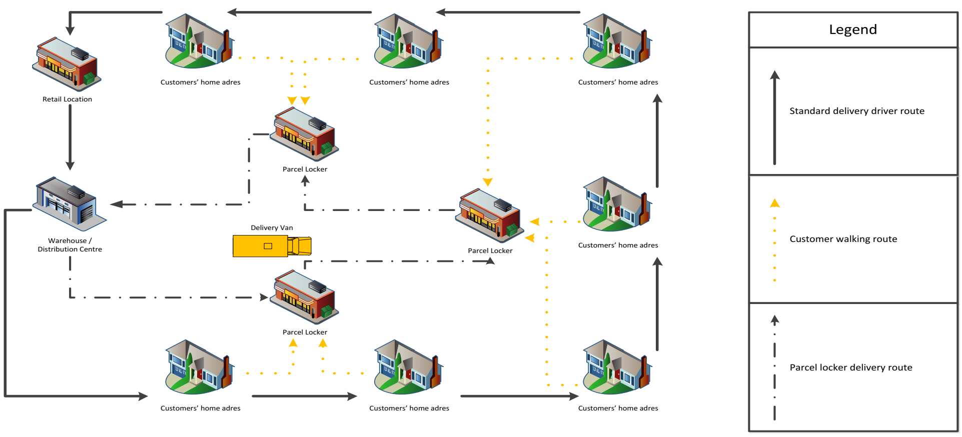


Figure 38 Alternative 2: Parcel lockers as substitution for current parcel delivery model

Alternative 3: Distribution only delivery model

This alternative will only distribute the parcels and will not collect any parcels, not at retail locations, not a parcel lockers and not at home addresses. The delivery of the parcels will be conducted on the same manner as in alternative 2. The parcels will be delivered to parcel lockers at first and the parcel that don't fit will be sorted out at the depot and delivered via the standard route as indicated in alternative 0. If people are not home during delivery or a parcel lockers is full the parcels will be delivered to a retail location. Only when there is no other option. When the delivery of the parcels is over the driver will go back to the depot and do a debrief, since there is no collection this will be short.

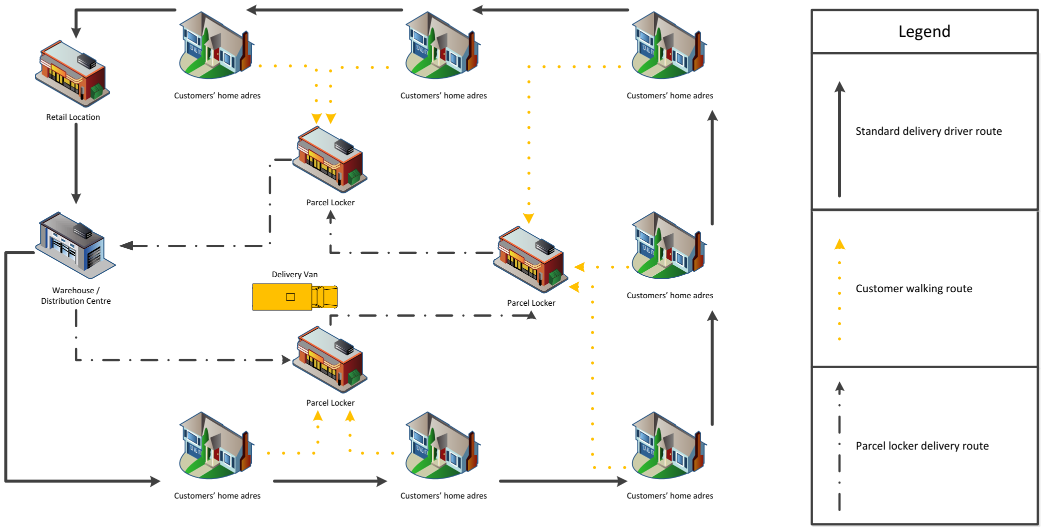


Figure 39 Alternative 3: Distribution only delivery model

Looking at the lean process of the design of these alternatives, three important wastes come forward that need to be limited as much as possible. Transport, motion and waiting are the three wastes that occur the most. Transport can be reduced by driving efficiently and not driving the same route twice, for example first distribution and then collection. It's better to do this simultaneously for example. Having less parcels to bring back to the depot will reduce wastes a lot. The goal with the designs is to create variants or combinations in such a way that the parcels that will be brought back will be limited to a low number. Extensive details about the lean process can be found in Appendix XV Lean design improving.

The alternatives that have been designed are base scenario's. Meaning that with all the new alternatives different variables can and will be adjusted. The variation can be regarding the number of drivers to operate the route, regarding the number of parcels that fit in a locker, the yearly growth of the parcel market and others. The next paragraph will elaborate on the different variants within the three designs and their numbers.

Before variations within designs can be made some things need to be fixed, especially some variables need to be fixed. Since if some variables aren't fixed an almost unlimited number of combinations can be made. The variables that will be fixed will be displayed down below in the bullets.

- The daily number of delivered parcels amounts 1770, this is a total amount for all three postal codes and all routes. This is a maximum taken in the period of the 26th of June until the 1st of July of 2017. Not chosen for an average due to the reason this is one of the weeks that has most deliveries in the year (excluding the 12-month) and therefore is good for the busiest day method.
- The percentage of insured goods of 0.5% and the reimbursement goods of 1.0% are fixed. These are assumed to be delivered to home addresses and retail locations at all times and not placed in parcel lockers. Since the percentages are so small the assumption will be made that these goods are part of the non-parcel locker delivery.
- The average capacity of a delivery van will be based on the average parcel volume of $0.0203m^3$ and the maximum capacity of a delivery van of $6m^3$. For safety margins $5.5m^3$ will be taken into account. This means a capacity of 270 parcels per delivery van. However, when creating

variants with selected parcel dimensions this can vary. Though the $5.5m^3$ will still be a fixed volume.

- The assumption will be made that the parcel lockers can be placed on street location free of charge due to the fact they have a mailbox. With this mail box and the “Postwet” mailboxes can be placed freely on street locations.
- An average working day amounts 8.5 hours
- Sorting time will be a maximum of 1 hour
- Driving to and from the delivery location will not differ from the standard model being called the response time of 22,4 minutes and 22,3 kilometres
- Outer dimension of the parcel locker will not change, the size of the lockers can vary though.
- Collection of parcels from the parcel locker is 1/3 of the parcel locker capacity, meaning 2/3 is available for distribution.
- Average percentage of parcels that can be delivered in a locker successfully is assumed to be 100% (since the 1770 is a maximum)
- Price for one parcel locker is set to €10,000. –
- Assumption that a percentage of lower than 5% no fit will be part of home delivery.
- Max capacity per day of retail location is 20 parcels, De Pijp has 6 retail locations

For every alternative three variations will be made. These variations are based on the percentage of fit of the parcels in the parcel lockers. The first fit is the standard percentage of the current parcel locker, this fit is 88% and is based on the various dimensions of the lockers available. Differing in Medium, Large and Extra-Large, since the number of large parcels is relatively small in comparison with the smaller parcels no distinctions will be made based on the amount of parcel lockers. This will be based on the total number of lockers, which is 16 in the current situation. The second fit is 66%, this fit is based on reducing the size of the lockers within the parcel locker but maintaining the overall dimensions. The size of this locker is a S sized locker and one parcel locker will fit 38 lockers. The third fit is 50%, this fit is based on taking the same width and depth of the medium locker but reducing the height in half. Creating a total of 50 lockers in one parcel lockers. These three variants on the alternatives will create in total 9 different variants.

These 9 variants will be varied on two different aspects. This will be the growth percentage and the number of drivers.

Alternative 1: Substitution of retail location with parcel locker

Variant 1A 88% parcel locker fit (M, L, XL lockers)

Taking into consideration a FTHR of 84% for all parcels that are being delivered, this includes neighbour delivery for the first time as well. A 12% share of the parcels that is delivered at a retail location. A small number of parcels, 4% to be exact, couldn’t be delivered straight away. And therefore, need to be sent back to the depot and put through the distribution process all over again. The goal with variant 1A is to have this 16% that couldn’t be delivered the first time at a home address diverted to a parcel locker, saving costs on the retail location and creating a potential 100% FTHR. This to be done the same day of delivery after delivering at home addresses. This 84% of the parcels will be delivered according to the current situation. The remaining 16% will be delivered with the same number of drivers, since these parcels are left over in the delivery van and thus need to be delivered with the same delivery driver. Important to keep in mind is the size of the parcels, since 12% of the parcels will not fit in a parcel locker these parcels still need to be delivered. This 12% is part of the 16% that cannot be delivered. This amount to be 2% of the total number of delivered parcels. Since this percentage is so small the assumption will be made that this 2% can be delivered to home addresses, thus part of the 84%. Taking these numbers into account and the number of 1770 parcels delivered on a Wednesday in De Pijp it can be determined how much lockers are required for the first year, which is displayed in Table 58 below. The collection of parcels is done with the same drivers, they will collect the parcels that are placed in the parcel lockers. This will be done at the end of the delivery route, therefore having the same characteristics as the normal retail location pick up at the end of the shift.

Table 58 Alternative 1 M, L, XL lockers (88% of parcels fit in locker)

Variable	Number
Parcels delivered at home	1487
Parcels delivered in locker	283
Number of lockers required (excl. collection)	18
Number of lockers required (incl. collection)	26
Number of drivers required	7

Delivery in the parcel lockers will be done on the same manner as current delivery in parcel lockers. The parcel will be scanned with the hand terminal, will be marked as delivered if there is a locker available, the parcel will be scanned at the machine and a locker opens, the parcel is placed in the locker and the door is closed. This will be done for every parcel there is for the parcel locker. The parcel lockers will be placed as much as possible around current mailbox locations and on the side of the street out of walking paths or important corridors. Since the large magnitude of parcel lockers to be placed the assumption will be made that this can be done easily in De Pijp. Since time doesn't allow to do extensive research in De Pijp itself to point out perfect locations. Since the total number of parcel lockers is so low it's possible to replace all the current mailboxes with parcel lockers with mailboxes and add some extra. Figure 40 below will show the current locations of the mailboxes. In Figure 41 the overview of the parcel lockers can be seen and in Figure 42 the parcel lockers with a 200m walking radius can be seen.

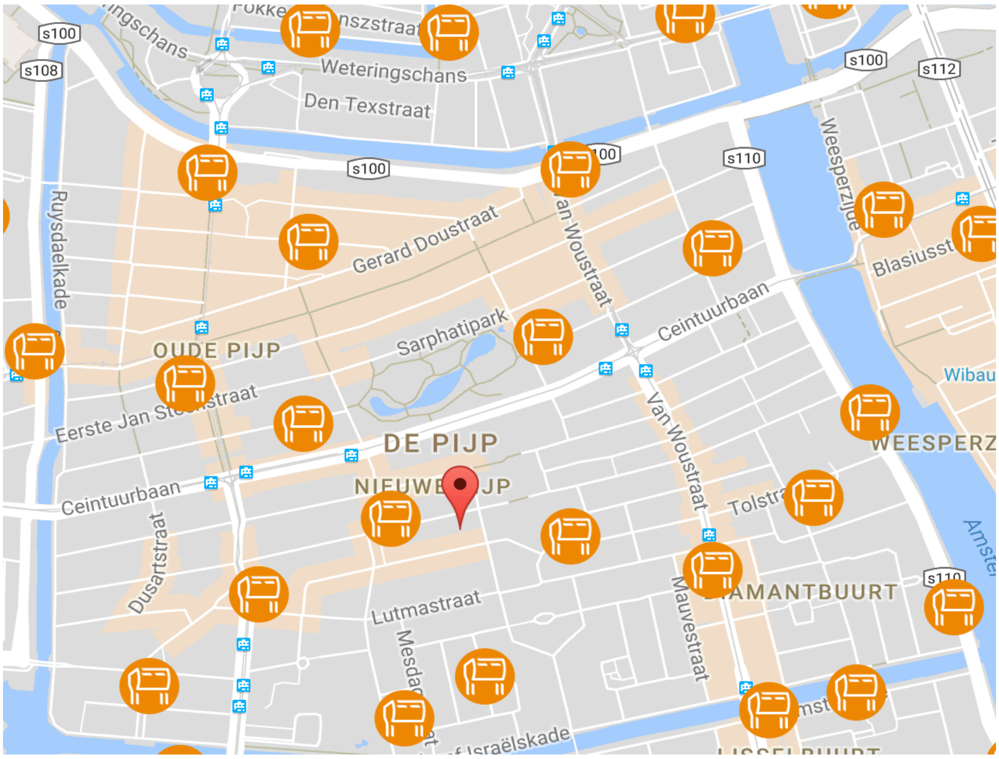


Figure 40 Current mailbox locations

As can be seen on both of the figures the locations of the parcel lockers are spread across the district. Replacing the current mailboxes. People want to travel a maximum of five to ten minutes to a parcel locker. With an average walking speed of 5 km/h this is 400 to 800 m roughly, meaning that the parcel lockers should be within this perimeter of houses. Figure 42 displays the parcel locker locations with their 200m walking distance radius. Keep in mind this is in a straight line, thus in reality this can be shorter or longer. Looking at the 200m radiuses around 96% of the people can be reached, indicating that a 5-min walking distance (400m) is possible for everybody.

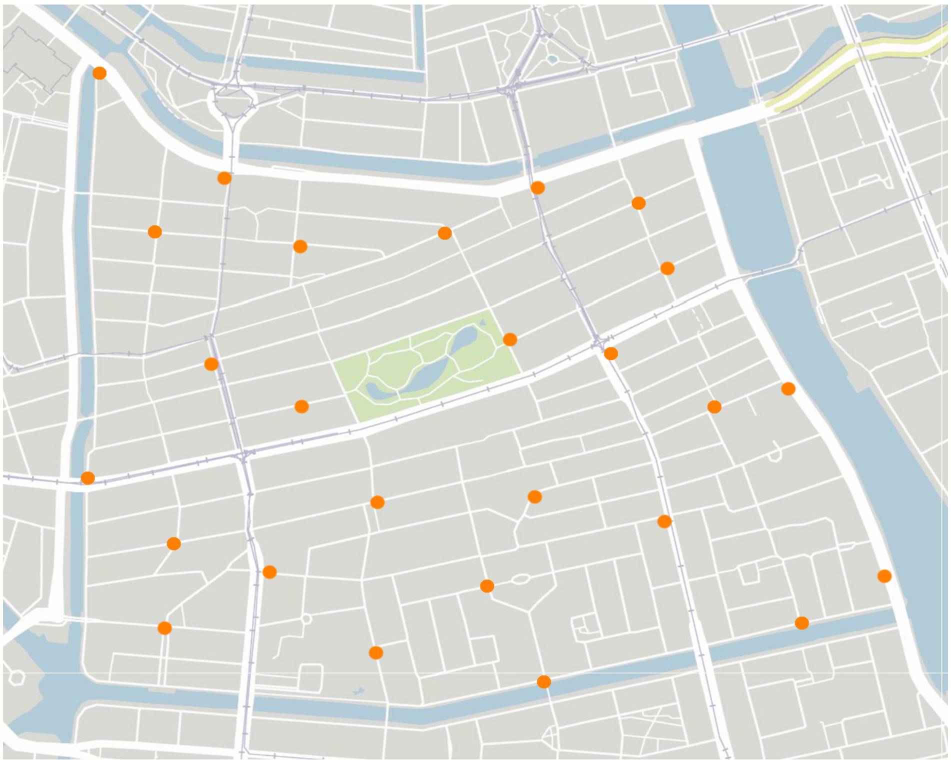


Figure 41 Alternative 1 M, L, XL lockers (88% of parcels fit in locker) locations

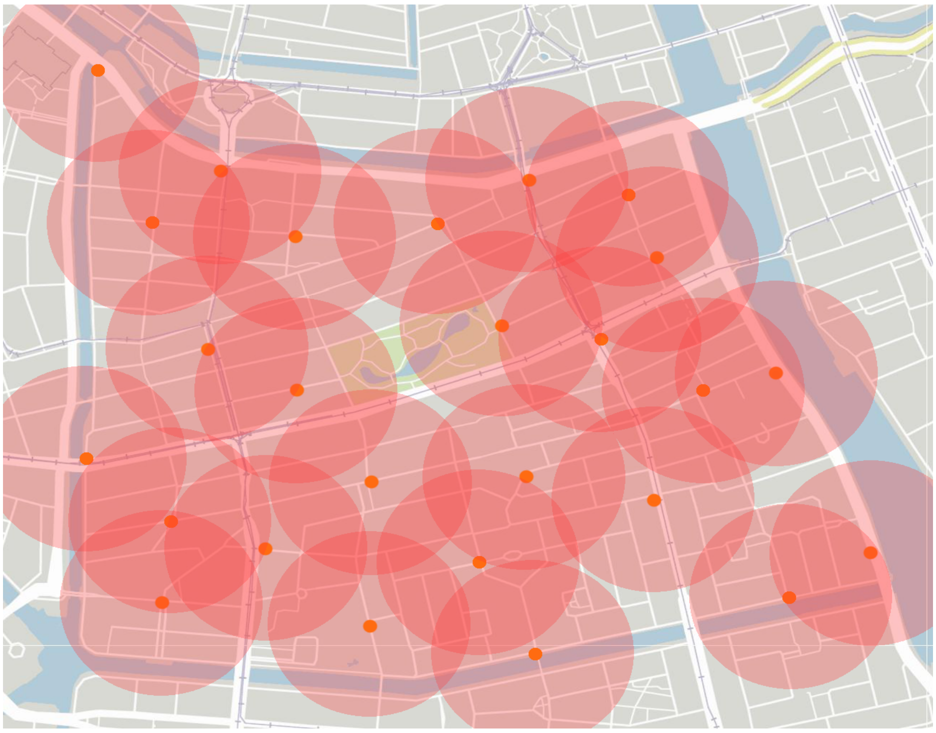


Figure 42 Alternative 1 M, L, XL lockers (88% of parcels fit in locker)200m walking radius

Alternative 1, S lockers (66% of parcels fit in locker)

This variant will use the same hit rate percentage of 84% to home addresses as variant 1A. Meaning 16% of the parcels needs to be delivered in parcel lockers. However instead of having an 88% fit this variant has a 66% fit in the parcel lockers. With this new fit of 66% more lockers can be placed in the same dimensions of the current parcel locker. Instead of having 16 lockers available now 38 lockers for every parcel locker are available. This 66% is 5.5 % of the total delivered parcels. Meaning that 5.5% of the parcels returns to the depot. In Table 59 below the overview of the delivered parcels, the need for collections and the number of drivers is displayed. The collection of parcels is done with the same drivers, they will collect the parcels that are placed in the parcel lockers. This will be done at the end of the delivery route, therefore having the same characteristics as the normal retail location pick up at the end of the shift. Since the lockers are smaller in size this also means less collection of large parcels can take place. The assumption will be made that for large parcels people will go to a postal office instead of a retail location. Which is somewhat different than a standard retail location.

Table 59 Alternative 1, S Lockers (66% of parcels fit in locker)

Variable	Number
Parcels delivered at home	1487
Parcels delivered in locker	186
Parcels back to depot	97
Number of lockers required (excl. collection)	5
Number of lockers required (incl. collection)	8
Number of drivers required	7

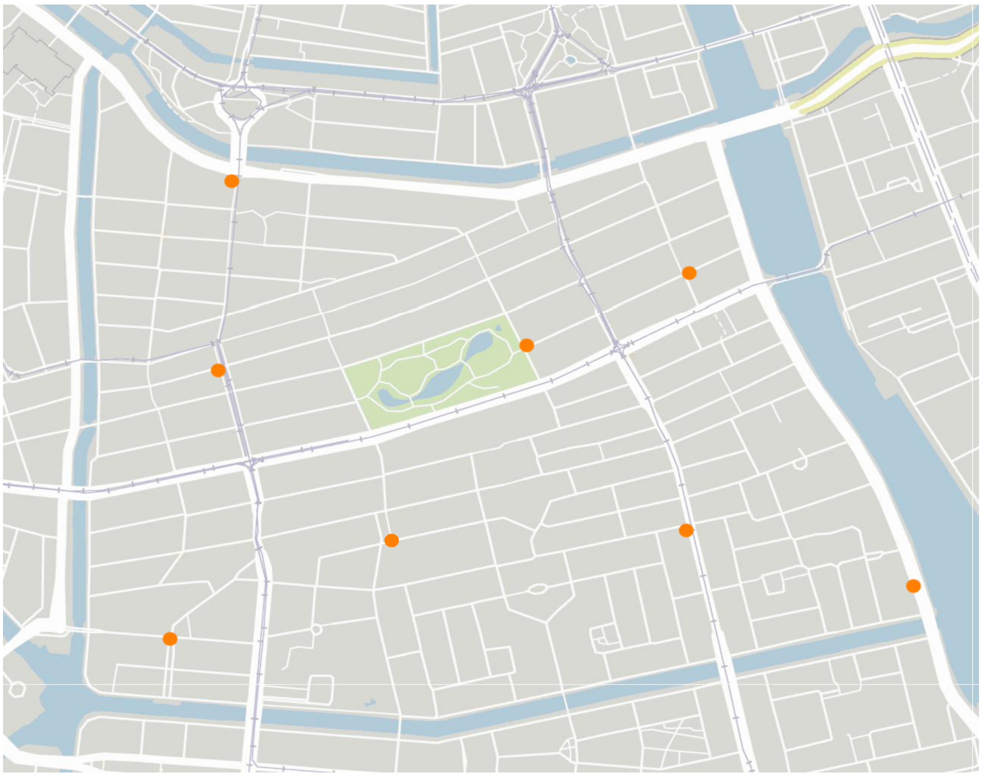


Figure 43 Alternative 1, S Lockers (66% of parcels fit in locker) locations

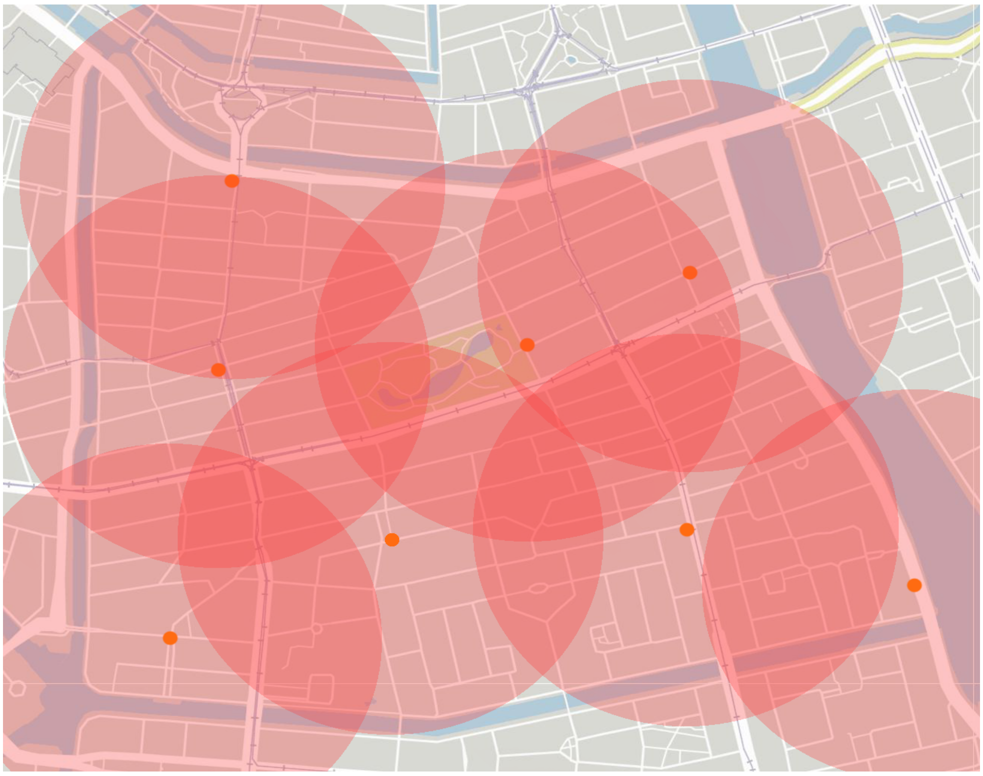


Figure 44 Alternative 1 S lockers (66% of parcels fit in locker) with 400 m walking radius

As can be seen on both of the figures the locations of the parcel lockers are spread across the district. Replacing the current mailboxes. People want to travel a maximum of five to ten minutes to a parcel locker. With an average walking speed of 5 km/h this is 400 to 800 m roughly, meaning that the parcel lockers should be within this perimeter of houses. Figure 44 displays the parcel locker locations with their 400m walking distance radius. Keep in mind this is in a straight line, thus in reality this can be shorter or longer. Looking at the 400m radiuses around 98% of the people can be reached, indicating that a 5-min walking distance (400m) is possible for everybody.

Alternative 1, XS Lockers (50% of parcels fit in locker)

This variant will use the same hit rate percentage of 84% to home addresses as variant 1A. Meaning 16% of the parcels needs to be delivered in parcel lockers. However instead of having an 88% fit this variant has a 50% fit in the parcel lockers. With this new fit of 50% more lockers can be placed in the same dimensions of the current parcel locker. Instead of having 16 lockers available now 50 lockers for every parcel locker are available. This 66% is 8 % of the total delivered parcels. Meaning that 8% of the parcels returns to the depot. In Table 60 below the overview of the delivered parcels, the need for collections and the number of drivers is displayed. The collection of parcels is done with the same drivers, they will collect the parcels that are placed in the parcel lockers. This will be done at the end of the delivery route, therefore having the same characteristics as the normal retail location pick up at the end of the shift. Since the lockers are smaller in size this also means less collection of large parcels can take place. The assumption will be made that for large parcels people will go to a postal office instead of a retail location. Which is somewhat different than a standard retail location.

Table 60 Alternative 2, XS lockers (50% of parcels fit in locker)

Variable	Number
Parcels delivered at home	1487
Parcels delivered in locker	141
Parcels back to depot	142
Number of lockers required (excl. collection)	3
Number of lockers required (incl. collection)	5
Number of drivers required	7

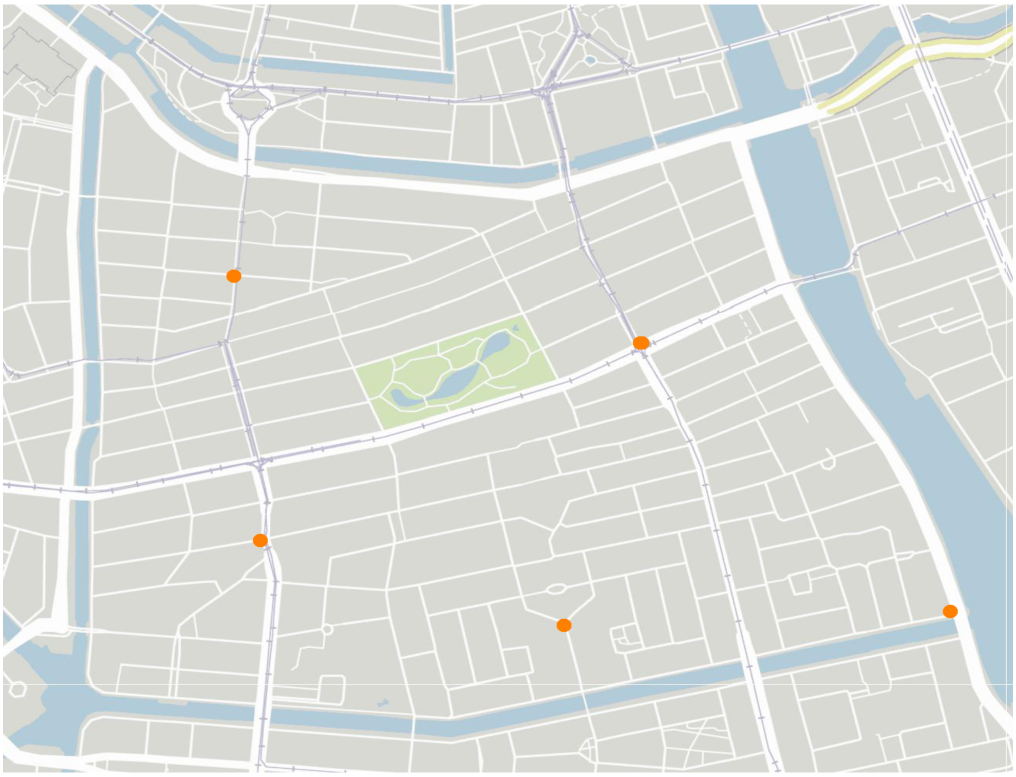


Figure 45 Alternative 1, XS lockers (50% of parcels fit in locker) locations

As can be seen on both of the figures the locations of the parcel lockers are spread across the district. Replacing the current mailboxes. People want to travel a maximum of five to ten minutes to a parcel locker. With an average walking speed of 5 km/h this is 400 to 800 m roughly, meaning that the parcel lockers should be within this perimeter of houses. Figure 46 displays the parcel locker locations with their 400m walking distance radius.

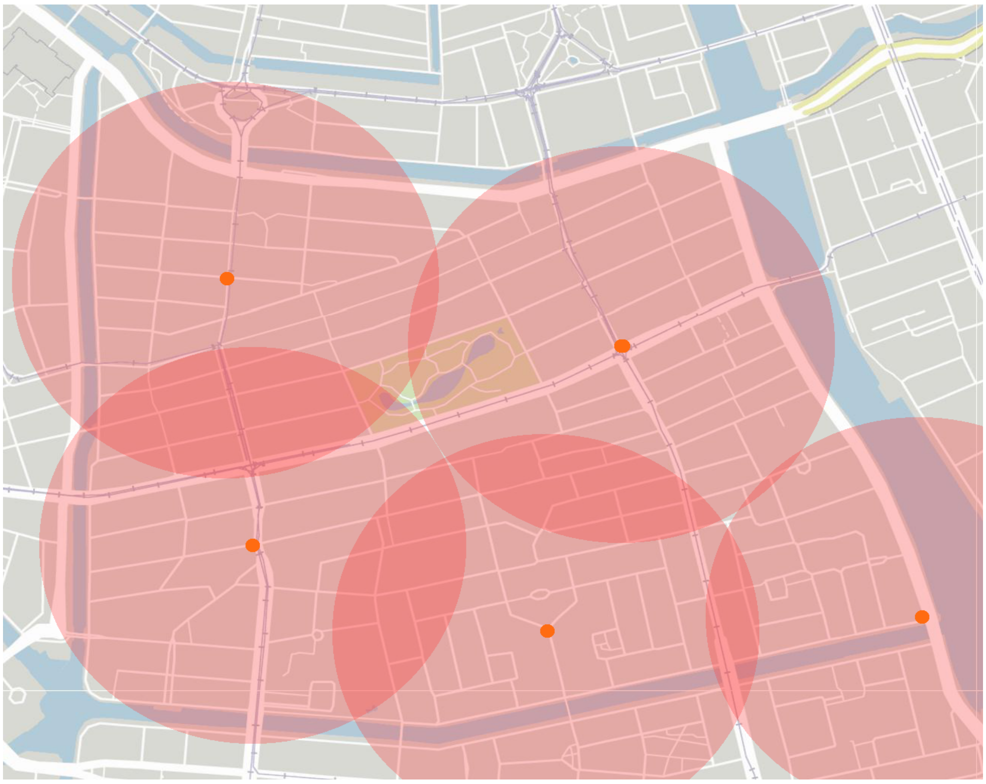


Figure 46 Alternative 1, XS parcel locker locations with 400m walking radius

Keep in mind this is in a straight line, thus in reality this can be shorter or longer. Looking at the 400m radiuses around 98% of the people can be reached, indicating that a 5-min walking distance (400m) is possible for everybody.

Alternative 2 M, L, XL lockers (88% of parcels fit in locker)

This alternative will deliver all the parcels that normally will be delivered to home addresses to parcel lockers. This includes as well the parcels delivered to the retail locations. The parcel lockers will be delivered with a different route than the standard delivery. The parcel locker route will only deliver at parcel lockers and the other route will deliver at house addresses and retail locations.
Taking into consideration a FTHR of 84% for all parcels that are being delivered, this includes neighbour delivery for the first time as well. A 12% share of the parcels that is delivered at a retail location. A small number of parcels, 4% to be exact, couldn't be delivered straight away. And therefore, need to be sent back to the depot and put through the distribution process all over again. The goal with variant 2A is to try to deliver 100% in a parcel locker, the parcels that do not fit will be delivered at home and at a retail location. This means that of the 12% that doesn't fit in a parcel locker, 84% will be delivered at home and 16% to a retail location. This will save costs on the retail location and creates a potential 100% FTHR. This to be done the same day of delivery after delivering at home addresses. This 12% of the parcels will be delivered according to the current situation. The 88% will be delivered with the parcel locker route and thus only parcel lockers will be filled. Looking at the total percentage 10% of the parcels will be delivered to home addresses and 2% will be delivered to a retail location. Taking these numbers into account and the number of 1770 parcels delivered on a Wednesday in De Pijp it can be determined how much lockers are required for the first year, which is displayed in Table 61 below.

Table 61 Alternative 2 M, L, XL lockers (88% of parcels fit in locker)

Variable	Number
Parcels delivered at home	177
Parcels delivered in locker	1558
Parcels delivered to retail location	35
Number of lockers required (excl. collection)	98
Number of lockers required (incl. collection)	142
Number of locker drivers required	6
Number of normal drivers required	1

Delivery in the parcel lockers will be done on the same manner as current delivery in parcel lockers. The parcel will be scanned with the hand terminal, will be marked as delivered if there is a locker available, the parcel will be scanned at the machine and a locker opens, the parcel is placed in the locker and the door is closed. This will be done for every parcel there is for the parcel locker. Since the large magnitude of parcel lockers to be placed the assumption will be made that this can be done easily in De Pijp. Since time doesn't allow to do extensive research in De Pijp itself to point out perfect locations. In Figure 47 the overview of the parcel lockers can be seen.

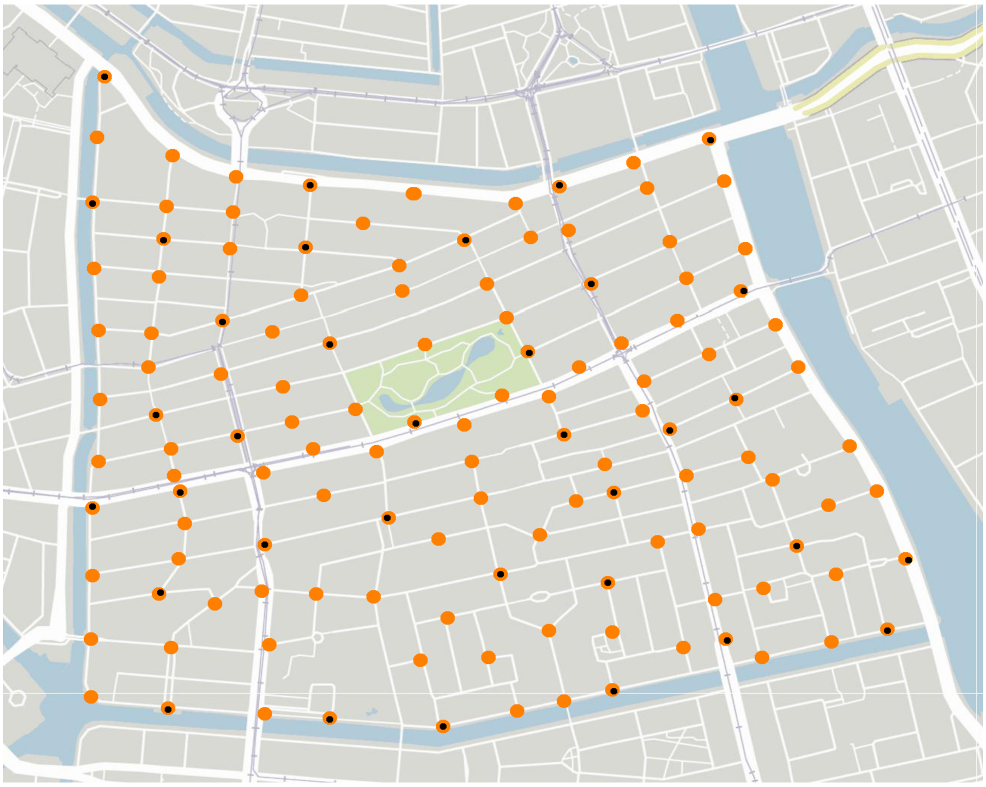


Figure 47 Alternative 3 M, L, XL lockers (88% of parcels fit in locker) locations

As can be seen in Figure 47 the locations of the parcel lockers are large in number and thus closely placed to each other. The orange dots are single parcel lockers of 16 lockers and the orange with black dots are double sided parcel lockers creating a total of 32 parcel lockers. Since parcel lockers are so closely placed to each other walking distance won't be of any problem for anyone.

Alternative 2, S Lockers (66% of parcel fit in locker)

This alternative will deliver all the parcels that normally will be delivered to home addresses to parcel lockers. This includes as well the parcels delivered to the retail locations. The parcel lockers will be delivered with a different route than the standard delivery. The parcel locker route will only deliver at parcel lockers and the other route will deliver at house addresses and retail locations.
Taking into consideration a FTHR of 84% for all parcels that are being delivered, this includes neighbour delivery for the first time as well. A 12% share of the parcels that is delivered at a retail location. A small number of parcels, 4% to be exact, couldn't be delivered straight away. And therefore, need to be sent back to the depot and put through the distribution process all over again. The goal with variant 2B is to try to deliver 100% in a parcel locker, the parcels that do not fit will be delivered at home and at a retail location. This means that of the 34% that doesn't fit in a parcel locker, 84% will be delivered at home and 16% to a retail location. This will save costs on the retail location and creates a potential 100% FTHR. This to be done the same day of delivery after delivering at home addresses. This 34% of the parcels will be delivered according to the current situation. The 88% will be delivered with the parcel locker route and thus only parcel lockers will be filled. Looking at the total percentage 29% of the parcels will be delivered to home addresses and 5% will be delivered to a retail location. Taking these numbers into account and the number of 1770 parcels delivered on a Wednesday in De Pijp it can be determined how much lockers are required for the first year, which is displayed in Table 62 below. With this new fit of 66% more lockers can be placed in the same dimensions of the current parcel locker. Instead of having 16 lockers available now 38 lockers for every parcel locker are available

Table 62 Alternative 2, S Lockers (66% of parcels fit in locker)

Variable	Number
Parcels delivered at home	513
Parcels delivered in locker	1169
Parcels delivered to retail location	88
Number of lockers required (excl. collection)	31
Number of lockers required (incl. collection)	47
Number of locker drivers required	5
Number of normal drivers required	3

Delivery in the parcel lockers will be done on the same manner as current delivery in parcel lockers. The parcel will be scanned with the hand terminal, will be marked as delivered if there is a locker available, the parcel will be scanned at the machine and a locker opens, the parcel is placed in the locker and the door is closed. This will be done for every parcel there is for the parcel locker. Since the large magnitude of parcel lockers to be placed the assumption will be made that this can be done easily in De Pijp. Since time doesn't allow to do extensive research in De Pijp itself to point out perfect locations. In Figure 48 the overview of the parcel lockers can be seen.

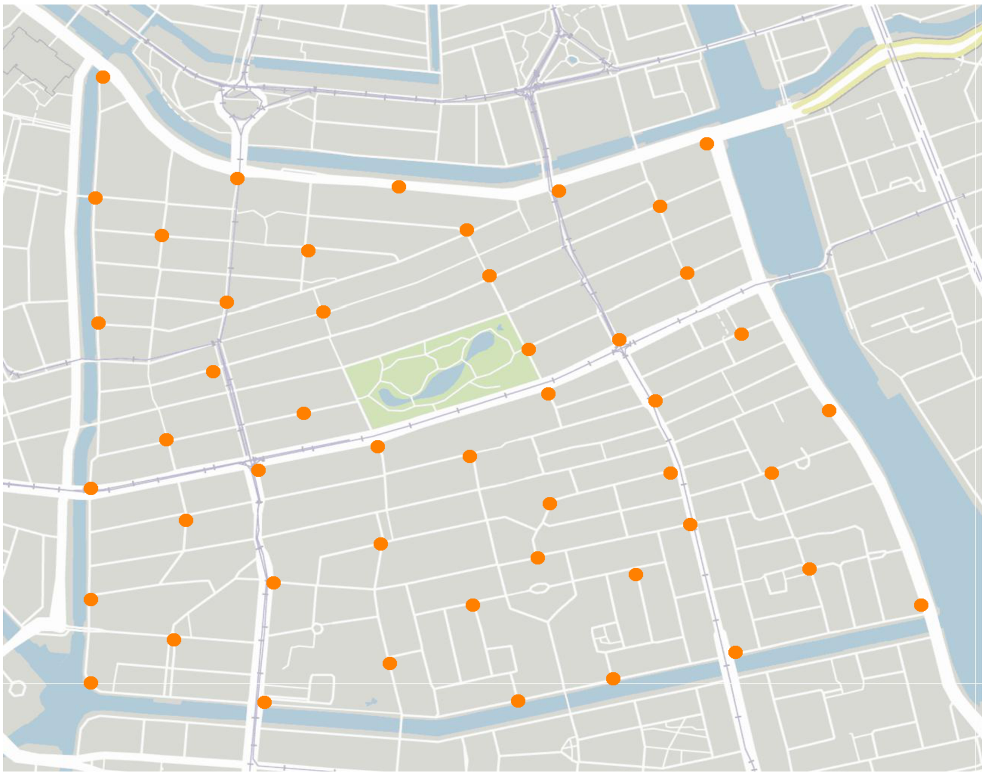


Figure 48 Alternative 2, S Lockers (66% of parcels fit in locker) locations

As can be seen in Figure 48 the locations of the parcel lockers are large in number and thus closely placed to each other. Since parcel lockers are so closely placed to each other walking distance won't be of any problem for anyone.

Alternative 2, XS Lockers (50% of parcels fit in locker)

This variant will use the same hit rate percentage of 84% to home addresses as variant 2A. Though the goal of 100% parcel locker delivery is still the same. Since this variant has a 50% parcel locker fit this means 50% of the parcels needs to be delivered regularly. Taking into account the 84% of FTHR and the 16% remaining delivery this will create new percentage for the total delivery. Of all the parcels 42% will be delivered at home and 8% to a retail location. Since the assumption has been made that the maximum capacity of a retail location 120 parcels is this will create a return flow unfortunately. With this new fit of 50% more lockers can be placed in the same dimensions of the current parcel locker. Instead of having 16 lockers available now 50 lockers for every parcel locker are available. Since the number of parcels delivered to retail locations amounts to be. In Table 63 below the overview of the delivered parcels, the need for collections and the number of drivers is displayed.

Table 63 Alternative 2, XS lockers (50% of parcels fit in locker

Variable	Number
Parcels delivered at home	744
Parcels delivered in locker	885
Parcels delivered to retail location	120
Parcels return to depot	21
Number of lockers required (excl. collection)	18
Number of lockers required (incl. collection)	27
Number of locker drivers required	4
Number of normal drivers required	4

As can be seen in Figure 49 the locations of the parcel lockers are large in number and thus closely placed to each other. Since parcel lockers are so closely placed to each other walking distance won't be of any problem for anyone.

Figure 49 Alternative 2, XS lockers (50% of parcels fit in locker) locations

Alternative 3: Distribution only delivery model

Alternative 3 M, L, XL lockers (88% of parcels fit in locker)

This alternative will deliver all the parcels that normally will be delivered to home addresses to parcel lockers. This includes as well the parcels delivered to the retail locations. The parcel lockers will be delivered with a different route than the standard delivery. The parcel locker route will only deliver at parcel lockers and the other route will deliver at house addresses and retail locations.
Taking into consideration a FTHR of 84% for all parcels that are being delivered, this includes neighbour delivery for the first time as well. A 12% share of the parcels that is delivered at a retail location. A small number of parcels, 4% to be exact, couldn't be delivered straight away. And therefore, need to be sent back to the depot and put through the distribution process all over again. The goal with variant 3A is to try to deliver 100% in a parcel locker, the parcels that do not fit will be delivered at home and at a retail location. This means that of the 12% that doesn't fit in a parcel locker, 84% will be delivered at home and 16% to a retail location. This will save costs on the retail location and creates a potential 100% FTHR. This to be done the same day of delivery after delivering at home addresses. This 12% of the parcels will be delivered according to the current situation. The 88% will be delivered with the parcel locker route and thus only parcel lockers will be filled. Looking at the total percentage 10% of the parcels will be delivered to home addresses and 2% will be delivered to a retail location. Taking these numbers into account and the number of 1770 parcels delivered on a Wednesday in De Pijp it can be determined how much lockers are required for the first year, which is displayed in Table 64 below. Since this is only distribution the collection routes will be done by the collection routes that are currently taking place at the end of the day and are clearing the retail locations. This will save a lot of parcel lockers on the streets since no extra lockers are needed.

Table 64 Alternative 3 M, L, XL lockers (88% of parcels fit in locker)

Variable	Number
Parcels delivered at home	177
Parcels delivered in locker	1558
Parcels delivered to retail location	35
Number of lockers required	98
Number of locker drivers required	6
Number of normal drivers required	1

Delivery in the parcel lockers will be done on the same manner as current delivery in parcel lockers. The parcel will be scanned with the hand terminal, will be marked as delivered if there is a locker available, the parcel will be scanned at the machine and a locker opens, the parcel is placed in the locker and the door is closed. This will be done for every parcel there is for the parcel locker. Since the large magnitude of parcel lockers to be placed the assumption will be made that this can be done easily in De Pijp. Since time doesn't allow to do extensive research in De Pijp itself to point out perfect locations. In Figure 50 the overview of the parcel lockers can be seen.

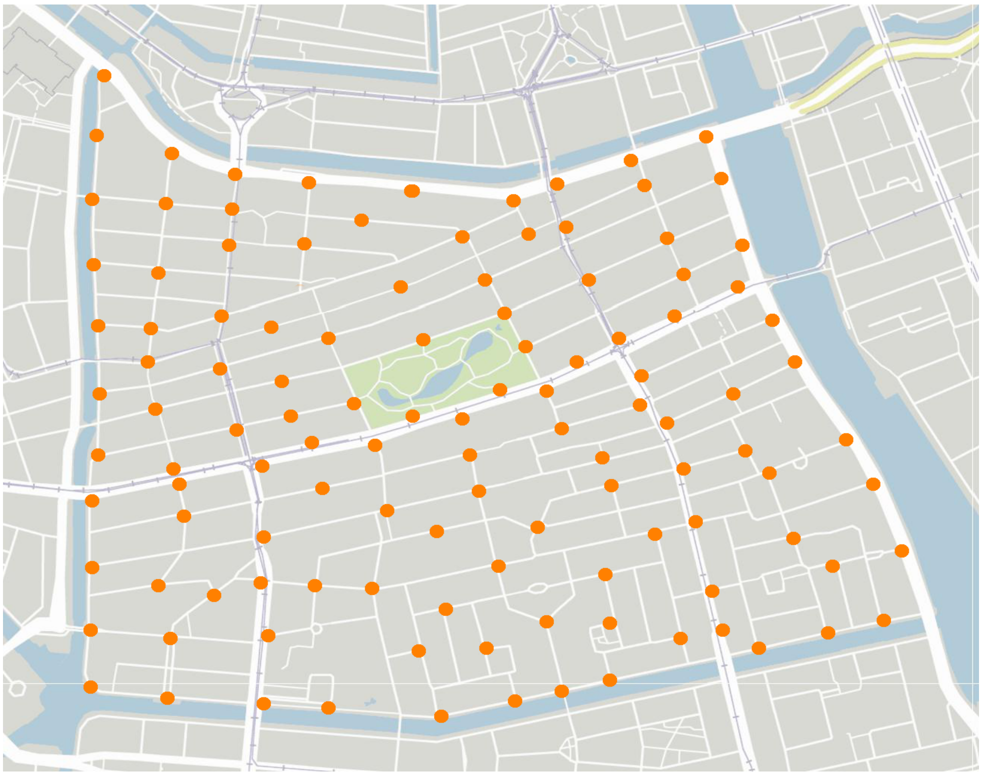


Figure 50 Alternative 3 M, L, XL lockers (88% of parcels fit in locker) locations

As can be seen in Figure 50 the locations of the parcel lockers are large in number and thus closely placed to each other. The orange dots are single parcel lockers of 16 lockers and the orange with black dots are double sided parcel lockers creating a total of 32 parcel lockers. Since parcel lockers are so closely placed to each other walking distance won't be of any problem for anyone.

Alternative 3, S Lockers (66% of parcel fit in locker)

This alternative will deliver all the parcels that normally will be delivered to home addresses to parcel lockers. This includes as well the parcels delivered to the retail locations. The parcel lockers will be delivered with a different route than the standard delivery. The parcel locker route will only deliver at parcel lockers and the other route will deliver at house addresses and retail locations.
Taking into consideration a FTHR of 84% for all parcels that are being delivered, this includes neighbour delivery for the first time as well. A 12% share of the parcels that is delivered at a retail location. A small number of parcels, 4% to be exact, couldn't be delivered straight away. And therefore, need to be sent back to the depot and put through the distribution process all over again. The goal with variant 2B is to try to deliver 100% in a parcel locker, the parcels that do not fit will be delivered at home and at a retail location. This means that of the 34% that doesn't fit in a parcel locker, 84% will be delivered at home and 16% to a retail location. This will save costs on the retail location and creates a potential 100% FTHR. This to be done the same day of delivery after delivering at home addresses. This 34% of the parcels will be delivered according to the current situation. The 88% will be delivered with the parcel locker route and thus only parcel lockers will be filled. Looking at the total percentage 29% of the parcels will be delivered to home addresses and 5% will be delivered to a retail location. Taking these numbers into account and the number of 1770 parcels delivered on a Wednesday in De Pijp it can be determined how much lockers are required for the first year, which is displayed in Table 65 below. With this new fit of 66% more lockers can be placed in the same dimensions of the current parcel locker. Instead of having 16 lockers available now 38 lockers for every parcel locker are available. Since this is only distribution the collection routes will be done by the collection routes that are currently taking place at the end of the day and are clearing the retail locations. This will save a lot of parcel lockers on the streets since no extra lockers are needed.

Table 65 Alternative 3, S Lockers (66% of parcels fit in locker)

Variable	Number
Parcels delivered at home	513
Parcels delivered in locker	1169
Parcels delivered to retail location	88
Number of lockers required (excl. collection)	31
Number of locker drivers required	5
Number of normal drivers required	3

Delivery in the parcel lockers will be done on the same manner as current delivery in parcel lockers. The parcel will be scanned with the hand terminal, will be marked as delivered if there is a locker available, the parcel will be scanned at the machine and a locker opens, the parcel is placed in the locker and the door is closed. This will be done for every parcel there is for the parcel locker. Since the large magnitude of parcel lockers to be placed the assumption will be made that this can be done easily in De Pijp. Since time doesn't allow to do extensive research in De Pijp itself to point out perfect locations. In Figure 51 the overview of the parcel lockers can be seen.

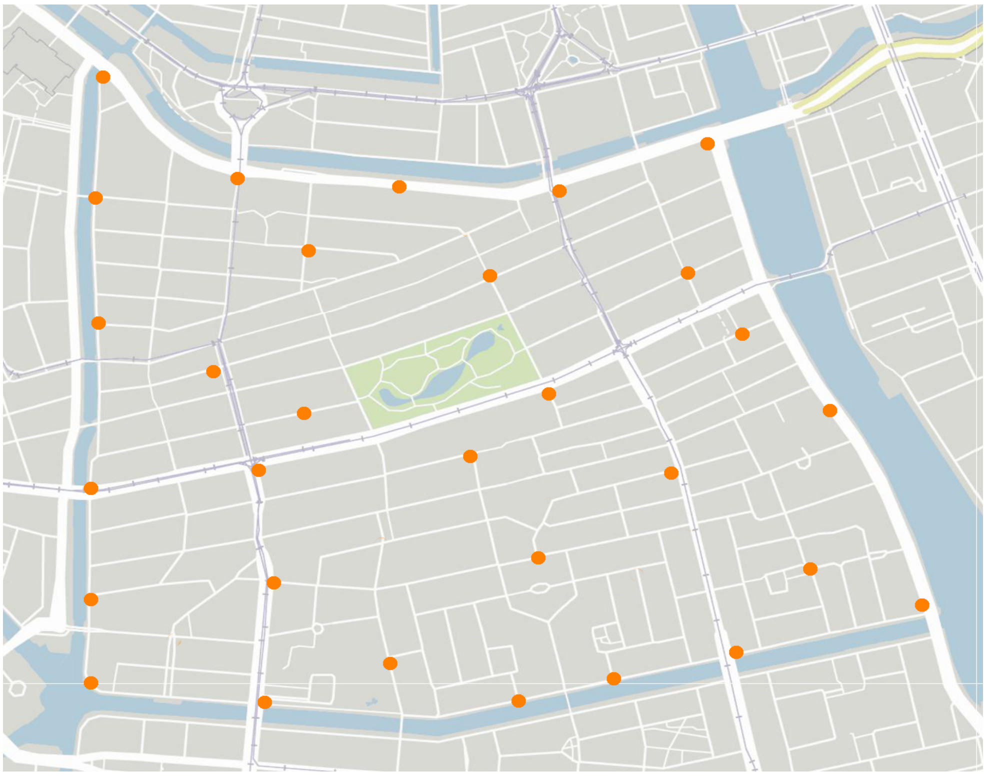


Figure 51 Alternative 3, S Lockers (66% of parcels fit in locker) locations

As can be seen in Figure 51 the locations of the parcel lockers are large in number and thus closely placed to each other. Since parcel lockers are so closely placed to each other walking distance won't be of any problem for anyone.

Alternative 3, XS Lockers (50% of parcels fit in locker)

This variant will use the same hit rate percentage of 84% to home addresses as variant 2A. Though the goal of 100% parcel locker delivery is still the same. Since this variant has a 50% parcel locker fit this means 50% of the parcels needs to be delivered regularly. Taking into account the 84% of FTHR and the 16% remaining delivery this will create new percentage for the total delivery. Of all the parcels 42% will be delivered at home and 8% to a retail location. Since the assumption has been made that the maximum capacity of a retail location 120 parcels is this will create a return flow unfortunately. With this new fit of 50% more lockers can be placed in the same dimensions of the current parcel locker. Instead of having 16 lockers available now 50 lockers for every parcel locker are available. Since the number of parcels delivered to retail locations amounts to be. In Table 66 below the overview of the delivered parcels, the need for collections and the number of drivers is displayed. Since this is only distribution the collection routes will be done by the collection routes that are currently taking place at the end of the day and are clearing the retail locations. This will save a lot of parcel lockers on the streets since no extra lockers are needed.

Table 66 Alternative 3, XS lockers (50% of parcels fit in locker)

Variable	Number
Parcels delivered at home	744
Parcels delivered in locker	885
Parcels delivered to retail location	120
Parcels return to depot	21
Number of lockers required (excl. collection)	18
Number of locker drivers required	4
Number of normal drivers required	4

As can be seen in Figure 52 the locations of the parcel lockers are not so large in number, however they are closely placed to each other where possible. Since parcel lockers are relatively close to each other walking distance won't be of any problem for anyone.

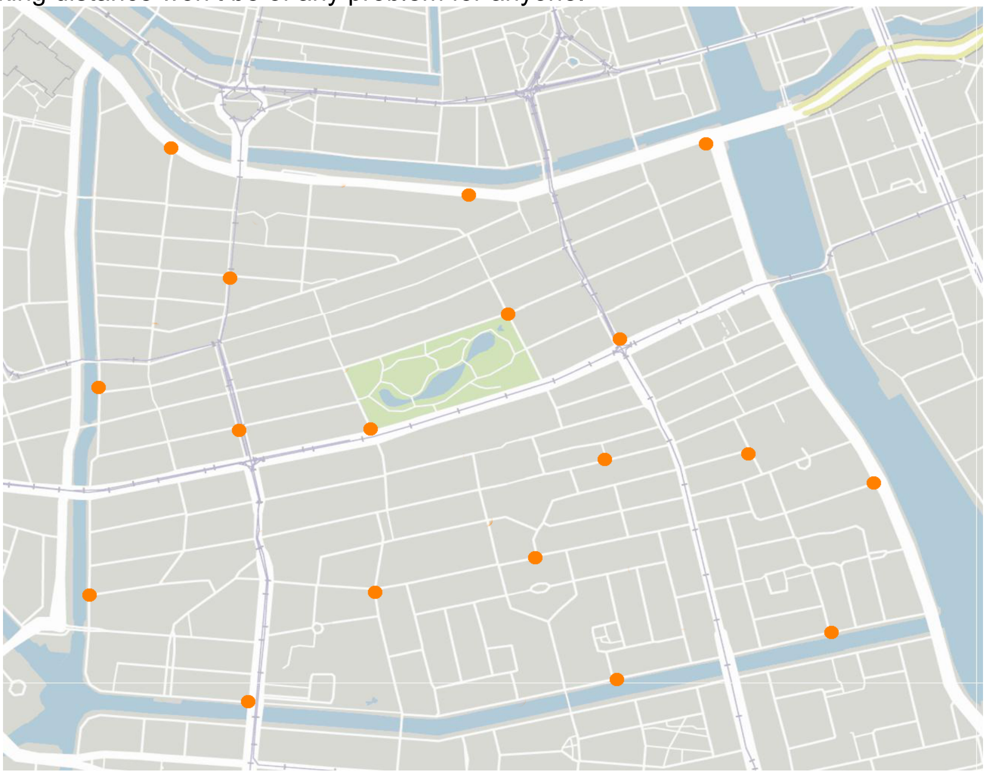


Figure 52 Alternative 3, XS lockers (50% of parcels fit in locker) locations

Appendix XVII Cost Analysis

For every of the three alternatives and the base alternative an analysis will be made of the costs per parcel. These costs are based on the formula of Appendix V Cost function, which is displayed below as well.

Last Mile Cost per parcel shipped:

$$\frac{(T \cdot t + D \cdot d \cdot v)}{(\frac{STOP}{w} \cdot ip \cdot ad \cdot cp \cdot P)} \cdot (1 + r) + (C_s + C_d) \cdot r + r_1 \cdot C_{rt} + (r_1 + ip) \cdot C_p \qquad \text{(XVI1)}$$

Table 67 below will give an overview of all the used variables with their symbols in the equation.

Table 67 Used Symbols

Symbol	Variable	Symbol	Variable
T	Duration of route in hours	ad	Area density coefficient
t	Time coefficient	cp	Collection point coefficient
D	Distance of route in kilometre	R_1	Percentage sent to retailers
d	Distance coefficient	r	Return logistics coefficient
v	Vehicle type coefficient	Cs	Evening sorting costs per parcel
P	Parcel multiplication coefficient	Cd	Debrief costs per parcel
STOP	Average number of stops per delivery route per driver	Cp	Parcel compensation cost
w	Time window coefficient	Crt	Retailer costs per parcel
ip	First time hit rate coefficient		

A lot of variables can be changed and some variables are fixed and therefore will not be changed. The variables which will be changed within every alternative are the duration of route, the distance of the route, the number of stops, first time hit rate coefficient, collection point coefficient, return logistics coefficient and the percentage sent to retailers. Most of these variables depend on the type of alternative and some of these variables will change only once or twice. In Table 68 below the variables which are needed for the CEA are displayed. Growth percentage based on (PostNL, 2017), cost of parcel locker (C. Smit, personal communication, September 14, 2017), maintenance cost is an assumption and the discount factor based on (Rijksoverheid, 2016).

Table 68 CBA variables

Variable	Value	Unit
Growth percentage	10	%
Cost of parcel locker	[redacted]	€
Maintenance costs	5	%
Discount factor	0	%

Alternative 0: Current parcel delivery model

Below in Table 69 the values used as input of alternative 0 are displayed as is in the current delivery situation.

Table 69 Input values for alternative 0: current parcel delivery model

Symbol	Value	Unit	Symbol	Value	Unit
T	56	hours	cp	1	-
t	[redacted]	€/hour	P	1.2	-
D	357	kilometre	r	4	%
d	[redacted]	€/kilometre	Cs	[redacted]	€/parcel
v	1	-	Cp		€/parcel
STOP	1475	-	Cd		€/parcel
w	1.4	-	R1	12	%
ip	84	%	Crt	[redacted]	€/parcel
ad	1.31	-			

In Table 70 below the overview of the costs per parcel are shown. As well as the weekly costs. The weekly costs are separated in the costs for only successful deliveries and costs for all parcel delivery attempts.

Table 70 Cost per parcel alternative 0: current parcel delivery model

Type of cost	Costs
Last mile cost per parcel De Pijp	€1.14
Total cost per day, all the parcels intended for delivery	€2,012.81
Average daily costs 10-year period (CEA)	€3,210.49

Alternative 1: Substitution of retail location with parcel locker

Below in Table 71, Table 72 and Table 73 the values used as input of alternative 1 are displayed as is in the current delivery situation. For every variant, a table has been constructed with the variables that are different. To create a clear overview of the differences within the alternative. Highlighted in orange are the variables that have been changed for the different variants, relative to alternative 0.

Table 71 Input values for alternative 1: substitution of retail location with parcel lockers, Variant 1A

Symbol	Value	Unit	Symbol	Value	Unit
T	56	hours	cp	1	-
t	[redacted]	€/hour	P	1.2	-
D	357	kilometre	r	0	%
d	[redacted]	€/kilometre	Cs	[redacted]	€/parcel
v	1	-	Cp		€/parcel
STOP	1475	-	Cd		€/parcel
w	1.4	-	R1	0	%
ip	100	%	Crt	[redacted]	€/parcel
ad	1.31	-			

Table 72 Input values for alternative 1: substitution of retail location with parcel lockers, Variant 1B

Symbol	Value	Unit	Symbol	Value	Unit
T	56	hours	cp	1	-
t	[redacted]	€/hour	P	1.2	-
D	357	kilometre	r	5.5	%
d	[redacted]	€/kilometre	Cs	[redacted]	€/parcel
v	1	-	Cp		€/parcel
STOP	1475	-	Cd		€/parcel
w	1.4	-	R1	0	%
ip	94.5	%	Crt	[redacted]	€/parcel
ad	1.31	-			

Table 73 Input values for alternative 1: substitution of retail location with parcel lockers, Variant 1C

Symbol	Value	Unit	Symbol	Value	Unit
T	56	hours	cp	1	-
t	[redacted]	€/hour	P	1.2	-
D	357	kilometre	r	8	%
d	[redacted]	€/kilometre	Cs	[redacted]	€/parcel
v	1	-	Cp	[redacted]	€/parcel
STOP	1475	-	Cd	[redacted]	€/parcel
w	1.4	-	R1	0	%
ip	92	%	Crt	[redacted]	€/parcel
ad	1.31	-			

In Table 74 below the overview of the costs per parcel are shown for all the three variants. As well as the weekly costs. The weekly costs are separated in the costs for only successful deliveries and costs for all parcel delivery attempts.

Table 74 Cost per parcel alternative 1: substitution of retail location with parcel lockers

Variant	Type of cost	Costs
Alternative 1 M, L and XL Lockers	Last mile cost per parcel De Pijp	€0.92
	Total cost per day, all the parcels intended for delivery 1st year	€1.624,15
	Average daily costs 10-year period (CEA)	€2,840.55
Alternative 1 S Lockers	Last mile cost per parcel De Pijp	€1.01
	Total cost per day, all the parcels intended for delivery 1st year	€1,788.03
	Average daily costs 10-year period (CEA)	€2,522.88
Alternative 1 XS Lockers	Last mile cost per parcel De Pijp	€1.06
	Total cost per day, all the parcels intended for delivery 1st year	€1,868.69
	Average daily costs 10-year period (CEA)	€2,428.58

Below in Table 75 the CEA overviews can be found with the input of the variables in Table 68 and the costs of Table 74.

Table 75 CEA Analysis Alternative 1

		Discount Factor	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
		Year	1	2	3	4	5	6	7	8	9	10
		Parcels delivered retail										
Alternative 1 M, L & XL lockers		Parcels delivered at home	1487	1636	1800	1980	2178	2396	2636	2900	3190	3509
		Parcels delivered in locker	283	312	344	379	417	459	505	556	612	674
		Number of lockers	26	29	32	35	38	42	46	51	56	62
		Number of lockers built	26	3	3	3	3	4	4	5	5	6
	-€620,000.00	Building Costs	-€260,000.00	-€30,000.00	-€30,000.00	-€30,000.00	-€30,000.00	-€40,000.00	-€40,000.00	-€50,000.00	-€50,000.00	-€60,000.00
	-€208,500.00	Maintenance	-€13,000.00	-€14,500.00	-€16,000.00	-€17,500.00	-€19,000.00	-€21,000.00	-€23,000.00	-€25,500.00	-€28,000.00	-€31,000.00
	-€8,658,945.96	Operational Costs (11 months)	-€542,467.50	-€597,020.73	-€657,090.58	-€722,983.52	-€795,312.52	-€874,997.02	-€962,649.96	-€1,059,190.78	-€1,165,232.45	-€1,282,000.88
Overall Costs	-€9,487,445.96											
Avg daily costs (11-month period)	-€2,840.55											
		Discount Factor	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
		Year	1	2	3	4	5	6	7	8	9	10
		Parcels delivered retail										
Alternative 1 XS lockers		Parcels delivered at home	1487	1636	1800	1980	2178	2396	2636	2900	3190	3509
		Parcels delivered in locker	141	156	172	190	209	230	253	279	307	338
		Number of lockers	5	5	6	6	7	7	8	9	10	11
		Number of lockers built	5	0	1	0	1	0	1	1	1	1
	-€110,000.00	Building Costs	-€50,000.00	€0.00	-€10,000.00	€0.00	-€10,000.00	€0.00	-€10,000.00	-€10,000.00	-€10,000.00	-€10,000.00
	-€37,000.00	Maintenance	-€2,500.00	-€2,500.00	-€3,000.00	-€3,000.00	-€3,500.00	-€3,500.00	-€4,000.00	-€4,500.00	-€5,000.00	-€5,500.00
	-€7,964,464.96	Operational Costs (11 months)	-€498,947.51	-€549,210.04	-€604,376.22	-€665,059.03	-€731,564.93	-€804,813.37	-€885,417.30	-€974,296.15	-€1,071,756.42	-€1,179,024.00
Overall Costs	-€8,111,464.96											
Avg daily costs (11-month period)	-€2,428.58											
		Discount Factor	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
		Year	1	2	3	4	5	6	7	8	9	10
		Parcels delivered retail										
Alternative 1 S lockers		Parcels delivered at home	1487	1636	1800	1980	2178	2396	2636	2900	3190	3509
		Parcels delivered in locker	186	205	226	249	274	302	333	367	404	445
		Number of lockers	8	9	10	10	11	13	14	15	17	18
		Number of lockers built	8	1	1	0	1	2	1	1	2	1
	-€180,000.00	Building Costs	-€80,000.00	-€10,000.00	-€10,000.00	€0.00	-€10,000.00	-€20,000.00	-€10,000.00	-€10,000.00	-€20,000.00	-€10,000.00
	-€62,500.00	Maintenance	-€4,000.00	-€4,500.00	-€5,000.00	-€5,000.00	-€5,500.00	-€6,500.00	-€7,000.00	-€7,500.00	-€8,500.00	-€9,000.00
	-€8,183,903.79	Operational Costs (11 months)	-€512,739.06	-€564,227.50	-€620,926.08	-€683,141.28	-€751,486.05	-€826,879.84	-€909,935.60	-€1,001,266.29	-€1,101,484.86	-€1,211,817.23
Overall Costs	-€8,426,403.79											
Avg daily costs (11-month period)	-€2,522.88											

Alternative 2: Parcel lockers as substitution for current parcel delivery model

Below in Table 76 until Table 81 the values used as input of alternative 2 are displayed as is in the current delivery situation. For every variant, a table has been constructed with the variables that are different. To create a clear overview of the differences within the alternative. Highlighted in orange are the variables that have been changed for the different variants, relative to alternative 0. Since this alternative has 2 different routes for every variant the values for the normal delivery route and the parcel locker delivery route are displayed in separate tables.

Table 76 Input values for alternative 2: parcel lockers as substitution for current parcel delivery model, M, L, XL parcel locker route

Symbol	Value	Unit	Symbol	Value	Unit
T	48	hours	cp	11	-
t	[redacted]	€/hour	P	1	-
D	306	kilometre	r	0	%
d	[redacted]	€/kilometre	Cs	[redacted]	€/parcel
v	1	-	Cp	[redacted]	€/parcel
STOP	142	-	Cd	[redacted]	€/parcel
w	1.4	-	R1	0	%
ip	100	%	Crt	[redacted]	€/parcel
ad	1.31	-			

Table 77 Input values for alternative 2: parcel lockers as substitution for current parcel delivery model, M, L, XL parcel locker normal delivery route

Symbol	Value	Unit	Symbol	Value	Unit
T	8	hours	cp	1	-
t	[redacted]	€/hour	P	1.2	-
D	51	kilometre	r	0	%
d	[redacted]	€/kilometre	Cs	[redacted]	€/parcel
v	1	-	Cp	[redacted]	€/parcel
STOP	175	-	Cd	[redacted]	€/parcel
w	1.4	-	R1	16	%
ip	84	%	Crt	[redacted]	€/parcel
ad	1.31	-			

Table 78 Input values for alternative 2: parcel lockers as substitution for current parcel delivery model, S parcel locker route

Symbol	Value	Unit	Symbol	Value	Unit
T	40	hours	cp	24	-
t	[redacted]	€/hour	P	1	-
D	255	kilometre	r	0	%
d	[redacted]	€/kilometre	Cs	[redacted]	€/parcel
v	1	-	Cp		€/parcel
STOP	48	-	Cd		€/parcel
w	1,4	-	R1	0	%
ip	100	%	Crt	[redacted]	€/parcel
ad	1,31	-			

Table 79 Input values for alternative 2: parcel lockers as substitution for current parcel delivery model, S parcel locker normal route

Symbol	Value	Unit	Symbol	Value	Unit
T	24	hours	cp	1	-
t	[redacted]	€/hour	P	1,2	-
D	153	kilometre	r	0	%
d	[redacted]	€/kilometre	Cs	[redacted]	€/parcel
v	1	-	Cp		€/parcel
STOP	501	-	Cd		€/parcel
w	1,4	-	R1	16	%
ip	84	%	Crt	[redacted]	€/parcel
ad	1,31	-			

Table 80 Input values for alternative 2: parcel lockers as substitution for current parcel delivery model, XS parcel locker route

Symbol	Value	Unit	Symbol	Value	Unit
T	32	hours	cp	33	-
t	[redacted]	€/hour	P	1	-
D	204	kilometre	r	0	%
d	[redacted]	€/kilometre	Cs	[redacted]	€/parcel
v	1	-	Cp		€/parcel
STOP	27	-	Cd		€/parcel
w	1,4	-	R1	0	%
ip	100	%	Crt	[redacted]	€/parcel
ad	1,31	-			

Table 81 Input values for alternative 2: parcel lockers as substitution for current parcel delivery model, XS parcel locker normal route

Symbol	Value	Unit	Symbol	Value	Unit
T	32	hours	cp	1	-
t	[redacted]	€/hour	P	1,2	-
D	204	kilometre	r	2	%
d	[redacted]	€/kilometre	Cs	[redacted]	€/parcel
v	1	-	Cp	[redacted]	€/parcel
STOP	737	-	Cd	[redacted]	€/parcel
w	1,4	-	R1	14	%
ip	84	%	Crt	[redacted]	€/parcel
ad	1,31	-			

In Table 82 below the overview of the costs per parcel are shown. As well as the weekly costs. The weekly costs are separated in the costs for only successful deliveries and costs for all parcel delivery attempts.

Table 82 Cost per parcel alternative 2: parcel lockers as substitution for current parcel delivery model

Variant	Type of cost	Costs Locker route	Costs Normal route	Overall cost two routes
Alternative 2 M, L, XL lockers	Last mile cost per parcel De Pijp	€0,90	€1,29	€1,09
	Total cost per day, all the parcels intended for delivery 1st year	€1.399,31	€271.73	€1,671.04
	Average daily costs 10-year period (CEA)	-	-	€4,012.71
Alternative 2 S lockers	Last mile cost per parcel De Pijp	€0,99	€1,35	€1,17
	Total cost per day, all the parcels intended for delivery 1st year	€1.142,14	€809.21	€1,821.88
	Average daily costs 10-year period (CEA)	-	-	€3,361.92
Alternative 2 XS lockers	Last mile cost per parcel De Pijp	€1,02	€1,26	€1,14
	Total cost per day, all the parcels intended for delivery 1st year	€908,82	€1,110.52	€1,841.66
	Average daily costs 10-year period (CEA)	-	-	€3,312.26

Below in Table 83 the CBA overviews can be found with the input of the variables in Table 68 and the costs of Table 82.

Table 83 CEA Analysis Alternative 2

		Discount Factor	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
		Year	1	2	3	4	5	6	7	8	9	10
		Parcels delivered retail	35	39	43	48	53	59	65	72	80	88
Alternative 2 M, L & XL lockers		Parcels delivered at home	177	195	215	237	261	288	317	349	384	423
		Parcels delivered in locker	1558	1714	1886	2075	2283	2512	2764	3041	3346	3681
		Number of lockers	142	156	172	189	208	229	252	277	305	335
		Number of lockers built	142	14	16	17	19	21	23	25	28	30
	-€3,350,000.00	Building Costs	-€1,420,000.00	-€140,000.00	-€160,000.00	-€170,000.00	-€190,000.00	-€210,000.00	-€230,000.00	-€250,000.00	-€280,000.00	-€300,000.00
	-€1,132,500.00	Maintenance (5%)	-€71,000.00	-€78,000.00	-€86,000.00	-€94,500.00	-€104,000.00	-€114,500.00	-€126,000.00	-€138,500.00	-€152,500.00	-€167,500.00
	-€8,919,945.07	Savings (11 months)	-€557,795.80	-€613,980.97	-€675,817.91	-€744,038.01	-€818,807.50	-€901,589.20	-€992,117.15	-€1,091,854.14	-€1,201,697.81	-€1,322,246.58
	-€13,402,445.07											
	-€4,012.71											
		Discount Factor	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
		Year	1	2	3	4	5	6	7	8	9	10
		Parcels delivered retail	88	97	107	118	130	143	158	174	192	212
Alternative 2 S lockers		Parcels delivered at home	513	565	622	685	754	830	913	1005	1106	1217
		Parcels delivered in locker	1169	1286	1415	1557	1713	1885	2074	2282	2511	2763
		Number of lockers	47	52	57	63	69	76	83	92	101	111
		Number of lockers built	47	5	5	6	6	7	7	9	9	10
	-€1,110,000.00	Building Costs	-€470,000.00	-€50,000.00	-€50,000.00	-€60,000.00	-€60,000.00	-€70,000.00	-€70,000.00	-€90,000.00	-€90,000.00	-€100,000.00
	-€375,500.00	Maintenance (5%)	-€23,500.00	-€26,000.00	-€28,500.00	-€31,500.00	-€34,500.00	-€38,000.00	-€41,500.00	-€46,000.00	-€50,500.00	-€55,500.00
	-€9,743,316.59	Savings (11 months)	-€609,522.47	-€670,893.61	-€738,448.40	-€812,918.25	-€894,602.37	-€984,531.37	-€1,083,436.64	-€1,192,348.80	-€1,312,298.45	-€1,444,316.21
Overall Costs	-€11,228,816.59											
Avg daily costs (11-month period)	-€3,361.92											
		Discount Factor	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
		Year	1	2	3	4	5	6	7	8	9	10
		Parcels delivered retail	120	132	146	161	178	196	216	238	262	289
Alternative 2 XS lockers		Parcels delivered at home	744	819	901	992	1092	1202	1323	1456	1602	1763
		Parcels delivered in locker	885	974	1072	1180	1298	1428	1571	1729	1902	2093
		Number of lockers	27	30	33	36	40	44	48	53	58	64
		Number of lockers built	27	3	3	3	4	4	4	5	5	6
	-€640,000.00	Building Costs	-€270,000.00	-€30,000.00	-€30,000.00	-€30,000.00	-€40,000.00	-€40,000.00	-€40,000.00	-€50,000.00	-€50,000.00	-€60,000.00
	-€216,500.00	Maintenance (5%)	-€13,500.00	-€15,000.00	-€16,500.00	-€18,000.00	-€20,000.00	-€22,000.00	-€24,000.00	-€26,500.00	-€29,000.00	-€32,000.00
	-€10,206,456.14	Savings (11 months)	-€638,211.04	-€702,441.06	-€773,253.66	-€851,380.23	-€937,252.97	-€1,031,470.30	-€1,135,195.79	-€1,249,460.07	-€1,374,695.31	-€1,513,095.71
Overall Costs	-€11,062,956.14											
Avg daily costs (11-month period)	-€3,312.26											

Alternative 3: Distribution only delivery model

Below in Table 84 until Table 89 the values used as input of alternative 0 are displayed as is in the current delivery situation. For every variant, a table has been constructed with the variables that are different. To create a clear overview of the differences within the alternative. Highlighted in orange are the variables that have been changed for the different variants, relative to alternative 0. Since this alternative has 2 different routes for every variant the values for the normal delivery route and the parcel locker delivery route are displayed in separate tables.

Table 84 Input values for alternative 3: distribution only delivery model, M, L, XL parcel locker route

Symbol	Value	Unit	Symbol	Value	Unit
T	48	hours	cp	16	-
t	[redacted]	€/hour	P	1	-
D	306	kilometre	r	0	%
d	[redacted]	€/kilometre	Cs	[redacted]	€/parcel
v	1	-	Cp	[redacted]	€/parcel
STOP	98	-	Cd	[redacted]	€/parcel
w	1,4	-	R1	0	%
ip	100	%	Crt	[redacted]	€/parcel
ad	1,31	-			

Table 85 Input values for alternative 3: distribution only delivery model, M, L, XL parcel locker normal delivery route

Symbol	Value	Unit	Symbol	Value	Unit
T	8	hours	cp	1	-
t	[redacted]	€/hour	P	1,2	-
D	51	kilometre	r	0	%
d	[redacted]	€/kilometre	Cs	[redacted]	€/parcel
v	1	-	Cp	[redacted]	€/parcel
STOP	175	-	Cd	[redacted]	€/parcel
w	1,4	-	R1	16	%
ip	84	%	Crt	[redacted]	€/parcel
ad	1,31	-			

Table 86 Input values for alternative 3: distribution only delivery model, S parcel locker route

Symbol	Value	Unit	Symbol	Value	Unit
T	40	hours	cp	38	-
t	[redacted]	€/hour	P	1	-
D	255	kilometre	r	0	%
d	[redacted]	€/kilometre	Cs	[redacted]	€/parcel
v	1	-	Cp	[redacted]	€/parcel
STOP	31	-	Cd	[redacted]	€/parcel
w	1,4	-	R1	0	%
ip	100	%	Crt	[redacted]	€/parcel
ad	1,31	-			

Table 87 Input values for alternative 3: distribution only delivery model, S parcel locker normal delivery route

Symbol	Value	Unit	Symbol	Value	Unit
T	24	hours	cp	1	-
t	[redacted]	€/hour	P	1,2	-
D	153	kilometre	r	0	%
d	[redacted]	€/kilometre	Cs	[redacted]	€/parcel
v	1	-	Cp	[redacted]	€/parcel
STOP	501	-	Cd	[redacted]	€/parcel
w	1,4	-	R1	16	%
ip	84	%	Crt	[redacted]	€/parcel
ad	1,31	-			

Table 88 Input values for alternative 3: distribution only delivery model, XS parcel locker route

Symbol	Value	Unit	Symbol	Value	Unit
T	32	hours	cp	50	-
t	[redacted]	€/hour	P	1	-
D	204	kilometre	r	0	%
d	[redacted]	€/kilometre	Cs	[redacted]	€/parcel
v	1	-	Cp	[redacted]	€/parcel
STOP	18	-	Cd	[redacted]	€/parcel
w	1,4	-	R1	0	%
ip	100	%	Crt	[redacted]	€/parcel
ad	1,31	-			

Table 89 Input values for alternative 3: distribution only delivery model, XS parcel locker normal delivery route

Symbol	Value	Unit	Symbol	Value	Unit
T	32	hours	cp	1	-
t	[redacted]	€/hour	P	1,2	-
D	204	kilometre	r	2	%
d	[redacted]	€/kilometre	Cs	[redacted]	€/parcel
v	1	-	Cp	[redacted]	€/parcel
STOP	737	-	Cd	[redacted]	€/parcel
w	1,4	-	R1	14	%
ip	84	%	Crt	[redacted]	€/parcel
ad	1,31	-			

In Table 90 below the overview of the costs per parcel are shown. As well as the weekly costs. The weekly costs are separated in the costs for only successful deliveries and costs for all parcel delivery attempts.

Table 90 Cost per parcel alternative 3: distribution only delivery model

Variant	Type of cost	Costs Locker route	Costs Normal route	Overall cost two routes
Alternative 3 M, L, XL lockers	Last mile cost per parcel De Pijp	€0,89	€1,29	€1,09
	Total cost per day, all the parcels intended for delivery 1st year	€1.400,27	€271.73	€1,672.00
	Average daily costs 10-year period (CEA)	-	-	€3,588.64
Alternative 3 S lockers	Last mile cost per parcel De Pijp	€0,97	€1,35	€1,16
	Total cost per day, all the parcels intended for delivery 1st year	€1.146,30	€809.21	€1,955.51
	Average daily costs 10-year period (CEA)	-	-	-€3,204.72
Alternative 3 XS lockers	Last mile cost per parcel De Pijp	€1,01	€1,26	€1,13
	Total cost per day, all the parcels intended for delivery 1st year	€910,26	€1,110.52	€2,020.78
	Average daily costs 10-year period (CEA)	-	-	€3,220.56

Below in Table 91 the CBA overviews can be found with the input of the variables in Table 68 and the costs of Table 90.

		Discount Factor	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
		Year	1	2	3	4	5	6	7	8	9	10
		Parcels delivered retail	35	39	43	48	53	59	65	72	80	88
Alternative 3 M, L & XL lockers		Parcels delivered at home	177	195	215	237	261	288	317	349	384	423
		Parcels delivered in locker	1558	1714	1886	2075	2283	2512	2764	3041	3346	3681
		Number of lockers	98	108	118	130	143	157	173	191	210	231
		Number of lockers built	98	10	10	12	13	14	16	18	19	21
	-€2,310,000.00	Building Costs	-€980,000.00	-€100,000.00	-€100,000.00	-€120,000.00	-€130,000.00	-€140,000.00	-€160,000.00	-€180,000.00	-€190,000.00	-€210,000.00
	-€779,500.00	Maintenance (5%)	-€49,000.00	-€54,000.00	-€59,000.00	-€65,000.00	-€71,500.00	-€78,500.00	-€86,500.00	-€95,500.00	-€105,000.00	-€115,500.00
	-€8,896,565.37	Savings (11 months)	-€556,330.57	-€612,369.03	-€674,044.21	-€742,086.56	-€816,660.45	-€899,226.78	-€989,517.73	-€1,088,994.21	-€1,198,551.05	-€1,318,784.77
Overall Costs	-€11,986,065.37											
Avg daily costs (11-month period)	-€3,588.64											
		Discount Factor	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
		Year	1	2	3	4	5	6	7	8	9	10
		Parcels delivered retail	88	97	107	118	130	143	158	174	192	212
Alternative 3 S lockers		Parcels delivered at home	513	565	622	685	754	830	913	1005	1106	1217
		Parcels delivered in locker	1169	1286	1415	1557	1713	1885	2074	2282	2511	2763
		Number of lockers	31	34	38	41	46	50	55	61	67	73
		Number of lockers built	31	3	4	3	5	4	5	6	6	6
	-€730,000.00	Building Costs	-€310,000.00	-€30,000.00	-€40,000.00	-€30,000.00	-€50,000.00	-€40,000.00	-€50,000.00	-€60,000.00	-€60,000.00	-€60,000.00
	-€248,000.00	Maintenance (5%)	-€15,500.00	-€17,000.00	-€19,000.00	-€20,500.00	-€23,000.00	-€25,000.00	-€27,500.00	-€30,500.00	-€33,500.00	-€36,500.00
	-€9,725,772.42	Savings (11 months)	-€608,423.08	-€669,684.18	-€737,117.66	-€811,453.97	-€892,991.37	-€982,758.61	-€1,081,486.14	-€1,190,202.68	-€1,309,936.97	-€1,441,717.74
Overall Costs	-€10,703,772.42											
Avg daily costs (11-month period)	-€3,204.72											
		Discount Factor	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
		Year	1	2	3	4	5	6	7	8	9	10
		Parcels delivered retail	120	132	146	161	178	196	216	238	262	289
Alternative 3 XS lockers		Parcels delivered at home	744	819	901	992	1092	1202	1323	1456	1602	1763
		Parcels delivered in locker	885	974	1072	1180	1298	1428	1571	1729	1902	2093
		Number of lockers	18	20	22	24	26	29	32	35	39	42
		Number of lockers built	18	2	2	2	2	3	3	3	4	3
	-€420,000.00	Building Costs	-€180,000.00	-€20,000.00	-€20,000.00	-€20,000.00	-€20,000.00	-€30,000.00	-€30,000.00	-€30,000.00	-€40,000.00	-€30,000.00
	-€143,500.00	Maintenance (5%)	-€9,000.00	-€10,000.00	-€11,000.00	-€12,000.00	-€13,000.00	-€14,500.00	-€16,000.00	-€17,500.00	-€19,500.00	-€21,000.00
	-€10,193,165.64	Savings (11 months)	-€637,378.73	-€701,525.06	-€772,245.49	-€850,270.50	-€936,032.26	-€1,030,127.33	-€1,133,718.34	-€1,247,834.02	-€1,372,906.56	-€1,511,127.33
Overall Costs	-€10,756,665.64											
Avg daily costs (11-month period)	-€3,220.56											

Table 91 CEA Analysis Alternative 3

Appendix XVIII Alternatives Cost Sensitivity Analysis

Using the alternatives that have been created in this research a sensitivity analysis can be made as well. The start will be the base scenario that has been analysed in Appendix XVII Cost Analysis. In this base scenario 1770 parcels will be delivered, a growth of 10% is taken into account, 5% maintenance costs and the number of drivers does not differ from the current situation. In this sensitivity analysis four things will be researched and looked more closely into. This will be the growth, the discount factor, the change in drivers and the maintenance percentage. For the growth three different percentages will be taken into account. This will be 5%, so a growth lower than the trend is at the moment. And 15% a growth that is higher than the trend is at the moment. For the discount factor three different percentages will be used as well. The first being 0%, which is currently the case for mark conform projects (Rijksoverheid, 2016), a 3% rate which is the standard rate and a higher one of 4.5%. For the number of drivers this will be a bit more complicated. Since for the first alternative this number cannot change. This alternative does not have a separate parcel locker route and normal delivery route. One of the important requirements that will not be altered with is the capacity of the delivery van, therefore the same number of parcels in one van can be delivered. This creates no room to reduce any drivers. Though with alternative 2 and 3 there is a separate parcel locker route available. In this parcel locker route, there will be possibilities to reduce the number of drivers available. The maintenance percentage will have three different percentages as well, 5%, 10% and 15% of the purchase price of a parcel locker.

Alternative 2 has the possibility of reducing the number of drivers, since this alternative has a separate parcel locker route. With having two different routes it is possible to reduce the number of drivers for the parcel locker route. Since filling up a parcel locker requires less time than a normal route. Due to having less need for drivers' costs can be cheaper, since hourly costs will be reduced.

The goal is that delivery men will fill up the maximum number of lockers they can based on the capacity in their delivery van and then return to the depot to fill their delivery van again and drive back to De Pijp again. Repeating this process for a whole working day. On average, it takes a delivery man around 10 seconds to scan a parcel and place it inside a locker, filling the entire parcel locker would require 160 seconds of work (standard locker size), a little bit more than 2.5 minutes. This speed has great potential. However, the delivery man needs to drive around the route as well, this takes time also. Unloading the parcels from the van takes time as well. Making the assumption that unloading parcels takes 15 seconds per parcel, for one locker this takes 4 minutes. Meaning that one parcel locker takes a delivery man 6.5 minutes to fill, from stopping his van, unloading the parcels and filling up the parcel locker. Below in Figure 53 an example a route the driver can drive is displayed.

Figure 53 Route Parcel Locker Delivery Variant 1B

This route is 2.5km long and takes 10 minutes taken into account a speed of 15km/h. Reason for the 15km/h being the accelerating and decelerating on small parts, causing the delivery van not to drive efficiently. Not taken into account is the directions a delivery van can drive due to one or two way streets for example. Since this level of detail is to extensive for this research. For alternative 2 a driver can fill 24 lockers with 11 parcels, the remaining 5 is for collection. It should be possible for a driver to fill and empty these lockers within 120 minutes. This means looking over the whole day one driver can drive two times to the delivery location roughly. Therefore, to reduce the number of drivers the assumption will be made that for a parcel locker route half of the current drivers can be used. For every variant and alternative 2 and 3. This will be rounded up, since 2.5 drivers is impossible in practise, this will be 3 drivers.

In Table 92 below the overview of the sensitivity analysis can be seen. Important to take into account is the fact when one of the variables will be changed the remaining variables will be kept on the base scenario numbers. Therefore, some values can be seen multiple times for the same alternative. The basic scenario is listed below, together with the minimum and maximum values of the performing alternative. At the bottom of the table the rankings of the performing alternatives are displayed. The rankings are based on the basic scenario.

Sensitivity Analysis	Alternative 0	Alternative 1 M, L, XL lockers	Alternative 1 S lockers	Alternative 1 XS lockers	Alternative 2 M, L, XL lockers	Alternative 2 S lockers	Alternative 2 XS lockers	Alternative 3 M, L, XL lockers	Alternative 3 S lockers	Alternative 3 XS lockers
Effect growth change										
5% growth	-€2,533.98	-€2,221.22	-€1,987.22	-€1,914.91	-€3,036.40	-€2,610.98	-€2,590.16	-€2,741.21	-€2,501.89	-€2,527.74
10% growth	-€3,210.49	-€2,840.55	-€2,522.88	-€2,428.58	-€4,012.71	-€3,361.92	-€3,312.26	-€3,588.64	-€3,204.72	-€3,220.56
15% growth	-€4,091.13	-€3,658.80	-€3,228.98	-€3,102.85	-€5,329.38	-€4,354.72	-€4,254.59	-€4,722.11	-€4,131.55	-€4,126.02
Effect drivers change										
Current number drivers	-€3,210.49	-€2,840.55	-€2,522.88	-€2,428.58	-€4,012.71	-€3,361.92	-€3,312.26	-€3,588.64	-€3,204.72	-€3,220.56
Reduced number of drivers	-€3,210.49	-€2,840.55	-€2,522.88	-€2,428.58	-€3,137.09	-€2,704.85	-€2,814.50	-€2,716.37	-€2,550.17	-€2,724.71
Effect changing discount factor										
0% Low discount factor	-€3,210.49	-€2,840.55	-€2,522.88	-€2,428.58	-€4,012.71	-€3,361.92	-€3,312.26	-€3,588.64	-€3,204.72	-€3,220.56
3% Standard discount factor	-€2,756.47	-€2,465.08	-€2,173.69	-€2,089.79	-€3,586.84	-€2,933.28	-€2,870.68	-€3,178.72	-€2,782.21	-€2,782.64
4.5% High discount factor	-€2,564.93	-€2,306.67	-€2,026.38	-€1,946.86	-€3,407.19	-€2,752.44	-€2,684.40	-€3,005.78	-€2,603.97	-€2,597.89
Effect maintenance cost change										
5% of Locker price	-€3,210.49	-€2,840.55	-€2,522.88	-€2,428.58	-€4,012.71	-€3,361.92	-€3,312.26	-€3,588.64	-€3,204.72	-€3,220.56
10% of Locker price	-€3,210.49	-€2,902.98	-€2,541.59	-€2,439.66	-€4,351.78	-€3,474.35	-€3,377.08	-€3,822.03	-€3,278.97	-€3,263.52
15% of locker price	-€3,210.49	-€2,965.40	-€2,560.30	-€2,450.74	-€4,690.85	-€3,586.77	-€3,441.90	-€4,055.41	-€3,353.23	-€3,306.49
Basic calculation costs	-€3,210.49	-€2,840.55	-€2,522.88	-€2,428.58	-€4,012.71	-€3,361.92	-€3,312.26	-€3,588.64	-€3,204.72	-€3,220.56
Minimum	-€2,533.98	-€2,221.22	-€1,987.22	-€1,914.91	-€3,036.40	-€2,610.98	-€2,590.16	-€2,716.37	-€2,501.89	-€2,527.74
Maximum	-€4,091.13	-€3,658.80	-€3,228.98	-€3,102.85	-€5,329.38	-€4,354.72	-€4,254.59	-€4,722.11	-€4,131.55	-€4,126.02
Ranking Performance	**5**	**3**	**2**	**1**	**10**	**7**	**8**	**9**	**4**	**6**

Table 92 Cost Sensitivity Analysis

There are two things that can be concluded from the cost sensitivity analysis that has been done, which can be seen in Table 92. One of those things is the fact that for almost every change in variables, except for the change in drivers, the alternatives perform overall relative similar. Alternative 1 and 2 perform without any change in rankings with the changing variables. For alternative 3 the scores differ sometimes within the alternatives when comparing with alternative 0. This means the alternatives overall perform well. The second thing that can be noticed is the fact that when the amount of drivers' changes, where possible, this will change the complete ranking of the alternatives. The comparison of ranking in the alternatives can be seen in Table 93 below.

Table 93 Sensitivity Ranking

Alternative	Ranking Current number of drivers	Ranking New number of drivers	Change in Ranking
Alternative 0	5	10	-5
Alternative 1 M, L, XL lockers	3	7	-4
Alternative 1 S lockers	2	2	0
Alternative 1 XS lockers	1	1	0
Alternative 2 M, L, XL lockers	10	9	+1
Alternative 2 S lockers	7	4	+3
Alternative 2 XS lockers	8	8	0
Alternative 3 M, L, XL lockers	9	5	+4
Alternative 3 S lockers	4	3	+1
Alternative 3 XS lockers	6	6	0

Since the change of ranking is so drastically and the goal of the research is to create a cost efficient last mile delivery using parcel lockers, the new number of drivers will be taken into account where possible. This means the MCA will have a note mentioning alternative 2 and 3 have the possibility to reduce the number of drivers. The simulation will be simulated if possible with a lower number of drivers or if not possible will be analysed regarding the possibility for a lower number of drivers. Since the costs perform good on sensitivity and not much change can be seen between alternatives, no new cost sensitivity analysis will be conducted.

Appendix XIIX MCA Results

In this appendix, the results of the MCA survey will be discussed and elaborated on. The MCA received input from 25 people in total. This varies between employees from PostNL and transport and logistics experts. Of the 25 respondents, unfortunately two were not useable due to incompleteness. Therefore, the MCA will be based on the input of 23 people. The respondents were first asked to compare the different criteria with each other based on their importance and after this value the different alternatives based on their performance. The criteria that have been used are based on the requirements set in this research and can be found in Table 94 below.

Table 94 MCA criteria

Criteria	Explanation
Accessibility	How easy is it for customers to collect their parcels, is a large travel distance required?
Consumer Service	How easy to use is the delivery model for consumers? Do customers get notifications by email/sms, operating system easy to use, delivery close to home?
Efficiency	How efficient is the delivery model to use for a logistics provider? Does it require a lot of steps to operate or is it simple to operate?
Feasibility	How feasible is it to build and operate the system? Building a lot of parcel lockers on street locations can be perceived and unfeasible.
Safety	Is the delivery model safe to operate? Is it possible for people whom shouldn't be involved in the process to intervene and take away parcels?
Sustainability	Regarding the environment is the delivery model sustainable. Having a lot of stops is less sustainable and having a lot of delivery vans is not preferred.
Reliability	How reliable is the system when operating? Does it always end up in a parcel locker or does this change depending on availability?

These eight criteria have been compared with each other by the respondents. This creates a weight for each criterion based on their importance towards each other. For the two different groups a distinction has been made for the different weights. The overall weights for the criteria are the average between the two groups. In Table 95 below the weights can be seen as well as the standard deviation, more details about the calculation of weights can be found in Appendix IX MCA Model.

Table 95 Criteria weights

Criteria	Overall weights	Standard Deviation	PostNL weights	Standard Deviation	Experts weights	Standard Deviation
Accessibility	0.191	0.090	0.154	0.077	0.215	0.092
Consumer Service	0.125	0.075	0.143	0.071	0.113	0.078
Efficiency	0.135	0.061	0.127	0.071	0.141	0.056
Feasibility	0.115	0.049	0.111	0.044	0.117	0.054
Safety	0.194	0.133	0.254	0.144	0.154	0.113
Sustainability	0.080	0.062	0.070	0.050	0.086	0.070
Reliability	0.160	0.085	0.141	0.071	0.173	0.094

Interesting to see is the difference between some criteria and the resemblance between criteria. To start with the resemblance. Efficiency, feasibility, sustainability and reliability score relatively the same for the two different groups. Especially feasibility has almost no difference between the two groups. Reliability differs a bit but not that substantial in comparison with other criteria. Especially the costs and safety are two factors that differ quite substantially between the two groups. This difference is large and unexpected, the low weight for cost for the PostNL respondents especially. Apparently, safety is much more important than the costs of the model, despite PostNL being a commercial business and thus operating to make money. The transport experts value safety and cost almost equally important, something that would be expected of parcel delivery for a commercial company. One factor that can be the explanation for the difference in values is the fact that the transport experts are less biased than the PostNL employees. PostNL employees whom filled in this MCA may not be focussed on costs but more on safety due to the type of function they fulfil within PostNL. The respondents from PostNL whom filled in this survey are from one specific department therefore combining these results with the less biased transport experts will create the most unbiased values for weights possible.

Looking at the overall weights for the different criteria, the most important criteria are safety and accessibility, the least important criteria are sustainability and surprisingly feasibility. The rest of the criteria is roughly the same regarding importance. As can be seen when looking at the standard deviation these are quite high. The higher the standard deviation means more spreading in the data, thus people do not think the same about the importance of certain criteria. The most important criteria have the largest standard deviation as well, this is a downside. Indicating that the importance of this criteria is not a as important for every respondent. Feasibility however performs reasonably well on standard deviation, overall and for the different groups. Sustainability is the worst performing regarding standard deviation. Overall the standard deviation for this MCA is quite high for every criterion this doesn't have to be a bad thing, however making hard conclusions that safety is clearly favoured above other criteria is not naturally anymore and a side note indicating this should be added.

The weights of the criteria that can be seen in Table 95 will be used to be able to compare the different alternatives with each other. The respondents have valued the different alternatives for the same eight criteria in relation to the base alternative. Whether the respondents value the alternative better or worse than the base alternative, which is the current delivery model as it is right now. Below in Table 96, Table 97 and Table 98 the average overall scores for the different alternatives is displayed.

Table 96 Overall score alternative 1

Criteria	Alternative 1 M, L, XL lockers	Standard Deviation	Alternative 1 S lockers	Standard Deviation	Alternative 1 XS lockers	Standard Deviation
Accessibility	6.826	1.922	5.609	1.777	4.739	1.959
Consumer Service	6.565	1.927	5.565	1.701	4.826	2.103
Efficiency	5.913	1.649	5.783	1.536	5.522	2.064
Feasibility	5.826	2.125	5.739	1.685	5.870	1.890
Safety	4.957	2.286	4.870	2.074	4.826	1.969
Sustainability	5.174	1.800	5.261	1.514	5.478	1.780
Reliability	5.739	1.738	5.261	1.356	5.000	1.732

Table 97 Overall score alternative 2

Criteria	Alternative 2 M, L, XL lockers	Standard Deviation	Alternative 2 S lockers	Standard Deviation	Alternative 2 XS lockers	Standard Deviation
Accessibility	7.913	2.193	6.652	2.124	5.652	2.124
Consumer Service	6.391	2.950	5.652	2.308	5.087	2.043
Efficiency	6.565	2.446	6.522	1.855	6.087	1.756
Feasibility	4.391	2.759	5.043	2.246	5.217	2.022
Safety	4.783	2.662	4.652	2.102	4.652	1.945
Sustainability	4.696	2.098	5.391	1.644	5.739	1.657
Reliability	6.130	2.029	5.913	1.857	5.913	1.881

Table 98 Overall score alternative 3

Criteria	Alternative 3 M, L, XL lockers	Standard Deviation	Alternative 3 S lockers	Standard Deviation	Alternative 3 XS lockers	Standard Deviation
Accessibility	7.609	2.083	6.196	2.082	5.022	2.135
Consumer Service	6.087	3.088	5.152	2.484	4.413	2.415
Efficiency	6.348	2.604	5.674	2.172	5.413	2.103
Feasibility	4.826	2.839	4.804	2.104	5.239	2.235
Safety	4.435	2.409	4.370	2.013	4.283	1.970
Sustainability	4.717	2.005	5.217	1.622	5.500	1.971
Reliability	5.739	2.094	5.630	1.733	5.457	1.644

With these scores conclusions cannot be made yet. Since the weights for the criteria are not accounted for yet. A thing that can be concluded is the fact that alternative 2 and alternative 3 scores are relatively similar with each other. This is expected since there is not much difference between the alternatives besides the option for collection with alternative 2. Regarding the scores for costs these are quite similar with the CEA analysis which is according to expectation. Since the respondents were able to see the difference in cost between the base alternative and the new alternatives. However not everyone thinks €100 less costs are worth the same, one thinks it’s a lot another thinks it’s not. Therefore, the MCA is a good solution to tackle this problem.

Regarding the standard deviation for the scores for the alternatives these are high as well. Varying from 1.356 to 3.088, on a 10 point scale this is high. Indicating that the respondents whom filled in the MCA have a large spread in valuation for the different alternatives. Indicating that the alternatives that have been designed have a different importance for every respondent. Especially the consumer service is spread out a lot. Which is one of the factors which is highly subjective. Since one person thinks differently about what a certain level of service is. A thing that can be seen however is that the standard deviation decreases when the variation of the locker sizes decreases as well. Indicating that when the alternatives are more simple people think it easier to value the alternatives. However, the spread in data is still fairly high. This could have several reasons, one of the reason being that the number of respondents is fairly low with only 23 usable respondents. Another reason could be the situation that the MCA has not been clear enough for the respondents to fill in, the magnitude of the different alternatives generated to much questions with the respondents.

Combining the weights of Table 95 with the scores of Table 96, Table 97 and Table 98 the MCA can be finalized and conclusions can be drawn. In this last step, the base alternative will be evaluated as well. This to be able to see the relative scores of the alternatives in relation to each other, this needs to include the base alternative as well. Since the goal of an MCA is to see which alternative scores best in relation with all the other alternatives. If the new alternatives score good with each other but the base alternative still scores the best, the base alternative remains the best option to choose. Below in Table 99, Table 100, Table 101 and Table 102 the overview of the scores can be seen. In Table 103 the total scores per alternative and their relative importance are displayed.

Table 99 Relative score alternative 0

Criteria	Alternative 0
Accessibility	0.957
Consumer Service	0.625
Efficiency	0.677
Feasibility	0.574
Safety	0.968
Sustainability	0.399
Reliability	0.801
Total Score	5.000

Table 100 Relative score alternative 1

Criteria	Alternative 1 M, L, XL lockers	Alternative 1 S lockers	Alternative 1 XS lockers
Accessibility	1.306	1.073	0.907
Consumer Service	0.821	0.696	0.603
Efficiency	0.800	0.783	0.747
Feasibility	0.668	0.658	0.673
Safety	0.959	0.942	0.934
Sustainability	0.413	0.420	0.437
Reliability	0.920	0.843	0.801
Total Score	5.887	5.415	5.103

Table 101 Relative score alternative 2

Criteria	Alternative 2 M, L, XL lockers	Alternative 2 S lockers	Alternative 2 XS lockers
Accessibility	1.514	1.273	1.081
Consumer Service	0.799	0.706	0.636
Efficiency	0.889	0.883	0.824
Feasibility	0.504	0.579	0.599
Safety	0.926	0.900	0.900
Sustainability	0.375	0.430	0.458
Reliability	0.982	0.948	0.948
Total Score	5.988	5.719	5.446

Table 102 Relative score alternative 3

Criteria	Alternative 3 M, L, XL lockers	Alternative 3 S lockers	Alternative 3 XS lockers
Accessibility	1.456	1.185	0.961
Consumer Service	0.761	0.644	0.552
Efficiency	0.859	0.768	0.733
Feasibility	0.554	0.551	0.601
Safety	0.858	0.846	0.829
Sustainability	0.377	0.417	0.439
Reliability	0.920	0.902	0.874
Total Score	5.784	5.313	4.988

As can be seen due to the normalized weights the base alternative gets an overall score of 5. Where every individual criterion is valued at a 5 as well. Combining this with the normalized weights this will create the best score, this will be the same for all the different alternatives. Therefore, in this step it is clear to see which alternatives performs better than the base alternative and which scores worse. In this case, all the alternatives that have been designed score better than the base alternative does, except for alternative 3 XS lockers. Some more than others, alternative 3 XS lockers scores slightly below the base alternative and is almost the same. Another thing that can be seen is that alternative 2 almost scores the best for every variant, the first variant with the M, L and XL lockers scores slightly better than alternative 1 with the same locker sizes. The scores are quite close to each other as well, this indicates that the alternatives are quite similar to each other. Which in this research is the situation. Since it is almost impossible to create absolutely different designs for the delivery of parcels, the alternatives are quite similar. Especially alternative 2 and 3. However the alternatives are quite similar, they do differ substantially on certain aspects which are hard to quantify or made visible in a MCA. This means the relative scores of the alternatives are quite close to each other as well. This means two things; the alternatives do not differ from each other or a combination of different similar scoring alternatives is a good solution. Making some sort of hybrid form. In Table 103 below the alternatives and their relative scores can be seen, displayed in percentages.

Table 103 Alternatives relative overall scores

Alternative 0		
5.000		
84.9%		
Alternative 1 M, L, XL lockers	Alternative 1 S lockers	Alternative 1 XS lockers
5.887	5.415	5.103
98.3%	90.4%	85.2%
Alternative 2 M, L, XL lockers	Alternative 2 S lockers	Alternative 2 XS lockers
5.988	5.719	5.446
100.0%	95.5%	90.9%
Alternative 3 M, L, XL lockers	Alternative 3 S lockers	Alternative 3 XS lockers
5.784	5.313	4.988
96.6%	88.7%	83.31%

As can be seen in Table 103, the alternative that relatively scores the best is Alternative 2 M, L, XL lockers, closely followed by alternative 1 and 3 with the same size lockers. Indicating the people clearly have a preference for a delivery model where parcels are delivered as much as possible in a parcel locker. Taking into account criteria such as safety and feasibility. Alternative 2 S lockers scores good as well, where after alternative 1 S lockers scores good. A trend that can be seen is that the delivery model where parcels are not delivered at home have a preference over the model that delivers parcels at home. Expected as well is the fact that the different alternatives are really close to each other regarding the score. The alternatives score between a 5 and a 6, including the base alternative. It is not possible to state one alternative is clearly better than another alternative. To go into more detail the difference between the two groups can be researched as well. This can be found in Table 104 for the transport experts and Table 105 for the PostNL employees.

Table 104 Alternatives relative transport expert scores

Alternative 0		
5.000		
78.8%		
Alternative 1 M, L, XL lockers	Alternative 1 S lockers	Alternative 1 XS lockers
6.345	5.722	5.430
99.6%	89.9%	85.3%
Alternative 2 M, L, XL lockers	Alternative 2 S lockers	Alternative 2 XS lockers
6.368	6.104	5.794
100.0%	95.8%	91.0%
Alternative 3 M, L, XL lockers	Alternative 3 S lockers	Alternative 3 XS lockers
5.971	5.477	5.103
93.8%	86.0%	80.13%

Table 105 Alternatives relative PostNL employees scores

Alternative 0		
5.000		
92.6%		
Alternative 1 M, L, XL lockers	Alternative 1 S lockers	Alternative 1 XS lockers
5.068	4.840	4.532
93.8%	89.6%	83.9%
Alternative 2 M, L, XL lockers	Alternative 2 S lockers	Alternative 2 XS lockers
5.304	5.043	4.874
98.2%	93.4%	90.2%
Alternative 3 M, L, XL lockers	Alternative 3 S lockers	Alternative 3 XS lockers
5.402	4.921	4.700
100.0%	91.1%	87.00%

An important thing that can be concluded from Table 104 and Table 105 is the different value for scores given by the two different groups. The transport group values every alternative higher than the PostNL group. This is a bit in the line of expectation again. Since the transport experts have a less biased view on the delivery model. PostNL have a biased view of their current delivery model, why change something that is good at the moment. Innovation is a hard aspect in logistics. With the transport expert group, all the alternatives are valued higher than the current delivery model. With the PostNL employees this is not the case, 5 out of the 9 variants are valued lower than the current situation. All 5 of these variants are variants where not every parcel is delivered in a parcel locker but more of a separation between normal delivery and parcel locker delivery is made. What can be concluded from the two groups is the fact that the transport experts are in favour of innovations and see positive things in every variant. With the PostNL employees the conclusion that can be taken from the MCA is the fact they value simplicity really high. Put everything in a locker or don't put it in a locker at all, since the base alternative is better than the other locker alternatives. No distinction should be made between the size of the parcels. The reason for this can be the fact PostNL employees know more about the sorting and distribution process than the transport experts and thus see issues before the last mile starts. This is important to take into account, though this research focuses on last mile logistics. Another thing that was remarkable was the case that the PostNL employees score every alternative low on reliability, in comparison with the transport experts. This again could be due to the reasons of thinking further than only last mile logistics and all the other aspects that are involved. This is important together with the unbiased view, therefore the overall combination as can be found in Table 103 is the leading combination that will be taken into account.

Appendix XIX Simulation Results

The program that has been used for simulation is called Simio. The reason for choosing this program and other information can be found in Appendix X Simulation Study. This appendix will discuss all the results from the simulation together with the layout of the model, the variables that have been chosen and the programming to define this model. To start off the simulation is based on the situation as it is in the PostNL Depots at the moment. Parcels will be distributed from a conveyer to a dock, at this dock a delivery van is located where the parcels will be loaded in to. The number of parcels that is distributed is based on the busiest day recorded in the selected week, which can be found in Appendix III “De Pijp” PostNL Data. This number amounts to be 1770 parcels, which are distributed in one hour of time. These parcels are distributed amongst the different docks, depending on the alternative how many docks this will be. The distribution will take place from 09:00 to 10:00, the delivery van will be located at the dock 15 min prior and will leave the dock 15 min after distribution is finished. This is the same for every alternative. The delivery van is assigned a maximum capacity of 270 parcels, this number is based on the maximum capacity of the delivery van. Meaning that when the situation occurs that more than 270 parcels are being distributed to a single dock, parcels need to wait at the dock to be distributed the next day. The simulation is simulated for 144 hours, starting on a Tuesday. This means simulation for 6 days. Tuesday until Saturday parcels are being distributed and delivered to the different locations. The Sunday is simulated to process the parcels that have been delivered to the different locations. This in order to be able to process all the parcels that are being delivered. Depending on the alternative parcels can be delivered to houses, retail location, lockers or debrief. The debrief is designed to retrieve all the parcels that couldn’t be delivered the first day and need to be distributed again. The parcels that are delivered to this location will be forwarded to the dock it originated from. And will be delivered the next day of simulation. Between the different locations, the delivery vans drive with a defined speed of 30 kilometres per hour. This to simulate an average driving speed in a city. The number of parcels that will be delivered to each location is based on data from PostNL including the FTHR. The percentages can be found in Table 106 below.

Table 106 Distribution Percentages

Alternative	House Distribution	Retail Distribution	Locker Distribution	Debrief/Undelivered
Alternative 0	84%	12%	0%	4%
Alternative 1 M, L, XL lockers	84%	0%	16%	0%
Alternative 1 S lockers	84%	0%	11%	5%
Alternative 1 XS lockers	84%	0%	8%	8%
Alternative 2 M, L, XL lockers	10%	2%	88%	0%
Alternative 2 S lockers	29%	5%	66%	0%
Alternative 2 XS lockers	42%	7%	50%	1%
Alternative 3 M, L, XL lockers	10%	2%	88%	0%
Alternative 3 S lockers	29%	5%	66%	0%
Alternative 3 XS lockers	42%	7%	50%	1%

Important to mention is that all the different alternatives have been simulated looking at distribution only, the collection part is not taken into account in this simulation. The reason for this being lack of time and the situation that the simulation model needed to be made so complicated that the researcher of this research couldn't cope with it. Therefore, there has been choosen to make a simulation that works properly and doesn't have complicated aspects to it which will make the data unreliable. This means there will be no difference in simulation between alternative 2 and 3. Since the difference between these alternatives only is the collection part and the number of lockers. Having tried to simulate a maximum in the number of lockers, the model didn't perform according to standard anymore. It started distributing a selection of parcels instead of all the parcels, therefore the data is unreliable. The alternative is being reviewed on their results. Where every alternative is being rated on the same outcomes. This will be the fact if there is a situation where a delivery van is operating off shift (shifts for the delivery vans are from 8.45 until 17.15 (an 8.5 hour working day)), the average time a parcel is in a locker, the average occupancy of a parcel locker and the operating time.

Alternative 0 Simulation Lay-Out & Programming

This alternative is the base alternative. This alternative only distributes to houses, retail location and when undelivered to the debrief location. This simulation consists of eight operating docks, and thus eight operating vehicles. All the parcels are evenly distributed amongst the eight docks, due to the reason in the base alternative eight different routes are driven.

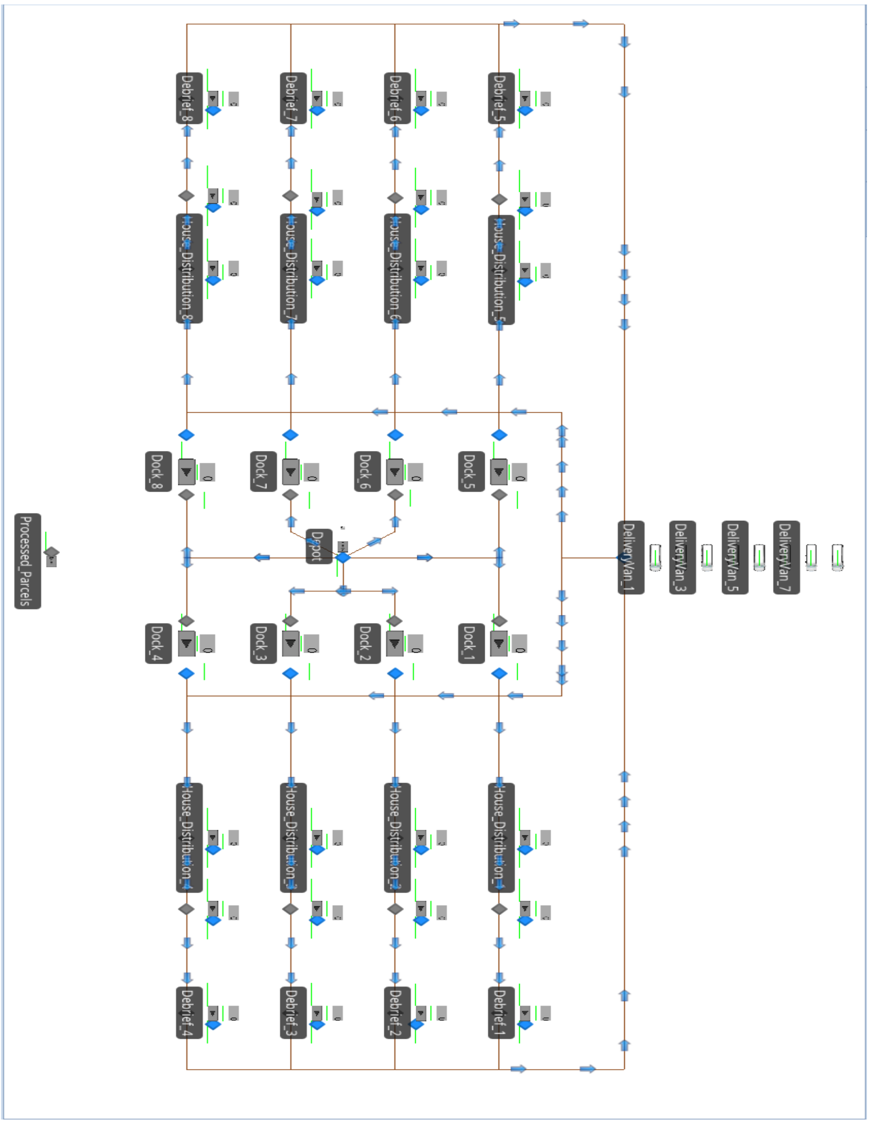


Figure 54 Alternative 0 Simulation Lay-Out Overview

In Figure 54 the overall lay-out of the simulation of Alternative 0 can be seen. Eight different delivery vans can be seen on top.
The depot in the middle which will distribute the parcels to the eight different docks to the right and left side of the dock are displayed as well. Every dock has three different locations where parcels can be distributed to. For Alternative 0 this is house distribution, retail distribution and debrief. This can be seen in more detail in Figure 55 below.

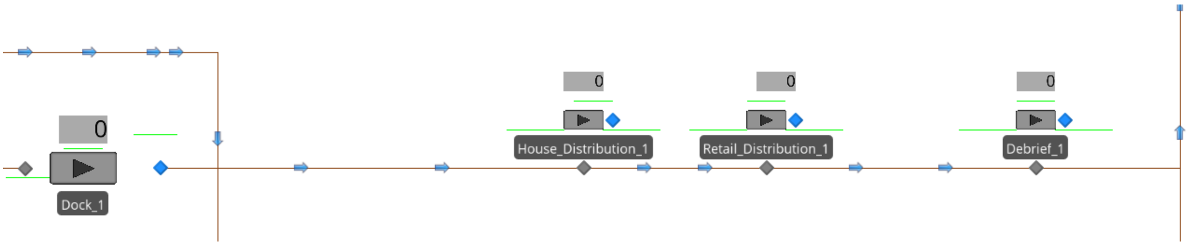


Figure 55 Alternative 0 Dock 1 and distribution locations

The delivery van will drive from the Dock_[X] when it is time to leave to House_Distribution_[X}, Retail_Distribution[X] and finally delivers the parcels that couldn't be delivered (according to the pre-set data) to the Debrief_[X] location. After this the delivery van will drive to the parking location where it parks at the end of the shift and will do the same route the next day. To make sure the right number of parcels is being delivered to each location a so-called Add-On Process has been made. This process ensures that every location will get a certain percentage of parcels. This process is displayed in Figure 56 below.

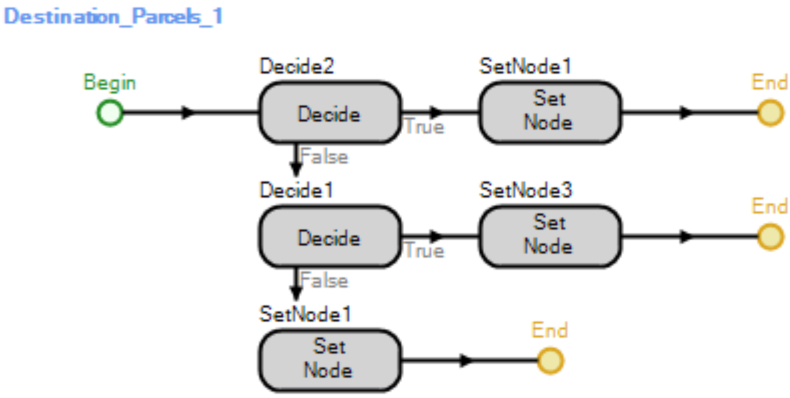


Figure 56 Destination Parcels (Simulation)

This process ensures that a certain percentage go to a certain node. Not only is it important that the parcels will be assigned to the correct location. It is important as well that the delivery van will drive a

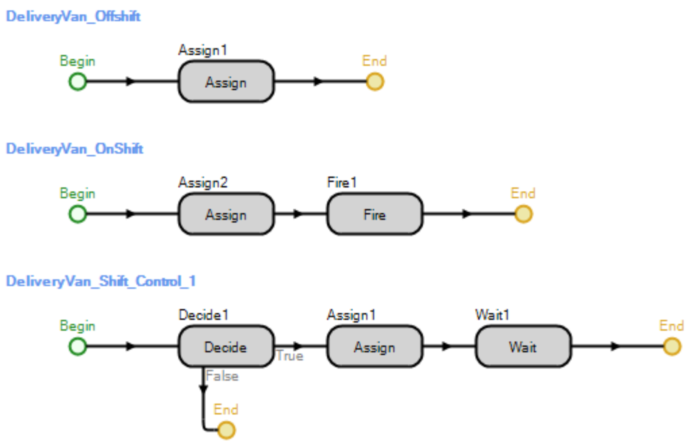


Figure 57 Shift Control (Simulation)

certain route and has a certain work schedule where it is able to operate within. This work schedule has been made into a process as well and can be seen below in Figure 57.

Alternative 1 Simulation Lay-Out & Programming

For alternative 1 the basic layout is the same layout as the one of alternative 0 which can be seen in Figure 54. Though with this alternative the retail distribution is being replaced with locker distribution and the percentage of parcels destined for the different locations is according to the percentages shown in Table 106. In Figure 58 below the detailed overview of the parcel delivery route can be seen.

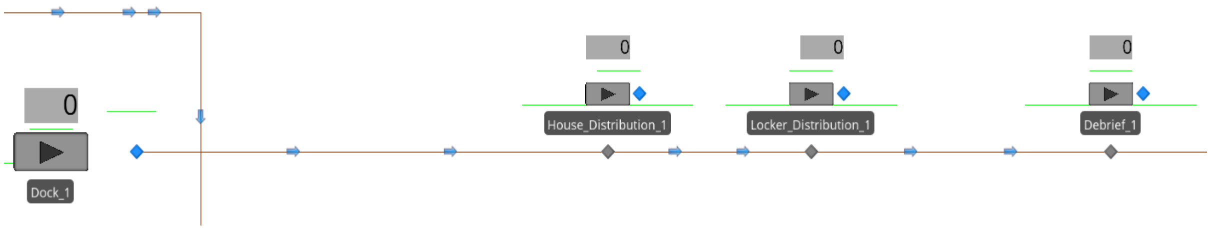


Figure 58 Alternative 1 Dock 1 and distribution locations

In the simulation for this alternative only seven docks are being used instead of having eight as the current model. Though the rest of the simulation is exactly the same and the add-on processes as described for alternative 0 are the same for this alternative. Though as mentioned before with the usage of different percentages. The add-on processes can be seen in Figure 56 and Figure 57.

Alternative 2 Simulation Lay-Out & Programming

For alternative 2 the basic layout is the same layout as the one of alternative 0 and 1 which can be seen in Figure 54. Though with this alternative the locker distribution is added to the delivery route and the percentage of parcels destined for the different locations is according to the percentages shown in Table 106. In Figure 59 below the detailed overview of the parcel delivery route can be seen.

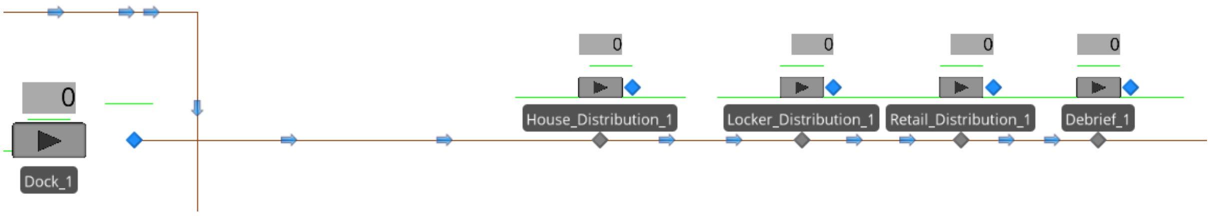


Figure 59 Alternative 2 Dock 1 and distribution locations

In the simulation for this alternative seven or eight docks are being used, depending on the variant within this alternative. Important to mention is that the route for the locker distribution only is the same as for the normal distribution route. However, the locker distribution route will only drop parcels at the locker distribution and not somewhere else. This will be brought to attention in the results. The rest of the simulation is exactly the same and the add-on processes as described for alternative 0 are the same for this alternative. Though as mentioned before with the usage of different percentages. The add-on processes can be seen in Figure 56 and Figure 57.

Alternative 3 Simulation Lay-Out & Programming

Since with the simulation only distribution is being simulated there is no difference in simulation lay-out and programming for alternative 2 and 3. Only the results can be evaluated for the different alternatives. Since the number of lockers will be different for alternative 2 and 3. Therefore this paragraph will not discuss simulation lay-out of alternative 3 any further.

Simulation Variables Alternatives

For the simulation, a basis scenario has been designed. This basis scenario has input variables that are based on the current situation and data given by PostNL. The base scenario is scenario 1, as can be seen in Table 107 below. For other scenario's five variables are changing, this to test the performance of the delivery model and how they will deal with sensitivity.

Table 107 Input Variables Simulation Scenario 1

	ProcessTimeDock (seconds)	ProcessTimeHouseDistribution (seconds)	ProcessTimeRetailDistribution (seconds)	ProcessTimeDebrief (seconds)	ProcessTimeLockerDistribution (hours)
Scenario 1	Random.Triangular(7,10,13)	Random.Triangular(5,7.5,10)	Random.Triangular(8,10,12)	Random.Triangular(7,10,13)	Random.Triangular(1,14,72)
	UnloadTimeHouse (seconds)	UnloadTimeRetail (seconds)	UnloadTimeDebrief (seconds)	UnloadTimeLocker (seconds)	
Scenario 1	Random.Triangular(40, 60, 80)	Random.Triangular(40, 60, 80)	Random.Triangular(30, 40, 50)	Random.Triangular(10, 20, 30)	

For every variable, there has been chosen to use a Random.Triangular distribution. This means there is a minimum, a mean and a maximum. With this the simulation will be performed. ProcessTimeDock represents the loading of the delivery van when its located at the Dock. ProcessTimeHouseDistribution represents the time it takes for a customer to process its parcel, this includes signature, opening the door and acceptance of the parcels. The assumption is made this will not influence performance, but the unloading time includes the performance of the driver. The ProcessTimeDebrief is the time at the debrief location it takes for the parcels that are brought back to be processed. The ProcessTimeLockerDistribution is the time it takes a customer to collect their parcels. This is a minimum of 1 hour and has a maximum of 72 hours (three days). On average it takes 14 hours, the reason for this 14 hours being the fact that 90% will collect its parcels within 24 hour, 5% within 48 hours and 5% within 72% hours. The UnloadTimeHouse is the time it takes for a delivery driver to take the parcel out of the delivery van, scan it and offer it to the customer. Taken into account is the time driving it takes in a city between stops, since in urban areas this is close. This is limited to a minimum. The UnloadTimeRetail is the time it takes the delivery driver to unload its parcels from the retail location and offer them to the retail location. The UnloadTimeDebrief is the time it takes the delivery driver the unload its parcels at the depot for the debrief. The UnloadTimeLocker is the time it takes the delivery driver to unload a parcel from the delivery van, scan the parcel and place it in a locker. The ProcessTimeDock, ProcessTimeHouseDistribution, ProcessTimeRetailDistribution and ProcessTimeDebrief do not differ amongst the different scenario's. These times will not influence the time of the delivery van and its driver. The other five variables differ amongst the variables this can be seen in Table 108 below.

Table 108 Input Variables Simulation Scenario 1-18

	ProcessTimeLockerDistribution (hours)	UnloadTimeHouse (seconds)	UnloadTimeRetail (seconds)	UnloadTimeDebrief (seconds)	UnloadTimeLocker (seconds)
Scenario 1	Random.Triangular(1,14,72)	Random.Triangular(40, 60, 80)	Random.Triangular(40, 60, 80)	Random.Triangular(30, 40, 50)	Random.Triangular(10, 20, 30)
Scenario 2	Random.Triangular(1,14,72)	Random.Triangular(60,80, 100)	Random.Triangular(40, 60,80)	Random.Triangular(30, 40, 50)	Random.Triangular(10, 20, 30)
Scenario 3	Random.Triangular(1,14,72)	Random.Triangular(80, 100, 120)	Random.Triangular(40, 60,80)	Random.Triangular(30, 40, 50)	Random.Triangular(10, 20, 30)
Scenario 4	Random.Triangular(1,14,72)	Random.Triangular(40, 60, 80)	Random.Triangular(40, 60, 80)	Random.Triangular(30, 40, 50)	Random.Triangular(10, 20, 30)
Scenario 5	Random.Triangular(1,14,72)	Random.Triangular(40, 60, 80)	Random.Triangular(60,80, 100)	Random.Triangular(40, 50, 60)	Random.Triangular(10, 20, 30)
Scenario 6	Random.Triangular(1,14,72)	Random.Triangular(40, 60, 80)	Random.Triangular(80, 100, 120)	Random.Triangular(50, 60, 70)	Random.Triangular(10, 20, 30)
Scenario 7	Random.Triangular(1,14,72)	Random.Triangular(40, 60, 80)	Random.Triangular(40, 60, 80)	Random.Triangular(30, 40, 50)	Random.Triangular(10, 20, 30)
Scenario 8	Random.Triangular(1,14,72)	Random.Triangular(40, 60, 80)	Random.Triangular(40, 60, 80)	Random.Triangular(30, 40, 50)	Random.Triangular(20, 30, 40)
Scenario 9	Random.Triangular(1,14,72)	Random.Triangular(40, 60, 80)	Random.Triangular(40, 60, 80)	Random.Triangular(30, 40, 50)	Random.Triangular(30, 40, 50)
Scenario 10	Random.Triangular(1,24,72)	Random.Triangular(40, 60, 80)	Random.Triangular(40, 60, 80)	Random.Triangular(30, 40, 50)	Random.Triangular(10, 20, 30)
Scenario 11	Random.Triangular(1,24,72)	Random.Triangular(60,80, 100)	Random.Triangular(40, 60, 80)	Random.Triangular(30, 40, 50)	Random.Triangular(10, 20, 30)
Scenario 12	Random.Triangular(1,24,72)	Random.Triangular(80, 100, 120)	Random.Triangular(40, 60, 80)	Random.Triangular(30, 40, 50)	Random.Triangular(10, 20, 30)
Scenario 13	Random.Triangular(1,24,72)	Random.Triangular(40, 60, 80)	Random.Triangular(40, 60, 80)	Random.Triangular(30, 40, 50)	Random.Triangular(10, 20, 30)
Scenario 14	Random.Triangular(1,24,72)	Random.Triangular(40, 60, 80)	Random.Triangular(60,80, 100)	Random.Triangular(40, 50, 60)	Random.Triangular(10, 20, 30)
Scenario 15	Random.Triangular(1,24,72)	Random.Triangular(40, 60, 80)	Random.Triangular(80, 100, 120)	Random.Triangular(50, 60, 70)	Random.Triangular(10, 20, 30)
Scenario 16	Random.Triangular(1,24,72)	Random.Triangular(40, 60, 80)	Random.Triangular(40, 60, 80)	Random.Triangular(30, 40, 50)	Random.Triangular(10, 20, 30)
Scenario 17	Random.Triangular(1,24,72)	Random.Triangular(40, 60, 80)	Random.Triangular(40, 60, 80)	Random.Triangular(30, 40, 50)	Random.Triangular(20, 30, 40)
Scenario 18	Random.Triangular(1,24,72)	Random.Triangular(40, 60, 80)	Random.Triangular(40, 60, 80)	Random.Triangular(30, 40, 50)	Random.Triangular(30, 40, 50)

Overall Simulation Results

Every Alternative that has been designed performed without any bugs or failures. The designs as they are right now are performing according to standard. Looking at Table 109 and seeing Alternative 0 this alternative performs like the real-life situation, when taking only distribution into account. The minimum operating of 2.49 hours is low, however when everything goes without any hassle this can be the case. Since the number of parcels that was assigned to the docks differed as well. The maximum operating time of 6.41 hours is realistic in comparison with normal operations.

Table 109 Simulation Results Scenario 1 All Alternatives

	ShiftOccupancyRate (percentage)	TotalDeliveryTimeLockerAVG (hours)	TotalDeliveryTimeLockerMIN (hours)	TotalDeliveryTimeLockerMAX (hours)	ShiftOccupancyRate (percentage)	TotalDeliveryTimeNormalAVG (hours)	TotalDeliveryTimeNormalMIN (hours)	TotalDeliveryTimeNormalMAX (hours)	AvgTimeParcelInLocker	LockerOccupancyRate #distributionlockers (percentage)	LockerOccupancyRate #collectionlockers (percentage)	AvgNumberInLocker	Undelivered	Retail Distribution	Locker Distribution	House Distribution	Dock Distribution
Alternative 0	X	X	X	X	64.83%	5.51	2.49	6.41	X	X	X	X	371	1115	X	7777	9263
Alternative 1 M, L, XL lockers	X	X	X	X	64.55%	5.49	2.37	6.34	27.13	X	66.50%	277	0	X	1428	7464	8893
Alternative 1 S lockers	X	X	X	X	67.14%	5.71	2.74	6.47	27.28	X	65.95%	200	460	X	1038	7846	9344
Alternative 1 XS lockers	X	X	X	X	68.83%	5.85	3.15	6.53	27.05	X	59.10%	148	771	X	779	8084	9634
Alternative 2 M, L, XL lockers	45.47%	3.86	3.77	3.95	80.68%	6.86	6.62	7.10	26.28	X	68.78%	1563	0	203	7576	1054	8833
Alternative 2 S lockers	40.55%	3.45	2.42	3.74	66.52%	5.65	2.59	6.53	27.48	X	60.92%	1088	0	494	5546	2822	8862
Alternative 2 XS lockers	40.53%	3.44	2.42	3.76	66.39%	5.64	2.61	6.53	27.46	X	64.37%	869	87	626	4431	3779	8836
Alternative 3 M, L, XL lockers	45.47%	3.86	3.77	3.95	80.68%	6.86	6.62	7.10	26.28	99.66%	X	1563	0	203	7576	1054	8833
Alternative 3 S lockers	40.55%	3.45	2.42	3.74	66.52%	5.65	2.59	6.53	27.48	92.37%	X	1088	0	494	5546	2822	8862
Alternative 3 XS lockers	40.53%	3.44	2.42	3.76	66.39%	5.64	2.61	6.53	27.46	96.56%	X	869	87	626	4431	3779	8836

On average a delivery route in the current situation takes 5 and a half hours. The researcher has delivered parcels as well as part of his research and has been working for the same number of hours. Asking delivery drivers themselves this operating time is indeed average for delivery of parcels. This means the simulation performs close to reality, thus having good perspective for the alternatives that have been designed.
Alternative 1 is performing almost the same as the current situation regarding operating time. This is a positive aspect. Since the FTHR is much higher but it doesn't take that much more time delivering. Looking at the occupancy of the lockers the lockers have relatively a lot of space left. This due to the fact alternative 1 has extra capacity due to collection possibilities as well. Looking at the simulation and the operating time, when collection is added the alternative still performs within the 8.5 hour operating time and thus performs well. The alternative however needs to be operated with the same amount of delivery drivers as the current situation since the operating time for one single driver is too large to perform twice per day.
Alternative 2 has two different routes. A normal delivery route which is comparable to alternative 0 and a locker route. In Table 109 this distinction can be seen as well. The normal route is performing the almost the same as alternative 0. However, for alternative 2 M, L, XL lockers the operating time is relatively high. This is due to the reason that instead of having 8 delivery vans, just 1 delivery van is driving the route. This means it's more sensitive for any external effects that can occur. The occupancy rate of the normal route is 14% higher than the alternative 2 S lockers and alternative 2 XS lockers this is a high number. For the locker route this amount to be 5%, when looking more closely into details the difference is in the minimum time it takes for alternative 2 M, L, XL lockers that causes the higher percentage. Looking at the occupancy rate of the lockers, in relation to alternative 1 this is comparable. Overall it is the same, per variant for the alternatives it differs a bit but not that much. Taking into account the fact that only distribution is simulated and collection not, therefore having more space. Looking at the occupancy rate of the locker routes this is below 50% which means that the work two delivery vans are doing at the moment can be replaced by one delivery van. For alternative 2 S and XS lockers this brings a good potential in cutting the labour force in half and thus saving a lot of costs. Though this is only distribution for collection extra time should be added. However, collecting parcels takes significantly less time. Since the parcels only need to be scanned and placed in the delivery van. This is an operation which doesn't cost a lot of time. Therefore alternative 2 has great potential looking at the simulation.

Alternative 3 has two different routes as well. This alternative performs exactly the same as alternative 2 when looking at operating times. Due to the reason being that the simulation could only be performed with distribution routes. However, when looking at the occupancy rate of the lockers this is high. With the base scenario as Table 109 displays alternative 3 M, L, XL lockers almost has a 100% occupancy rate for its lockers, the other variants are high as well with 93% and 97%. This means that delivery will be difficult when one or two parcel lockers are out of service for example. Or when people take a bit longer collecting their parcels, this means that the delivery needs to be diverted to another location, and thus the delivery model as it has been designed does not perform according to standard. Operation needs to be perfect every day and all the factors need to be perfect as well for this delivery model to be of optimal performance. Further along in this appendix the variables will be changed and a sensitivity analysis is performed to see what happens when this delivery models performs different from standard operation.

Comparing the different alternatives with each other it is hard to make a selection which alternative performs the best. All alternatives are performing without any bugs or failures, this is a positive result. Due to lack of time and expertise it wasn't possible to add collection to the simulation, this affects the conclusion that can be drawn from the simulation results. However, it is still possible to make an assumption based on the results of the simulation as it is right now. Ranking the alternatives is therefore hard as well. Since alternative 0 is the current alternative and performs similar to alternative 1 there it is not possible to draw the conclusion that a difference is noticeable. Alternative 1 and alternative 0 perform similarly. Alternative 2 performs better when looking at the overall simulation, there is room in the lockers and the locker routes have good potential to save on labour force. For alternative 3 the potential to cut on labour force is even better since no collection is required. However, when looking at the occupancy rate of the lockers this alternative performs relatively bad. Taking all this into consideration it can be concluded that alternative 3 performs the worst, alternative 0 and alternative 1 perform equally good being average and alternative 2 performs the best.

Alternative 0 Simulation Results

In Table 110 below nine different scenarios are displayed with their results. The nine-scenarios have different input variables as can be seen in the paragraph of Simulation Variables Alternatives. The model performs good. Varying the different input variables doesn't generate a difference in parcel distribution, this was expected to happen since the input variables do not have a direct link with the distribution. Though other things do change, scenario 2 and 3 are the two scenarios were things differ substantially. The other scenario's do not differ that much from the base scenario. Scenario 2 and 3 differ more due to the fact the input variables that have been changed affect the unloading time of the vehicle at house distribution. Since the majority of the parcels is being delivered to house, the expectation would be that different results can be seen. Especially in scenario 3 it can be concluded that the maximum delivery time exceed a normal working day of 8.5 hours. Though the average is still within limits, meaning it would be more an exception that normal operations. The input variable for scenario 3 almost doubled and operations are still relatively good. With the rest of the scenario's the model is operating according to expectations. Differences are not that large and the model performs good.

Table 110 Alternative 0 Simulation Results

	ShiftOccupanceRate (percentage)	TotalDeliveryTimeAVG (hours)	TotalDeliveryTimeMIN (hours)	TotalDeliveryTimeMAX (hours)	Undelivered	Retail Distribution	House Distribution	Dock Distribution
Scenario 1	64.83%	5.51	2.49	6.41	371	1115	7777	9263
Scenario 2	75.42%	6.41	2.53	7.58	372	1116	7779	9267
Scenario 3	86.06%	7.31	2.58	8.74	372	1116	7782	9269
Scenario 4	64.83%	5.51	2.49	6.41	371	1115	7777	9263
Scenario 5	66.34%	5.64	2.49	6.58	373	1114	7778	9265
Scenario 6	67.87%	5.77	2.50	6.75	370	1116	7775	9262
Scenario 7	64.83%	5.51	2.49	6.41	371	1115	7777	9263
Scenario 8	65.07%	5.53	2.49	6.44	372	1114	7778	9264
Scenario 9	65.32%	5.55	2.49	6.46	371	1113	7776	9261

Alternative 1 Simulation Results

Alternative 1 M, L, XL lockers

In Table 111 below eighteen different scenarios can be seen. The first nine scenarios have the standard input variables for the process time of the locker and the last nine scenarios have a different process time for the lockers as can be seen in paragraph Simulation Variables Alternatives. Amongst the eighteen-different scenario's the distribution of the parcels does not change as expected. Since alternative 1 is similar to alternative 0 but the retail location has been replaced by a parcel locker, largely the results are similar to alternative 0. Scenario 3 and scenario 12 are the scenarios with a larger average unloading time for house distribution. Since the majority of the parcels still are distributed to house distribution this is in the line of expectation. Interesting to see with alternative 1 M, L, XL lockers is to take a look at the occupancy rate of the parcel lockers. This alternative is a collection model as well, thus the focus point is on the occupancy rate for the collection lockers. However, to start with the distribution only since this has been simulated. It can be seen that with the expected process time of the parcel lockers the average occupancy is around 96%. This is high and no room for alterations is possible. When the process time on average goes up it can be seen that there even is a lack of parcel lockers available and parcels cannot be placed in lockers anymore. Which isn't good, since the remaining parcels that couldn't fit need to be brought back to the depot and the model performs not according to operation. This is important to take into consideration. However, with the number collection lockers there is around 25% to 33% room left for collection. A number that is preferred by PostNL.

Table 111 Alternative 1 M, L, XL lockers

	ShiftOccupancyRate (percentage)	TotalDeliveryTimeAVG (hours)	TotalDeliveryTimeMIN (hours)	TotalDeliveryTimeMAX (hours)	AvgTimeParcelInLocker (hours)	LockerOccupancyRate #distributionlockers (percentage)	LockerOccupancyRate #collectionlockers (percentage)	AvgNumberInLocker	Undelivered	Locker Distribution	House Distribution	Dock Distribution
Scenario 1	64.55%	5.49	2.37	6.34	27.13	96.06%	66.50%	277	0	1428	7464	8893
Scenario 2	76.17%	6.47	2.38	7.60	27.13	95.88%	66.38%	276	0	1428	7464	8893
Scenario 3	87.78%	7.46	2.39	8.86	27.05	95.53%	66.13%	275	0	1428	7464	8893
Scenario 4	64.55%	5.49	2.37	6.34	27.13	96.06%	66.50%	277	0	1428	7464	8893
Scenario 5	64.55%	5.49	2.37	6.34	27.13	96.06%	66.50%	277	0	1428	7464	8893
Scenario 6	64.55%	5.49	2.37	6.34	27.13	96.06%	66.50%	277	0	1428	7464	8893
Scenario 7	64.55%	5.49	2.37	6.34	27.13	96.06%	66.50%	277	0	1428	7464	8893
Scenario 8	65.66%	5.58	2.37	6.45	27.24	96.37%	66.72%	278	0	1428	7464	8893
Scenario 9	66.77%	5.68	2.37	6.57	27.25	96.37%	66.72%	278	0	1428	7464	8893
Scenario 10	64.55%	5.49	2.37	6.34	30.43	106.86%	73.98%	308	0	1428	7464	8893
Scenario 11	76.17%	6.47	2.38	7.60	30.43	106.58%	73.78%	307	0	1428	7464	8893
Scenario 12	87.78%	7.46	2.39	8.86	30.36	106.16%	73.50%	306	0	1428	7464	8893
Scenario 13	64.55%	5.49	2.37	6.34	30.43	106.86%	73.98%	308	0	1428	7464	8893
Scenario 14	64.55%	5.49	2.37	6.34	30.43	106.86%	73.98%	308	0	1428	7464	8893
Scenario 15	64.55%	5.49	2.37	6.34	30.43	106.86%	73.98%	308	0	1428	7464	8893
Scenario 16	64.55%	5.49	2.37	6.34	30.43	106.86%	73.98%	308	0	1428	7464	8893
Scenario 17	65.66%	5.58	2.37	6.45	30.55	107.19%	74.21%	309	0	1428	7464	8893
Scenario 18	66.77%	5.68	2.37	6.57	30.55	107.15%	74.18%	309	0	1428	7464	8893

Alternative 1 S lockers

In Table 112 below eighteen different scenarios can be seen. The first nine scenarios have the standard input variables for the process time of the locker and the last nine scenarios have a different process time for the lockers as can be seen in paragraph Simulation Variables Alternatives. Amongst the eighteen-different scenario's the distribution of the parcels does not change as expected. Since alternative 1 is similar to alternative 0 but the retail location has been replaced by a parcel locker, largely the results are similar to alternative 0. Scenario 3 and scenario 12 are the scenarios with a larger average unloading time for house distribution. Since the majority of the parcels still are distributed to house distribution this is in the line of expectation. Interesting to see with alternative 1 S lockers is to take a look at the occupancy rate of the parcel lockers. This alternative is a collection model as well, thus the focus point is on the occupancy rate for the collection lockers. However, to start with the distribution only since this has been simulated. It can be seen that with the expected process time of the parcel lockers the average occupancy is already 105%. This is too high and means with normal operation this model doesn't perform according to standard, which is having room for all parcels initially delivered. When the process time on average goes up it can be seen that there even is larger a lack of parcel lockers available and parcels cannot be placed in lockers anymore, a number of 20% shortage can be seen. Which isn't good, since the remaining parcels that couldn't fit need to be brought back to the depot and the model performs not according to operation. This is important to take into consideration. However, with the number collection lockers there is around 27% to 35% room left for collection. A number that is preferred by PostNL.

Table 112 Alternative 1 S lockers

	ShiftOccupancyRate (percentage)	TotalDeliveryTimeAVG (hours)	TotalDeliveryTimeMIN (hours)	TotalDeliveryTimeMAX (hours)	AvgTimeParcelInLocker	LockerOccupancyRate #distributionlockers (percentage)	LockerOccupancyRate #collectionlockers (percentage)	AvgNumberInLocker	Undelivered	LockerDistribution	HouseDistribution	DockDistribution
Scenario 1	67.14%	5.71	2.74	6.47	27.28	105.52%	65.95%	200	460	1038	7846	9344
Scenario 2	79.35%	6.74	2.86	7.75	27.14	105.23%	65.77%	200	461	1041	7842	9345
Scenario 3	91.56%	7.78	2.98	9.04	26.92	104.28%	65.17%	198	462	1038	7847	9347
Scenario 4	67.14%	5.71	2.74	6.47	27.28	105.52%	65.95%	200	460	1038	7846	9344
Scenario 5	67.49%	5.74	2.74	6.51	27.22	105.41%	65.88%	200	459	1038	7846	9343
Scenario 6	67.84%	5.77	2.75	6.54	27.18	105.31%	65.82%	200	461	1039	7841	9341
Scenario 7	67.14%	5.71	2.74	6.47	27.28	105.52%	65.95%	200	460	1038	7846	9344
Scenario 8	67.96%	5.78	2.74	6.55	27.13	105.05%	65.66%	200	462	1037	7849	9348
Scenario 9	68.78%	5.85	2.75	6.63	27.07	104.71%	65.44%	199	461	1038	7848	9347
Scenario 10	67.14%	5.71	2.74	6.47	30.59	117.20%	73.25%	223	460	1038	7846	9344
Scenario 11	79.35%	6.74	2.86	7.75	30.47	116.84%	73.02%	222	461	1041	7842	9345
Scenario 12	91.56%	7.78	2.98	9.04	30.27	115.80%	72.37%	220	462	1038	7847	9347
Scenario 13	67.14%	5.71	2.74	6.47	30.59	117.20%	73.25%	223	460	1038	7846	9344
Scenario 14	67.49%	5.74	2.74	6.51	30.54	117.07%	73.17%	222	459	1038	7846	9343
Scenario 15	67.84%	5.77	2.75	6.54	30.49	117.00%	73.13%	222	461	1039	7841	9341
Scenario 16	67.14%	5.71	2.74	6.47	30.59	117.20%	73.25%	223	460	1038	7846	9344
Scenario 17	67.96%	5.78	2.74	6.55	30.45	116.70%	72.94%	222	462	1037	7849	9348
Scenario 18	68.78%	5.85	2.75	6.63	30.39	116.39%	72.75%	221	461	1038	7848	9347

Alternative 1 XS lockers

In Table 113 below eighteen different scenarios can be seen. The first nine scenarios have the standard input variables for the process time of the locker and the last nine scenarios have a different process time for the lockers as can be seen in paragraph Simulation Variables Alternatives. Amongst the eighteen-different scenario's the distribution of the parcels does not change as expected. Since alternative 1 is similar to alternative 0 but the retail location has been replaced by a parcel locker, largely the results are similar to alternative 0. Scenario 3 and scenario 12 are the scenarios with a larger average unloading time for house distribution. Since the majority of the parcels still are distributed to house distribution this is in the line of expectation. Interesting to see with alternative 1 XS lockers is to take a look at the occupancy rate of the parcel lockers. This alternative is a collection model as well, thus the focus point is on the occupancy rate for the collection lockers. However, to start with the distribution only since this has been simulated. It can be seen that with the expected process time of the parcel lockers the average occupancy is around 99%. This is high and no room for alterations is possible. When the process time on average goes up it can be seen that there even is a lack of parcel lockers available and parcels cannot be placed in lockers anymore. Which isn't good, since the remaining parcels that couldn't fit need to be brought back to the depot and the model performs not according to operation. This is important to take into consideration. However, with the number collection lockers there is around 35% to 40% room left for collection. A number that is preferred by PostNL and even more than enough, since the preferred room left for collection is 33%.

Table 113 Alternative 1 XS lockers

	ShiftOccupancyRate (percentage)	TotalDeliveryTimeAVG (hours)	TotalDeliveryTimeMIN (hours)	TotalDeliveryTimeMAX (hours)	AvgTimeParcelInLocker	LockerOccupancyRate #distributionlockers (percentage)	LockerOccupancyRate #collectionlockers (percentage)	AvgNumberInLocker	Undelivered	LockerDistribution	HouseDistribution	DockDistribution
Scenario 1	68.83%	5.85	3.15	6.53	27.05	98.51%	59.10%	148	771	779	8084	9634
Scenario 2	81.41%	6.92	3.39	7.82	26.97	98.08%	58.85%	147	770	777	8085	9632
Scenario 3	93.98%	7.99	3.63	9.10	27.04	98.22%	58.93%	147	768	778	8086	9632
Scenario 4	68.83%	5.85	3.15	6.53	27.05	98.51%	59.10%	148	771	779	8084	9634
Scenario 5	69.44%	5.90	3.16	6.59	27.22	98.86%	59.31%	148	769	776	8087	9632
Scenario 6	70.02%	5.95	3.17	6.64	27.01	98.68%	59.21%	148	773	780	8082	9635
Scenario 7	68.83%	5.85	3.15	6.53	27.05	98.51%	59.10%	148	771	779	8084	9634
Scenario 8	69.43%	5.90	3.16	6.58	27.22	99.22%	59.53%	149	766	779	8087	9632
Scenario 9	70.05%	5.95	3.16	6.64	27.27	99.27%	59.56%	149	769	779	8085	9632
Scenario 10	68.83%	5.85	3.15	6.53	30.39	109.45%	65.67%	164	771	779	8084	9634
Scenario 11	81.41%	6.92	3.39	7.82	30.33	108.91%	65.34%	163	770	777	8085	9632
Scenario 12	93.98%	7.99	3.63	9.10	30.39	108.92%	65.35%	163	768	778	8086	9632
Scenario 13	68.83%	5.85	3.15	6.53	30.39	109.45%	65.67%	164	771	779	8084	9634
Scenario 14	69.44%	5.90	3.16	6.59	30.57	109.70%	65.82%	165	769	776	8087	9632
Scenario 15	70.02%	5.95	3.17	6.64	30.32	109.62%	65.77%	164	773	780	8082	9635
Scenario 16	68.83%	5.85	3.15	6.53	30.39	109.45%	65.67%	164	771	779	8084	9634
Scenario 17	69.43%	5.90	3.16	6.58	30.55	110.10%	66.06%	165	766	779	8087	9632
Scenario 18	70.05%	5.95	3.16	6.64	30.60	110.17%	66.10%	165	769	779	8085	9632

Alternative 2 Simulation Results

Alternative 2 M, L, XL lockers

In Table 114 and Table 115 below eighteen different scenarios can be seen. The first nine scenarios have the standard input variables for the process time of the locker and the last nine scenarios have a different process time for the lockers as can be seen in paragraph Simulation Variables Alternatives. Table 114 displays the operating times for all the different scenarios. As can be seen scenario 3 and scenario 12 are important for the normal delivery route. Since for the normal delivery route in an average situation overtime needs to be made. The rest of the scenarios is relatively high as well regarding occupancy rate of the operating time. When looking at the locker route the occupancy rate is around 45%, which means 1 delivery van could drive the route twice, thus 2 delivery vans can be replaced by 1 delivery van. However, for the scenario's 8,9,17 and 18 this is not the case. Due to the reasons being that the unloading time for lockers increases. For scenario 9 and 18 the unloading time is on average twice as much as the base scenario. This is important to take into account, since this means that drivers need to focus a lot on efficiency when filling up lockers. A 46% occupancy rate does not leave a lot of room for collection when trying to cut off labour as well, therefore this model is a close fit.

Table 114 Alternative 2 M, L, XL lockers

	ShiftOccupancyRate (percentage)	TotalDeliveryTimeLockerAVG (hours)	TotalDeliveryTimeLockerMIN (hours)	TotalDeliveryTimeLockerMAX (hours)	ShiftOccupancyRate (percentage)	TotalDeliveryTimeNormalAVG (hours)	TotalDeliveryTimeNormalMIN (hours)	TotalDeliveryTimeNormalMAX (hours)
Scenario 1	45.47%	3.86	3.77	3.95	80.68%	6.86	6.62	7.10
Scenario 2	45.47%	3.86	3.77	3.95	94.45%	8.03	7.72	8.34
Scenario 3	45.47%	3.86	3.77	3.94	108.25%	9.20	8.82	9.59
Scenario 4	45.47%	3.86	3.77	3.95	80.68%	6.86	6.62	7.10
Scenario 5	45.47%	3.86	3.77	3.95	80.68%	6.86	6.62	7.10
Scenario 6	45.47%	3.86	3.77	3.95	80.68%	6.86	6.62	7.10
Scenario 7	45.47%	3.86	3.77	3.95	80.68%	6.86	6.62	7.10
Scenario 8	53.73%	4.57	4.43	4.68	80.65%	6.86	6.61	7.10
Scenario 9	61.98%	5.27	5.08	5.42	80.62%	6.85	6.60	7.10
Scenario 10	45.47%	3.86	3.77	3.95	80.68%	6.86	6.62	7.10
Scenario 11	45.47%	3.86	3.77	3.95	94.45%	8.03	7.72	8.34
Scenario 12	45.47%	3.86	3.77	3.94	108.25%	9.20	8.82	9.59
Scenario 13	45.47%	3.86	3.77	3.95	80.68%	6.86	6.62	7.10
Scenario 14	45.47%	3.86	3.77	3.95	80.68%	6.86	6.62	7.10
Scenario 15	45.47%	3.86	3.77	3.95	80.68%	6.86	6.62	7.10
Scenario 16	45.47%	3.86	3.77	3.95	80.68%	6.86	6.62	7.10
Scenario 17	53.73%	4.57	4.43	4.68	80.65%	6.86	6.61	7.10
Scenario 18	61.98%	5.27	5.08	5.42	80.62%	6.85	6.60	7.10

Looking at Table 115 the occupancy rate of the lockers can be seen. Since alternative 2 is a distribution and collection delivery model, the number of lockers with collection is taken into account. Seen in the table is an average occupancy rate of 69% and 76% of the parcel lockers for the different scenarios. This means there is still plenty of room for collection and possible extra parcels for distribution. The benefit of this alternative is the situation that the retail location is still available as well. This means that when a parcel locker is full, parcels can be diverted to a retail location. This can be the case for collection and for distribution as well.

Table 115 Alternative 2 M, L, XL lockers

	AvgTimeParcelInLocker	LockerOccupancyRate #collectionlockers (percentage)	AvgNumberInLocker	Undelivered	RetailDistribution	LockerDistribution	HouseDistribution	DockDistribution
Scenario 1	26.28	68.78%	1563	0	203	7576	1054	8833
Scenario 2	26.30	68.80%	1563	0	203	7576	1054	8833
Scenario 3	26.26	68.73%	1562	0	203	7576	1054	8833
Scenario 4	26.28	68.78%	1563	0	203	7576	1054	8833
Scenario 5	26.28	68.78%	1563	0	203	7576	1054	8833
Scenario 6	26.28	68.78%	1563	0	203	7576	1054	8833
Scenario 7	26.28	68.78%	1563	0	203	7576	1054	8833
Scenario 8	26.26	68.47%	1556	0	203	7576	1054	8833
Scenario 9	26.29	68.30%	1552	0	203	7576	1054	8833
Scenario 10	29.76	75.90%	1725	0	203	7576	1054	8833
Scenario 11	29.78	75.92%	1725	0	203	7576	1054	8833
Scenario 12	29.75	75.86%	1724	0	203	7576	1054	8833
Scenario 13	29.76	75.90%	1725	0	203	7576	1054	8833
Scenario 14	29.76	75.90%	1725	0	203	7576	1054	8833
Scenario 15	29.76	75.90%	1725	0	203	7576	1054	8833
Scenario 16	29.76	75.90%	1725	0	203	7576	1054	8833
Scenario 17	29.73	75.57%	1717	0	203	7576	1054	8833
Scenario 18	29.75	75.38%	1713	0	203	7576	1054	8833

Alternative 2 S Lockers

In Table 116 and Table 117 below eighteen different scenarios can be seen. The first nine scenarios have the standard input variables for the process time of the locker and the last nine scenarios have a different process time for the lockers as can be seen in paragraph Simulation Variables Alternatives. Table 116 displays the operating times for all the different scenarios. As can be seen scenario 3 and scenario 12 are important for the normal delivery route. The occupancy rate is relatively high with 87%. The rest of the scenarios is comparable to alternative 0, regarding the normal delivery route. When looking at the locker route the occupancy rate is around 41%, which means 1 delivery van could drive the route twice, thus 2 delivery vans can be replaced by 1 delivery van. However, for the scenario's 9 and 18 this is not the case. Due to the reasons being that the unloading time for lockers increases. For scenario 9 and 18 the unloading time is on average twice as much as the base scenario. This is important to take into account, since this means that drivers need to focus a lot on efficiency when filling up lockers. A 41% occupancy rate does leave room for collection as well. This is a beneficial aspect of this alternative when trying to cut labour force in half.

Table 116 Alternative 2 S lockers

	ShiftOccupancyRate (percentage)	TotalDeliveryTimeLockerAVG (hours)	TotalDeliveryTimeLockerMIN (hours)	TotalDeliveryTimeLockerMAX (hours)	ShiftOccupancyRate (percentage)	TotalDeliveryTimeNormalAVG (hours)	TotalDeliveryTimeNormalMIN (hours)	TotalDeliveryTimeNormalMAX (hours)
Scenario 1	40.55%	3.45	2.42	3.74	66.52%	5.65	2.59	6.53
Scenario 2	40.55%	3.45	2.42	3.75	76.78%	6.53	2.59	7.66
Scenario 3	40.55%	3.45	2.42	3.75	87.04%	7.40	2.59	8.78
Scenario 4	40.55%	3.45	2.42	3.74	66.52%	5.65	2.59	6.53
Scenario 5	40.55%	3.45	2.42	3.74	66.52%	5.65	2.59	6.53
Scenario 6	40.55%	3.45	2.42	3.74	66.52%	5.65	2.59	6.53
Scenario 7	40.55%	3.45	2.42	3.74	66.52%	5.65	2.59	6.53
Scenario 8	46.58%	3.96	2.42	4.41	66.55%	5.66	2.59	6.53
Scenario 9	52.63%	4.47	2.42	5.07	66.54%	5.66	2.59	6.53
Scenario 10	40.55%	3.45	2.42	3.74	66.52%	5.65	2.59	6.53
Scenario 11	40.55%	3.45	2.42	3.75	76.78%	6.53	2.59	7.66
Scenario 12	40.55%	3.45	2.42	3.75	87.04%	7.40	2.59	8.78
Scenario 13	40.55%	3.45	2.42	3.74	66.52%	5.65	2.59	6.53
Scenario 14	40.55%	3.45	2.42	3.74	66.52%	5.65	2.59	6.53
Scenario 15	40.55%	3.45	2.42	3.74	66.52%	5.65	2.59	6.53
Scenario 16	40.55%	3.45	2.42	3.74	66.52%	5.65	2.59	6.53
Scenario 17	46.58%	3.96	2.42	4.41	66.55%	5.66	2.59	6.53
Scenario 18	52.63%	4.47	2.42	5.07	66.54%	5.66	2.59	6.53

Looking at Table 117 the occupancy rate of the lockers can be seen. Since alternative 2 is a distribution and collection delivery model, the number of lockers with collection is taken into account. Seen in the table is an average occupancy rate of 61% and 68% of the parcel lockers for the different scenarios. There is not a lot of difference in occupancy rate between the different process time of the lockers, this is positive. This means there is still plenty of room for collection and possible extra parcels for distribution. The preferred percentage of room available by PostNL is around 33%, with these occupancy rates as can be seen in the table this is possible. The benefit of this alternative is the situation that the retail location is still available as well. This means that when a parcel locker is full, parcels can be diverted to a retail location. This can be the case for collection and for distribution as well.

Table 117 Alternative 2 S lockers

	AvgTimeParcelInLocker	LockerOccupancyRate # collection lockers (percentage)	AvgNumberInLocker	Undelivered	RetailDistribution	LockerDistribution	HouseDistribution	DockDistribution
Scenario 1	27.48	60.92%	1088	0	494	5546	2822	8862
Scenario 2	27.51	60.98%	1089	0	494	5546	2822	8862
Scenario 3	27.44	60.85%	1087	0	494	5546	2822	8862
Scenario 4	27.48	60.92%	1088	0	494	5546	2822	8862
Scenario 5	27.48	60.92%	1088	0	494	5546	2822	8862
Scenario 6	27.48	60.92%	1088	0	494	5546	2822	8862
Scenario 7	27.48	60.92%	1088	0	494	5546	2822	8862
Scenario 8	27.46	60.88%	1087	0	494	5546	2822	8862
Scenario 9	27.44	60.87%	1087	0	494	5546	2822	8862
Scenario 10	30.76	67.78%	1210	0	494	5546	2822	8862
Scenario 11	30.79	67.83%	1212	0	494	5546	2822	8862
Scenario 12	30.72	67.71%	1209	0	494	5546	2822	8862
Scenario 13	30.76	67.78%	1210	0	494	5546	2822	8862
Scenario 14	30.76	67.78%	1210	0	494	5546	2822	8862
Scenario 15	30.76	67.78%	1210	0	494	5546	2822	8862
Scenario 16	30.76	67.78%	1210	0	494	5546	2822	8862
Scenario 17	30.75	67.72%	1210	0	494	5546	2822	8862
Scenario 18	30.72	67.69%	1209	0	494	5546	2822	8862

Alternative 2 XS Lockers

In Table 118 and Table 119 below eighteen different scenarios can be seen. The first nine scenarios have the standard input variables for the process time of the locker and the last nine scenarios have a different process time for the lockers as can be seen in paragraph Simulation Variables Alternatives. Table 118 displays the operating times for all the different scenarios. As can be seen scenario 3 and scenario 12 are important for the normal delivery route. The occupancy rate is relatively high with 87%. The rest of the scenarios is comparable to alternative 0, regarding the normal delivery route. When looking at the locker route the occupancy rate is around 41%, which means 1 delivery van could drive the route twice, thus 2 delivery vans can be replaced by 1 delivery van. However, for the scenario's 9 and 18 this is not the case. Due to the reasons being that the unloading time for lockers increases. For scenario 9 and 18 the unloading time is on average twice as much as the base scenario. This is important to take into account, since this means that drivers need to focus a lot on efficiency when filling up lockers. A 41% occupancy rate does leave room for collection as well. This is a beneficial aspect of this alternative when trying to cut labour force in half.

Table 118 Alternative 2 XS lockers

	ShiftOccupancyRate (percentage)	TotalDeliveryTimeLockerAVG (hours)	TotalDeliveryTimeLockerMIN (hours)	TotalDeliveryTimeLockerMAX (hours)	ShiftOccupancyRate (percentage)	TotalDeliveryTimeNormalAVG (hours)	TotalDeliveryTimeNormalMIN (hours)	TotalDeliveryTimeNormalMAX (hours)
Scenario 1	40.53%	3.44	2.42	3.76	66.39%	5.64	2.61	6.53
Scenario 2	40.53%	3.45	2.42	3.76	76.68%	6.52	2.64	7.65
Scenario 3	40.54%	3.45	2.42	3.76	86.96%	7.39	2.66	8.78
Scenario 4	40.53%	3.44	2.42	3.76	66.39%	5.64	2.61	6.53
Scenario 5	40.53%	3.44	2.42	3.76	66.51%	5.65	2.61	6.54
Scenario 6	40.53%	3.44	2.42	3.76	66.63%	5.66	2.61	6.55
Scenario 7	40.53%	3.44	2.42	3.76	66.39%	5.64	2.61	6.53
Scenario 8	46.57%	3.96	2.42	4.43	66.40%	5.64	2.61	6.53
Scenario 9	52.60%	4.47	2.42	5.09	66.39%	5.64	2.61	6.52
Scenario 10	40.53%	3.44	2.42	3.76	66.39%	5.64	2.61	6.53
Scenario 11	40.53%	3.45	2.42	3.76	76.68%	6.52	2.64	7.65
Scenario 12	40.54%	3.45	2.42	3.76	86.96%	7.39	2.66	8.78
Scenario 13	40.53%	3.44	2.42	3.76	66.39%	5.64	2.61	6.53
Scenario 14	40.53%	3.44	2.42	3.76	66.51%	5.65	2.61	6.54
Scenario 15	40.53%	3.44	2.42	3.76	66.63%	5.66	2.61	6.55
Scenario 16	40.53%	3.44	2.42	3.76	66.39%	5.64	2.61	6.53
Scenario 17	46.57%	3.96	2.42	4.43	66.40%	5.64	2.61	6.53
Scenario 18	52.60%	4.47	2.42	5.09	66.39%	5.64	2.61	6.52

Looking at Table 119 the occupancy rate of the lockers can be seen. Since alternative 2 is a distribution and collection delivery model, the number of lockers with collection is taken into account. Seen in the table is an average occupancy rate of 65% and 72% of the parcel lockers for the different scenarios. There is not a lot of difference in occupancy rate between the different process time of the lockers, this is positive. This means there is still plenty of room for collection and possible extra parcels for distribution. The preferred percentage of room available by PostNL is around 33%, with these occupancy rates as can be seen in the table this is possible. The benefit of this alternative is the situation that the retail location is still available as well. This means that when a parcel locker is full, parcels can be diverted to a retail location. This can be the case for collection and for distribution as well.

Table 119 Alternative 2 XS lockers

	AvgTimeParcelInLocker	LockerOccupancyRate #collectionlockers (percentage)	AvgNumberInLocker	Undelivered	RetailDistribution	LockerDistribution	HouseDistribution	DockDistribution
Scenario 1	27.46	64.37%	869	87	626	4431	3779	8836
Scenario 2	27.45	64.36%	869	87	626	4431	3779	8836
Scenario 3	27.43	64.32%	868	87	626	4431	3779	8836
Scenario 4	27.46	64.37%	869	87	626	4431	3779	8836
Scenario 5	27.46	64.37%	869	87	626	4431	3779	8836
Scenario 6	27.46	64.37%	869	87	626	4431	3779	8836
Scenario 7	27.46	64.37%	869	87	626	4431	3779	8836
Scenario 8	27.39	64.24%	867	87	626	4431	3779	8836
Scenario 9	27.40	64.24%	867	87	626	4431	3779	8836
Scenario 10	30.75	71.62%	967	87	626	4431	3779	8836
Scenario 11	30.74	71.61%	967	87	626	4431	3779	8836
Scenario 12	30.72	71.58%	966	87	626	4431	3779	8836
Scenario 13	30.75	71.62%	967	87	626	4431	3779	8836
Scenario 14	30.75	71.62%	967	87	626	4431	3779	8836
Scenario 15	30.75	71.62%	967	87	626	4431	3779	8836
Scenario 16	30.75	71.62%	967	87	626	4431	3779	8836
Scenario 17	30.69	71.49%	965	87	626	4431	3779	8836
Scenario 18	30.70	71.48%	965	87	626	4431	3779	8836

Alternative 3 Simulation Results

Alternative 3 M, L, XL lockers

In Table 120 and Table 121 below eighteen different scenarios can be seen. The first nine scenarios have the standard input variables for the process time of the locker and the last nine scenarios have a different process time for the lockers as can be seen in paragraph Simulation Variables Alternatives. Table 120 displays the operating times for all the different scenarios. As can be seen scenario 3 and scenario 12 are important for the normal delivery route. Since for the normal delivery route in an average situation overtime needs to be made. The rest of the scenarios is relatively high as well regarding occupancy rate of the operating time. When looking at the locker route the occupancy rate is around 45%, which means 1 delivery van could drive the route twice, thus 2 delivery vans can be replaced by 1 delivery van. However, for the scenario's 8,9,17 and 18 this is not the case. Due to the reasons being that the unloading time for lockers increases. For scenario 9 and 18 the unloading time is on average twice as much as the base scenario. This is important to take into account, since this means that drivers need to focus a lot on efficiency when filling up lockers. Since this is a distribution only delivery model, this model performs good looking only at operating time.

Table 120 Alternative 3 M, L, XL lockers

	ShiftOccupancyRate (percentage)	TotalDeliveryTimeLockerAVG (hours)	TotalDeliveryTimeLockerMIN (hours)	TotalDeliveryTimeLockerMAX (hours)	ShiftOccupancyRate (percentage)	TotalDeliveryTimeNormalAVG (hours)	TotalDeliveryTimeNormalMIN (hours)	TotalDeliveryTimeNormalMAX (hours)
Scenario 1	45.47%	3.86	3.77	3.95	80.68%	6.86	6.62	7.10
Scenario 2	45.47%	3.86	3.77	3.95	94.45%	8.03	7.72	8.34
Scenario 3	45.47%	3.86	3.77	3.94	108.25%	9.20	8.82	9.59
Scenario 4	45.47%	3.86	3.77	3.95	80.68%	6.86	6.62	7.10
Scenario 5	45.47%	3.86	3.77	3.95	80.68%	6.86	6.62	7.10
Scenario 6	45.47%	3.86	3.77	3.95	80.68%	6.86	6.62	7.10
Scenario 7	45.47%	3.86	3.77	3.95	80.68%	6.86	6.62	7.10
Scenario 8	53.73%	4.57	4.43	4.68	80.65%	6.86	6.61	7.10
Scenario 9	61.98%	5.27	5.08	5.42	80.62%	6.85	6.60	7.10
Scenario 10	45.47%	3.86	3.77	3.95	80.68%	6.86	6.62	7.10
Scenario 11	45.47%	3.86	3.77	3.95	94.45%	8.03	7.72	8.34
Scenario 12	45.47%	3.86	3.77	3.94	108.25%	9.20	8.82	9.59
Scenario 13	45.47%	3.86	3.77	3.95	80.68%	6.86	6.62	7.10
Scenario 14	45.47%	3.86	3.77	3.95	80.68%	6.86	6.62	7.10
Scenario 15	45.47%	3.86	3.77	3.95	80.68%	6.86	6.62	7.10
Scenario 16	45.47%	3.86	3.77	3.95	80.68%	6.86	6.62	7.10
Scenario 17	53.73%	4.57	4.43	4.68	80.65%	6.86	6.61	7.10
Scenario 18	61.98%	5.27	5.08	5.42	80.62%	6.85	6.60	7.10

Looking at Table 121 the occupancy rate of the lockers can be seen. Since alternative 3 is a distribution only delivery model, the number of lockers with only distribution is taken into account. Seen in the table is an average occupancy rate of 100% and 110% of the parcel lockers for the different scenarios. This means this alternative is not really beneficial when looking at the simulation and the expected input variables. Meaning this model only works if everything is perfect and no other circumstances occur, which is highly unlikely. If the process time of the parcel lockers increases this model performs not good, since there is a lack of capacity in the parcel lockers.

Table 121 Alternative 3 M, L, XL lockers

	AvgTimeParcelInLocker	LockerOccupancyRate #distributionlockers (percentage)	AvgNumberInLocker	Undelivered	RetailDistribution	LockerDistribution	HouseDistribution	DockDistribution
Scenario 1	26.28	99.66%	1563	0	203	7576	1054	8833
Scenario 2	26.30	99.68%	1563	0	203	7576	1054	8833
Scenario 3	26.26	99.59%	1562	0	203	7576	1054	8833
Scenario 4	26.28	99.66%	1563	0	203	7576	1054	8833
Scenario 5	26.28	99.66%	1563	0	203	7576	1054	8833
Scenario 6	26.28	99.66%	1563	0	203	7576	1054	8833
Scenario 7	26.28	99.66%	1563	0	203	7576	1054	8833
Scenario 8	26.26	99.21%	1556	0	203	7576	1054	8833
Scenario 9	26.29	98.96%	1552	0	203	7576	1054	8833
Scenario 10	29.76	109.98%	1725	0	203	7576	1054	8833
Scenario 11	29.78	110.01%	1725	0	203	7576	1054	8833
Scenario 12	29.75	109.92%	1724	0	203	7576	1054	8833
Scenario 13	29.76	109.98%	1725	0	203	7576	1054	8833
Scenario 14	29.76	109.98%	1725	0	203	7576	1054	8833
Scenario 15	29.76	109.98%	1725	0	203	7576	1054	8833
Scenario 16	29.76	109.98%	1725	0	203	7576	1054	8833
Scenario 17	29.73	109.50%	1717	0	203	7576	1054	8833
Scenario 18	29.75	109.22%	1713	0	203	7576	1054	8833

Alternative 3 S Lockers

In Table 122 and Table 123 below eighteen different scenarios can be seen. The first nine scenarios have the standard input variables for the process time of the locker and the last nine scenarios have a different process time for the lockers as can be seen in paragraph Simulation Variables Alternatives. Table 122 displays the operating times for all the different scenarios. As can be seen scenario 3 and scenario 12 are important for the normal delivery route. The occupancy rate is relatively high with 87%. The rest of the scenarios is comparable to alternative 0, regarding the normal delivery route. When looking at the locker route the occupancy rate is around 41%, which means 1 delivery van could drive the route twice, thus 2 delivery vans can be replaced by 1 delivery van. However, for the scenario's 9 and 18 this is not the case. Due to the reasons being that the unloading time for lockers increases. For scenario 9 and 18 the unloading time is on average twice as much as the base scenario. This is important to take into account, since this means that drivers need to focus a lot on efficiency when filling up lockers. A 41% occupancy rate does leave room for situations with more parcels for example.

Table 122 Alternative 3 S lockers

	ShiftOccupancyRate (percentage)	TotalDeliveryTimeLockerAVG (hours)	TotalDeliveryTimeLockerMIN (hours)	TotalDeliveryTimeLockerMAX (hours)	ShiftOccupancyRate (percentage)	TotalDeliveryTimeNormalAVG (hours)	TotalDeliveryTimeNormalMIN (hours)	TotalDeliveryTimeNormalMAX (hours)
Scenario 1	40.55%	3.45	2.42	3.74	66.52%	5.65	2.59	6.53
Scenario 2	40.55%	3.45	2.42	3.75	76.78%	6.53	2.59	7.66
Scenario 3	40.55%	3.45	2.42	3.75	87.04%	7.40	2.59	8.78
Scenario 4	40.55%	3.45	2.42	3.74	66.52%	5.65	2.59	6.53
Scenario 5	40.55%	3.45	2.42	3.74	66.52%	5.65	2.59	6.53
Scenario 6	40.55%	3.45	2.42	3.74	66.52%	5.65	2.59	6.53
Scenario 7	40.55%	3.45	2.42	3.74	66.52%	5.65	2.59	6.53
Scenario 8	46.58%	3.96	2.42	4.41	66.55%	5.66	2.59	6.53
Scenario 9	52.63%	4.47	2.42	5.07	66.54%	5.66	2.59	6.53
Scenario 10	40.55%	3.45	2.42	3.74	66.52%	5.65	2.59	6.53
Scenario 11	40.55%	3.45	2.42	3.75	76.78%	6.53	2.59	7.66
Scenario 12	40.55%	3.45	2.42	3.75	87.04%	7.40	2.59	8.78
Scenario 13	40.55%	3.45	2.42	3.74	66.52%	5.65	2.59	6.53
Scenario 14	40.55%	3.45	2.42	3.74	66.52%	5.65	2.59	6.53
Scenario 15	40.55%	3.45	2.42	3.74	66.52%	5.65	2.59	6.53
Scenario 16	40.55%	3.45	2.42	3.74	66.52%	5.65	2.59	6.53
Scenario 17	46.58%	3.96	2.42	4.41	66.55%	5.66	2.59	6.53
Scenario 18	52.63%	4.47	2.42	5.07	66.54%	5.66	2.59	6.53

Looking at Table 123 the occupancy rate of the lockers can be seen. Since alternative 3 is a distribution only delivery model, the number of lockers with only distribution is taken into account. Seen in the table is an average occupancy rate of 93% and 103% of the parcel lockers for the different scenarios. A 93% occupancy rate is high but manageable, since this alternative has retail locations available as well. However, when the process time of the parcel lockers increases capacity becomes an issue and thus the delivery model performs not according to operation, this is not beneficial.

Table 123 Alternative 3 S lockers

	AvgTimeParcelInLocker	LockerOccupancyRate #distributionlockers (percentage)	AvgNumberInLocker	Undelivered	RetailDistribution	LockerDistribution	HouseDistribution	DockDistribution
Scenario 1	27.48	92.37%	1088	0	494	5546	2822	8862
Scenario 2	27.51	92.45%	1089	0	494	5546	2822	8862
Scenario 3	27.44	92.26%	1087	0	494	5546	2822	8862
Scenario 4	27.48	92.37%	1088	0	494	5546	2822	8862
Scenario 5	27.48	92.37%	1088	0	494	5546	2822	8862
Scenario 6	27.48	92.37%	1088	0	494	5546	2822	8862
Scenario 7	27.48	92.37%	1088	0	494	5546	2822	8862
Scenario 8	27.46	92.30%	1087	0	494	5546	2822	8862
Scenario 9	27.44	92.28%	1087	0	494	5546	2822	8862
Scenario 10	30.76	102.76%	1210	0	494	5546	2822	8862
Scenario 11	30.79	102.85%	1212	0	494	5546	2822	8862
Scenario 12	30.72	102.65%	1209	0	494	5546	2822	8862
Scenario 13	30.76	102.76%	1210	0	494	5546	2822	8862
Scenario 14	30.76	102.76%	1210	0	494	5546	2822	8862
Scenario 15	30.76	102.76%	1210	0	494	5546	2822	8862
Scenario 16	30.76	102.76%	1210	0	494	5546	2822	8862
Scenario 17	30.75	102.68%	1210	0	494	5546	2822	8862
Scenario 18	30.72	102.62%	1209	0	494	5546	2822	8862

Alternative 3 XS Lockers

In Table 124 and Table 125 below eighteen different scenarios can be seen. The first nine scenarios have the standard input variables for the process time of the locker and the last nine scenarios have a different process time for the lockers as can be seen in paragraph Simulation Variables Alternatives. Table 124 displays the operating times for all the different scenarios. As can be seen scenario 3 and scenario 12 are important for the normal delivery route. The occupancy rate is relatively high with 87%. The rest of the scenarios is comparable to alternative 0, regarding the normal delivery route. When looking at the locker route the occupancy rate is around 41%, which means 1 delivery van could drive the route twice, thus 2 delivery vans can be replaced by 1 delivery van. However, for the scenario's 9 and 18 this is not the case. Due to the reasons being that the unloading time for lockers increases. For scenario 9 and 18 the unloading time is on average twice as much as the base scenario. This is important to take into account, since this means that drivers need to focus a lot on efficiency when filling up lockers.

Table 124 Alternative 3 XS lockers

	ShiftOccupancyRate (percentage)	TotalDeliveryTimeLockerAVG (hours)	TotalDeliveryTimeLockerMIN (hours)	TotalDeliveryTimeLockerMAX (hours)	ShiftOccupancyRate (percentage)	TotalDeliveryTimeNormalAVG (hours)	TotalDeliveryTimeNormalMIN (hours)	TotalDeliveryTimeNormalMAX (hours)
Scenario 1	40.53%	3.44	2.42	3.76	66.39%	5.64	2.61	6.53
Scenario 2	40.53%	3.45	2.42	3.76	76.68%	6.52	2.64	7.65
Scenario 3	40.54%	3.45	2.42	3.76	86.96%	7.39	2.66	8.78
Scenario 4	40.53%	3.44	2.42	3.76	66.39%	5.64	2.61	6.53
Scenario 5	40.53%	3.44	2.42	3.76	66.51%	5.65	2.61	6.54
Scenario 6	40.53%	3.44	2.42	3.76	66.63%	5.66	2.61	6.55
Scenario 7	40.53%	3.44	2.42	3.76	66.39%	5.64	2.61	6.53
Scenario 8	46.57%	3.96	2.42	4.43	66.40%	5.64	2.61	6.53
Scenario 9	52.60%	4.47	2.42	5.09	66.39%	5.64	2.61	6.52
Scenario 10	40.53%	3.44	2.42	3.76	66.39%	5.64	2.61	6.53
Scenario 11	40.53%	3.45	2.42	3.76	76.68%	6.52	2.64	7.65
Scenario 12	40.54%	3.45	2.42	3.76	86.96%	7.39	2.66	8.78
Scenario 13	40.53%	3.44	2.42	3.76	66.39%	5.64	2.61	6.53
Scenario 14	40.53%	3.44	2.42	3.76	66.51%	5.65	2.61	6.54
Scenario 15	40.53%	3.44	2.42	3.76	66.63%	5.66	2.61	6.55
Scenario 16	40.53%	3.44	2.42	3.76	66.39%	5.64	2.61	6.53
Scenario 17	46.57%	3.96	2.42	4.43	66.40%	5.64	2.61	6.53
Scenario 18	52.60%	4.47	2.42	5.09	66.39%	5.64	2.61	6.52

Looking at Table 125 the occupancy rate of the lockers can be seen. Since alternative 3 is a distribution and collection delivery model, the number of lockers with collection is taken into account. Seen in the table is an average occupancy rate of 97% and 107% of the parcel lockers for the different scenarios. A 97% occupancy rate is high and means operation needs to be perfect every single day, when a parcel locker is damaged or any other external circumstance occurs this will cause a failure in the delivery model. As well, when the process time of the parcel lockers increases capacity becomes an issue and thus the delivery model performs not according to operation, this is not beneficial.

Table 125 Alternative 3 XS lockers

	AvgTimeParcelInLocker	LockerOccupancyRate #distributionlockers (percentage)	AvgNumberInLocker	Undelivered	RetailDistribution	LockerDistribution	HouseDistribution	DockDistribution
Scenario 1	27.46	96.56%	869	87	626	4431	3779	8836
Scenario 2	27.45	96.54%	869	87	626	4431	3779	8836
Scenario 3	27.43	96.48%	868	87	626	4431	3779	8836
Scenario 4	27.46	96.56%	869	87	626	4431	3779	8836
Scenario 5	27.46	96.56%	869	87	626	4431	3779	8836
Scenario 6	27.46	96.56%	869	87	626	4431	3779	8836
Scenario 7	27.46	96.56%	869	87	626	4431	3779	8836
Scenario 8	27.39	96.36%	867	87	626	4431	3779	8836
Scenario 9	27.40	96.37%	867	87	626	4431	3779	8836
Scenario 10	30.75	107.43%	967	87	626	4431	3779	8836
Scenario 11	30.74	107.42%	967	87	626	4431	3779	8836
Scenario 12	30.72	107.36%	966	87	626	4431	3779	8836
Scenario 13	30.75	107.43%	967	87	626	4431	3779	8836
Scenario 14	30.75	107.43%	967	87	626	4431	3779	8836
Scenario 15	30.75	107.43%	967	87	626	4431	3779	8836
Scenario 16	30.75	107.43%	967	87	626	4431	3779	8836
Scenario 17	30.69	107.24%	965	87	626	4431	3779	8836
Scenario 18	30.70	107.22%	965	87	626	4431	3779	8836