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MASTER THESIS

Lead time reduction in the transport of reverse parcels

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Industrial Engineering and Management

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Master Thesis

Lead time reduction in the transport of reverse parcels

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Preface

With great pleasure I present this thesis, which is the result of my graduation project at Company X in Place A. This thesis marks an end of five years of study and is written in order to obtain my master's degree in Industrial Engineering and Management at the University of Twente in Enschede. I am glad that Company X gives me the opportunity to do my graduation project at the company. Therefore, I would like to thank several people who contributed to this result.

I thank the people at Company X for their contributions to this research. During this period, I experienced Company X as an open-minded company, where people are very helpful. Especially, I would like to thank my supervisors of the company for their guidance and collaboration during this research.

Moreover, I would like to thank my supervisors at the university, Eduardo Lalla and Leo van der Wegen for the feedback sessions. Your feedback on my own decisions, writing style, and structure of the report greatly contributed to this result. Also, I would like to thank Thijs for his feedback on my master's thesis. The sessions together at the university were helpful to reach this result.

Lastly, I would like to thank my family and friends who supported me during my graduation period.

Jordy Zomerdijk

Enschede, September 2019

Management summary

This research is conducted at Company X. Company X offers customized supply chain solutions for their clients. The reverse parcel process of five clients often takes more time than agreed in the Service Level Agreement (SLA). Due to this high lead time, the company cannot fulfil the SLA with its clients. Company X has the desire to reach a service level of 95 percent, which means that 95 percent of the reverse parcels must be back in the warehouse within the maximum lead time as stated in the SLA. Therefore, we formulate the following main research question:

How could Company X shorten its lead times of the reverse parcels, such that the desired service level of 95 percent is reached?

To answer this research question, we first analyse the performance of the current situation. We identify the number of reverse parcels for each client, based on historical data. Next, current lead times and the percentage of parcels above the maximum SLA lead times are computed. We conclude that the following five causes contribute to a high lead time:

- **Cause 1**: No daily pickup at carrier
- **Cause 2**: Mismatch between arrival and departure time truck
- **Cause 3**: Parcel has to travel multiple distances/hubs
- **Cause 4**: Uncertainty about number of reverse parcels
- **Cause 5**: Missed scans

We conclude that the first four causes relates to the scheduling of pickups and deliveries of parcels under uncertainty. Therefore, a literature review is performed on models to analyse a truck schedule in a cross-docking network. The fifth cause is a quality issue. Due to missed scans, parcels get lost and this causes a high lead time. In the literature, we find three types of models to analyse a truck schedule in a cross-docking network: truck scheduling, vehicle routing, and service network design models. The stochastic and robust variants of these models are modelled by using simulation. We conclude that simulation is a suitable approach to evaluate the reverse process of parcels at Company X, since simulation has a stochastic nature, so it incorporates the uncertainty in truck scheduling. Moreover, simulation is time based and therefore applicable to our research, since we deal with lead times. Discrete-event simulation (DES) is an appropriate type for this research, because the state of the system changes at discrete points in time. Moreover, discrete-event simulation is frequently used in distribution and planning problems, and more specific in analysing cross-docking networks.

Before building the simulation model, we describe the components of the model. We define which input data is needed and what the output parameters have to be. Moreover, we describe the scope and assumptions of the model. After these components have been clarified, we create flowcharts to describe the decision processes in the simulation model. Next, our model is verified and validated to make sure that the model presents the reality well enough. Lastly, we create the experimental design. With the simulation model, the performance of four scenarios are evaluated for the pickup of parcels at each carrier:

- **Scenario 1**: *Indirect transport* and the *current opening hours*
- **Scenario 2**: *Indirect transport* and the *extending opening hours*
- **Scenario 3**: *Direct transport* and the *current opening hours*
- **Scenario 4**: *Direct transport* and the *extending opening hours*

In consultation with my company supervisors, we conclude that Scenario 1 is the most preferred scenario to apply, since this scenario requires the least changes compared to the current situation and it is considered as the least costly scenario. Further, Scenario 2 is the second most preferred scenario, and

Scenario 3 and 4, the third and fourth most preferred scenario, respectively. The ranking with respect to costs of the scenarios is the same. We select for each maximum SLA lead time the minimal required scenario, based on this ranking and on the condition that the 95 percent service level is met. Table 1 shows the minimal required scenarios for each maximum SLA lead time of each carrier. In addition, it shows the reduction in average lead time compared to the current situation. For the carriers Carrier C, Carrier D, and Carrier E, it is not viable to have a second pickup on the same day, since the number of parcels per day is low. As a consequence, it would be too costly to have a second truck on the same day which picks up the parcels.

Carrier – Max SLA Lead Time	Pickup *once* a day Minimal required scenario	% Reduction in Average Lead Time	Pickup *twice* a day Minimal required scenario	% Reduction in Average Lead Time
Carrier A				
3 days	Scenario 4 - 5x/week	54.8 %	Scenario 2 - 12x/week	50.0 %
4 days	Scenario 2 - 5x/week	44.4 %	Scenario 2 - 10x/week	51.1 %
5 days	Scenario 1 - 5x/week	23.3 %	Scenario 1 - 10x/week	30.2 %
Carrier B				
5 days	Scenario 1 – 5x/week	32.6 %	Scenario 1 – 10x/week	34.8 %
6 days	Scenario 1 – 5x/week	27.9 %	Scenario 1 – 10x/week	30.2 %
Carrier C	None of the scenarios reach the 95 percent service level			
Carrier D				
6 days	Scenario 4 – 5x/week	34.6 %		
7 days	Scenario 4 – 4x/week	37.1 %		
Carrier E	None of the scenarios reach the 95 percent service level			
Carrier F				
5 days	Scenario 4 - 5x/week	78.4 %	Scenario 3 - 10x/week	76.4 %
6 days	Scenario 1 - 5x/week	28.6 %	Scenario 1 - 10x/week	33.9 %
Carrier G				
5 days	Scenario 3 - 5x/week	40.0 %	Scenario 1 - 10x/week	36.4 %
6 days	Scenario 1 - 5x/week	17.6 %	Scenario 1 - 10x/week	31.4 %
Carrier H				
4 days	Scenario 4 – 5x/week	28.9 %	Scenario 3 – 10x/week	31.6 %

Table 1: Minimal required scenarios for each maximum SLA lead time

To conclude, we first recommend Company X to consider which maximum SLA lead time it will offer to their clients. Based on that, the corresponding scenario in Table 1 should be chosen. Second, a detailed cost-benefit analysis of the corresponding scenario should be made. We recommend to make a cost-benefit analysis of the recommend scenario by a pickup of once a day, as well as a pickup of twice a day, if this is given. In general, picking up twice a day results in higher service level, but also results in more transportation costs compared to a pickup of once a day. Company X should consider this and decides which scenario fits best with regard to costs, lead times, and service level. Third, the results of Carrier C and Carrier E show that none of the scenarios reach a service level of 95 percent. We recommend to increase the maximum SLA lead time. Another option is to decrease the lead time Pick Up Drop Off (PUDO) point to the hub of the carrier. A possible solution to reduce this lead time is selecting another carrier in the corresponding country. For the parcels from Carrier D, we recommend to implement Scenario 4 with a pickup frequency of four or five days a week. However, since it turns out that on some days there are no parcels to be picked up, it could happen that the truck drives empty on some days. In case this is not desired, we recommend to do the same as in the situation of Carrier C and Carrier E. Therefore, we advise to increase the maximum SLA lead time or decrease the lead time PUDO to the hub of the carrier, by selecting another carrier. Finally, we recommend to actually scan the parcels if they leave or enter a certain warehouse or hub. In addition, we advise to add an exact location, like an address, in the scan. This improves the trackability of the parcels and reduces the chance on lost parcels. Therefore, it contributes to a shortening of the lead time in general.

Content

List of Abbreviations

Abbreviation	Description
Client 2	Client of Company X
B2C	Business-to-Consumer
Carrier H	Carrier in Belgium
Carrier B	Carrier in France
Carrier D	Carrier in Spain
Carrier A	Carrier in Germany
Carrier E	Carrier in Ireland
Carrier F	Carrier in England
Carrier I	Carrier in Germany
KPI(s)	Key Performance Indicator(s)
MBR(s)	Monthly Business Review(s)
Carrier C	Carrier in Italy
PUDO point	Pick Up Drop Off point, a local shop which offers a parcel pick up and drop off service of a carrier
Carrier G	Carrier in England
SLA(s)	Service Level Agreement(s)

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1. Introduction

This chapter introduces the research and the problem that initiates it. Section 1.1 introduces Company X and Section 1.2 gives the motivation for the research. The research problem is introduced in Section 1.3. Finally, we present the research design in Section 1.4

1.1 Introduction of the company

Some of the information is left out for confidentiality purposes.

The assignment takes place in the transport department of Company X. The employees within this department take care of all orders which are sent (B2B and B2C). They are tracking shipments and solve problems in the transport of the shipments, if they occur. Moreover, the people at the transport department send reports to the clients of Company X about the status of the shipments.

1.2 Motivation of the research

Due to the growth in online sales, the reverse logistics of Business-to-Consumer (B2C) e-commerce articles becomes more and more important for the clients of Company X. The online stores often offer free return service, resulting in a large amount of parcels which will be sent back to the warehouses. For example, this is because of customers who are ordering multiple sizes of one article and returning items that did not fit. Until now, Company X has mainly focused on the forward flow of parcels. But during the last years, Company X is more and more confronted with the growing reverse flow of parcels. It therefore seeks ways to effectively manage this.

Because of this growing flow of reverse parcels, the company often has problems to deliver the parcel back at the warehouse in the specified time. If this amount of time is exceeded, Company X does not comply with the agreement they make with the client.

1.3 Problem description

In the past, Company X used Carrier M as a carrier to pick up and deliver the parcels of all clients. Nowadays, the reverse logistics of B2C parcels at Company X is based on a 'Local Hero' concept, which means that Company X uses the technologies and networks of many partners (the Local Heroes) to deliver and pick up parcels (Company X, 2019). In the context of reverse logistics, this means that Company X selects the best suited carrier for its client to pick up the parcels from the customer in the different countries. By doing this, Company X offers more options for the client regarding costs and lead time. The reverse logistics can be divided into two types. If both or only one type are used depends on the wishes of the client. Figure 1 shows the first type in which the carrier (such as Carrier J, Carrier L, etc.) delivers the parcels directly to the warehouse of the client of Company X. At first, the customer delivers the parcel at a Pick Up Drop Off (PUDO) point, hereafter PUDO point, which is a location such as a local shop that offers a parcel pick up and drop off service of a carrier (Parcelholders, 2019). Second, the parcel is sent to a local depot of a carrier and after that eventually to a main hub of the carrier. The last step is the delivery at the warehouse of the client of Company X by a carrier. As a result, Company X does not provide any transport of parcels in this type. The carrier takes care of all transport from PUDO point to the warehouse of the client.

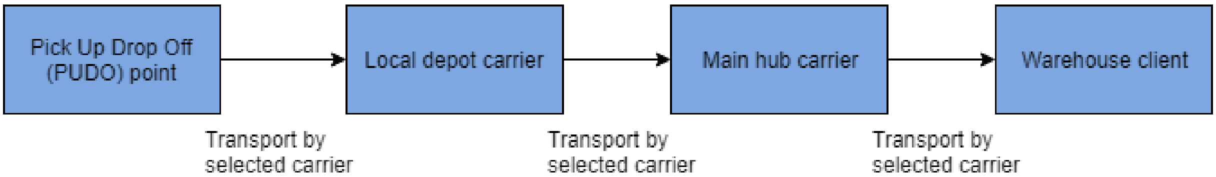

Figure 1: Type 1 flow – Selected carrier takes care of all the transportation

Figure 2 shows the second type of the reverse logistics of parcels at Company X. The return process starts again by a customer who delivers a parcel at a PUDO point. Second, the selected carrier transports the parcel to a local depot and from this point it is transported to a main hub of the carrier. This is where Company X comes in; Company X takes care of the transport between the main hub of the carrier and the Company X hub, which we call a linehaul. A linehaul refers to the movement of freight with any mode of transport by land, air or waterway between distant cities (Ortec, 2019). However, in some cases the carrier delivers the parcels at the Company X hub. The transport from Company X hub to the warehouse of the client is always done by Company X and we call this a linehaul as well.

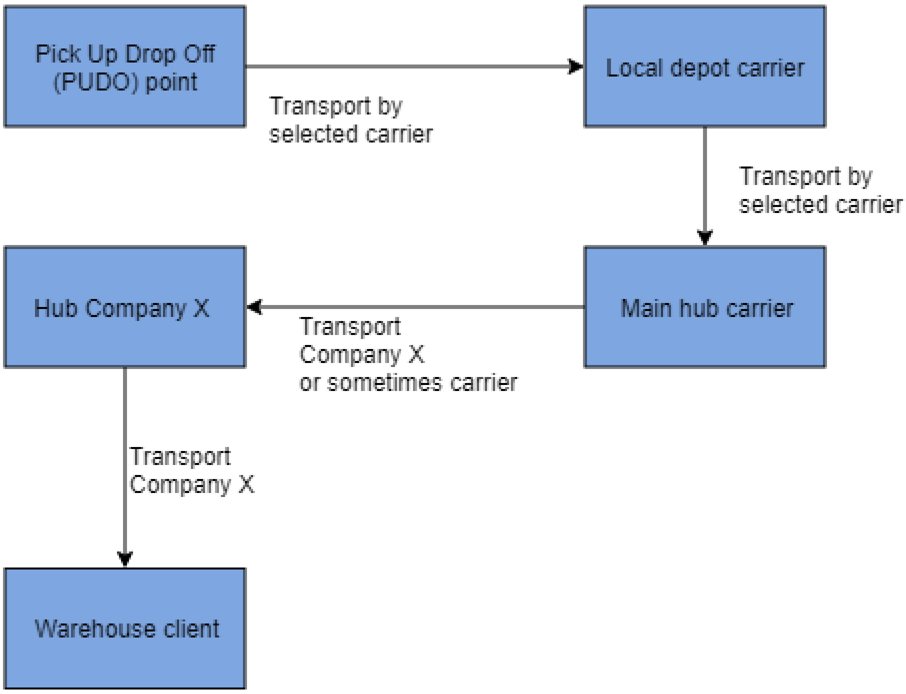

Figure 2: Type 2 flow – Company X takes care of some transportation

Company X encounters problems with the second type of transport, which is the category in which Company X picks up the parcels at the main hub of the carrier and delivers these at the warehouse of the client. This reverse process does often take more time than agreed in the Service Level Agreement (SLA). The SLA is a contract between a service provider, in this case Company X, and the end user, which is the client of Company X. It defines the level of service expected from the service provider. In this agreement is stated, amongst others, what time Company X might use for the return process. Due to the higher lead time than agreed with the client, Company X cannot fulfil the SLA. From a client perspective, this results in a less positive image of Company X as a good logistic service provider. Figure 3 shows this reasoning in a diagram.

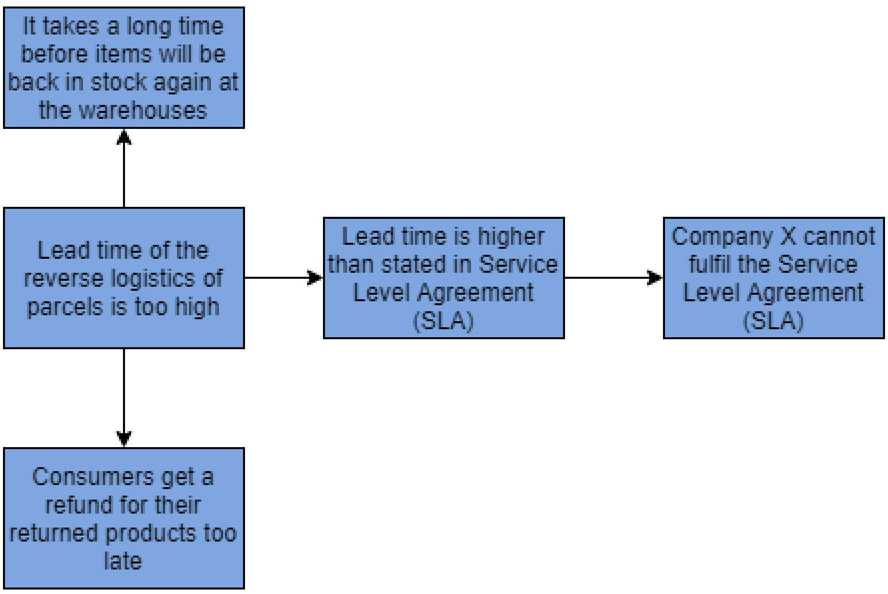

Figure 3: Problem diagram

Another consequence of the high lead time is that the customers will get a refund for their returned products too late. In the current way of working, customers will get a refund when the parcel has arrived at the final warehouse. Moreover, the client of Company X has an interest in a short lead time, because in this way the item can be quickly sold again.

Company X is in business with a lot of clients. Of course, the problem related to high lead times does not hold for each client. We select the following five clients of Company X to consider in this research:

- Client 2
- Client 5
- Client 4
- Client 3
- Client 1

We focus on these clients of Company X for several reasons. At first, these clients are part of the Business Unit Area X, because the transport department in which my assignment takes in, is part of the same Business Unit. The Business Unit Area X of Company X contains all clients with a warehouse in the region of Area X. Company X encounters problems with the high lead time of reverse parcels for these clients. Figure 4 shows the percentage of delayed parcels out of the total parcels per client. We only consider the delayed parcels of the indirect flows, as described in the previous section. We see that the clients Client 5, Client 3, and Client 1 face a high percentage of delays. Although the clients Client 2 and Client 4 face a lower percentage of delay, we take these clients into account because Company X expects that their B2C activities will grow in the future. Due to this growth, we expect more returns and more problems with the lead time of their reverse parcel flow.

In addition, Company X has the desire to reach a service level of 95 percent, because this is stated in the SLA for some clients. A service level of 95 percent means that 95 percent of the parcels should be back in the warehouse within the maximum lead time as stated in the SLA. As a result, a maximum of 5 percent can have a lead time above the maximum lead time as stated in the SLA. Table 2 shows the current average lead time, the maximum lead time according to the SLA, and the percentage of parcels above the maximum lead time. We can see per client which carriers they use in the different countries. For a detailed description of the flows and the lead times, we refer to Section 2.1 and 2.2.

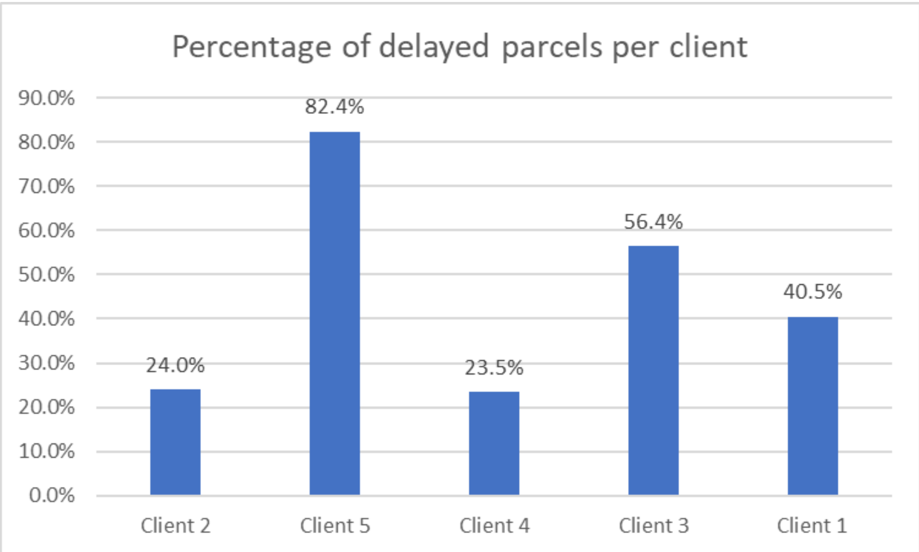

Figure 4: Percentage of delayed parcels out of total parcels per client

Client - Carrier	Current average lead time	Maximum lead time (SLA)	Percentage of parcels above the maximum lead time
Client 2 Carrier			
Carrier B (France)	6.2 days	6 days	32.1 %
Carrier D (Spain)	10.8 days	6 days	88.2 %
Carrier E (Ireland)	21.5 days	6 days	90.9 %
Carrier C (Italy)	14.6 days	7 days	98.8 %
Carrier G (England)	5.1 days	6 days	17.2 %
Client 5 Carrier			
Carrier F (England)	14.8 days	5 days	82.4 %
Client 4 Carrier			
Carrier H (Belgium)	3.8 days	4 days	29.6 %
Carrier B (France)	4.3 days	6 days	10.1 %
Carrier D (Spain)	8.9 days	7 days	50.7 %
Carrier A (Germany)	4.3 days	5 days	18.4 %
Carrier F (England)	5.6 days	6 days	28.0 %
Carrier I (Germany)	8.6 days	5 days	39.1 %
Client 3 Carrier			
Carrier B (France)	4.6 days	5 days	20.4 %
Carrier D (Spain)	8.1 days	6 days	53.3 %
Carrier A (Germany)	4.2 days	3 days	56.8 %
Carrier C (Italy)	14.3 days	6 days	56.4 %
Client 1 Carrier			
Carrier A (Germany)	4.5 days	4 days	39.3 %
Carrier G (England)	5.5 days	5 days	42.5 %

Table 2: Current average lead time versus maximum lead time (SLA)

Based on the problem description and figures above, we define the following core problem for this research:

The lead times of the reverse logistics of parcels are higher than agreed in the Service Level Agreements (SLA) for the selected clients of Company X, resulting in a service level below the desired level of 95%.

1.4 Research design

1.4.1 Research objective

The research objective is twofold. First, we describe the current situation and we gather information regarding the lead times of the different flows. Moreover, we analyse which problems exist regarding the high lead time of the reverse parcels. Second, we investigate which improvements can be made to shorten the lead times of the transport of parcels. We plan to give recommendations how Company X can shorten its lead times to reach the desired service level of 95 percent.

1.4.2 Research questions and approach

The main research question is:

How could Company X shorten its lead times of the reverse parcels, such that the desired service level of 95 percent is reached?

To answer the main research question, we formulate multiple sub-questions.

Analysis of the current situation

Chapter 2 presents the analysis of the current situation and gives an answer to the following research question:

RQ 1 What is the performance of the reverse process of parcels?

We define the following sub questions for this research question:

a) How do parcels flow in the current situation?

To answer this question we use the data from the Transport Management System of the company. Moreover, we consult two transport planners and one employee who is dealing with the reverse logistics of parcels. We make a visualization of the different flows, with the departure and arrival times of the trucks.

b) How many parcels are handled for each client of Company X?

To answer this question we collect data of the number of reverse parcels for each client in the past. This is done by using the Transport Management System of the company. We present the data of the number of parcels in graphs for each client.

c) How much time does it take on average, before a parcel is shipped back at the warehouse?

To answer this question, we collect historical data from the Transport Management System and the Business Intelligence and Performance Management System of the company. We analyse this data and give an overview per flow what time it on average take to ship the parcel back to the warehouses of the clients. In addition, the current minimum and maximum lead times are given. Moreover, we calculate the percentage of delayed parcels per client per carrier and present this in a graph.

d) What are the causes of the lead time being too high?

To answer this question we conduct interviews and analyse the data from previous questions. Semi-structured interviews are held with warehouse managers, team leaders and employees of the transport department, as well as with the business unit manager of Company X. Data collection might be necessary where data is not gathered yet.

Literature study

In Chapter 3, we perform a literature review on truck scheduling. We consider the following research question:

RQ 2 Which models exist to analyse a truck schedule in a cross-docking network, in the literature?

We define the following sub questions for this research question:

a) What are the pros and cons of the models?
b) What is the most appropriate model for this research?

The current schedule of pickup and delivery of parcels is not optimal in the reverse logistics of parcels. Therefore, we want to know from literature which approaches exists to analyse the truck schedule of Company X. Based on this literature review, we choose an approach to analyse the schedule of trucks in a cross-docking network.

Model design

In Chapter 4, we describe the model of the reverse logistics. We define the following research question:

RQ 3 How can we design the model found in the literature?

We define the following sub questions for this research question:

a) What are the components of the model?

   We answer this question by first giving the objective of the model. We define which input data we need for the model. Moreover, we describe what the output parameters have to be. In addition, we give information about the scope and assumptions made in the model. Lastly, we present logic flowcharts and describe the model itself.

b) How do we ensure that the simulation model meets the reality accurately enough?

   We verify if the programmed model corresponds with the model on paper. To check if the programmed model is an accurate representation of the actual system being studied, we validate the model by comparing the results of the model with real data. Moreover, we determine the run length, number of replications, and warm up period.

c) How does the experimental design look?

   The last step of the model design is to describe the experimental design. We specify the scenarios that we should analyse and describe which factors we use and how we vary them.

Analysis of results

In Chapter 5, we analyse the results of the experiments and answer the following research question:

RQ 4 What are the results of the experiments conducted with the model?

We define the following sub questions for this research question:

a) What are the results of the different scenarios?

   We carry out the experiments designed in the previous research question and report the results of the experiments in a clear way.

b) What are the implications of the results for the clients of Company X and Company X itself?

In the end, we describe what the results do mean for the selected clients of Company X. They are facing the problem of the high lead time and are therefore important stakeholders of this research. Moreover, we present the (practical) implications of the results for Company X itself.

In Chapter 6, conclusions and recommendations are given. Moreover, we give limitations and opportunities for further research.

1.4.3 Research scope

The research focuses on the transport of reverse parcels, which means that the reverse process in a warehouse or hub is out of scope. As described in Section 1.3, we consider the reverse logistics of the following clients:

- Client 2
- Client 3
- Client 4
- Client 5
- Client 1

Moreover, we focus on Type 2 flows, as described in Section 1.3, in which Company X does execute all or a part of the transport from the hub of the carrier to the warehouse of the client. In addition, we only consider the reverse logistics of the Business-to-Consumer shipments, which are shipments for online ordered articles. Business-to-Business shipments are thus out of scope of this research.

2. Analysis of the current situation

This chapter provides an answer to the research question: *What is the performance of the reverse process of parcels?* In Section 2.1 we present an overview of the number of parcels for each client. Moreover, we describe which reverse parcel flows exist. In Section 2.2 we present the lead times in the current situation. Section 2.3 presents the causes of the high lead times. We conclude this chapter in Section 2.4.

2.1 Number of parcels of the clients

In this section, we analyse historical data regarding the number of parcels for each client. We take a look at the different flows that exist for each client and we give a detailed overview of the number of parcels per carrier per month.

2.1.1 Number of parcels Client 1

Client 1 is a client of Company X. It is a relatively new client, because Company X started in November 2018 with its Business-to-Consumer (B2C) activities for Client 1. This implies that limited data is available regarding the number of parcels which are returned. For this client, we consider five flows of parcels:

- Parcels from France, collected by Carrier B
- Parcels from Germany, collected by Carrier A
- Parcels from England, collected by Carrier G
- Parcels from the Netherlands, collected by Carrier J
- Parcels from other countries than stated above

Carrier J picks up the reverse parcels from the Netherlands and delivers these directly at the warehouse of Client 1. As a result, Company X does not provide any transport in this reverse parcel flow. The same holds for parcels from other countries than France, Germany, and England. The customers from these countries has to return their items by themselves and they select a carrier that delivers directly at the warehouse of Client 1. These flows are Type 1 flows and therefore outside the scope of this research, as we described in Section 1.3. As a result, the first three flows are Type 2 flows and considered in this research.

Figure 5 and Figure 6 shows the number of parcels per carrier for this client. We see that carriers Carrier A and Carrier G carry the most number of parcels in this period. Carrier B carried only one parcel in the period November 2018 – February 2019.

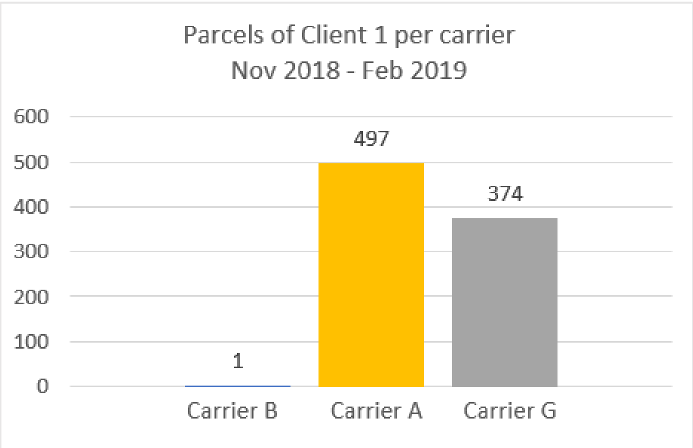

Figure 5: Number of parcels Client 1 per carrier (Nov 2018-Feb 2019)

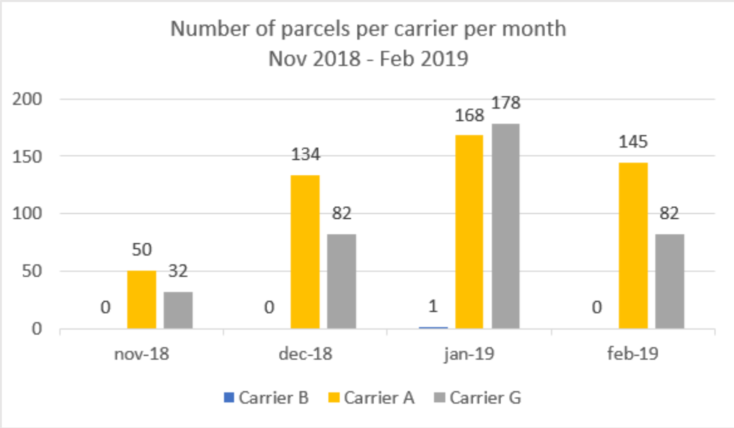

Figure 6: Number of parcels Client 1 per carrier per month

2.1.2 Number of parcels Client 2

Client 2 is a client of Company X. Data is available from September 2017 onwards. For this client, we consider eight flows of parcels:

- Parcels from France, collected by Carrier B
- Parcels from Spain, collected by Carrier D
- Parcels from Belgium, collected by Carrier K
- Parcels from Belgium and Germany, collected by Carrier L
- Parcels from Ireland, collected by Carrier E
- Parcels from Italy, collected by Carrier C
- Parcels from England, collected by Carrier G
- Parcels from the Netherlands, collected by Carrier J

The parcels from carriers Carrier K, Carrier L, and Carrier J are outside the scope of this research, because these carriers deliver the parcels directly to the warehouse of Client 2. As a result, five different flows of parcels are considered in this research.

Figure 7 shows the number of parcels of each carrier in the period September 2017 till February 2019. Figure 8 and Figure 9 show per month the number of parcels of the carriers Carrier B, Carrier D, Carrier E and Carrier C. Figure 10 shows the number of parcels per month of the carrier with the most reverse parcels in this period, Carrier G.

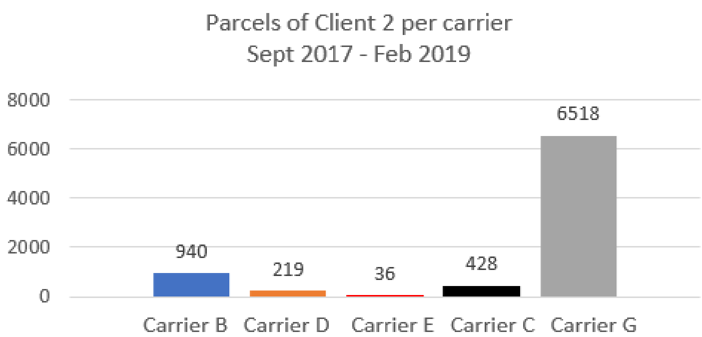

Figure 7: Number of parcels Client 2 per carrier (Sept 2017 - Feb 2019)

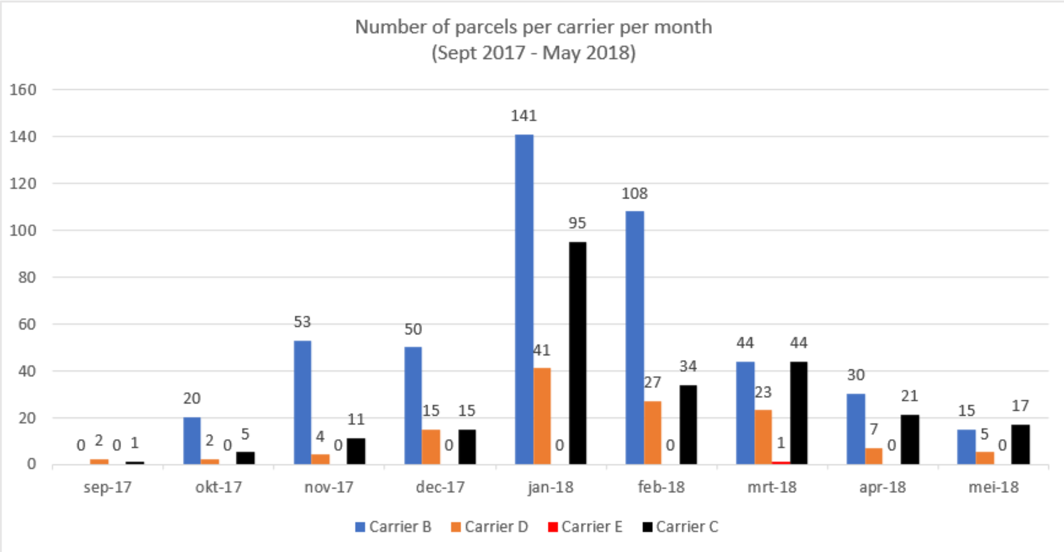

Figure 8: Number of parcels Carrier B, Carrier D, Carrier E and Carrier C (Sept 2017 – May 2018)

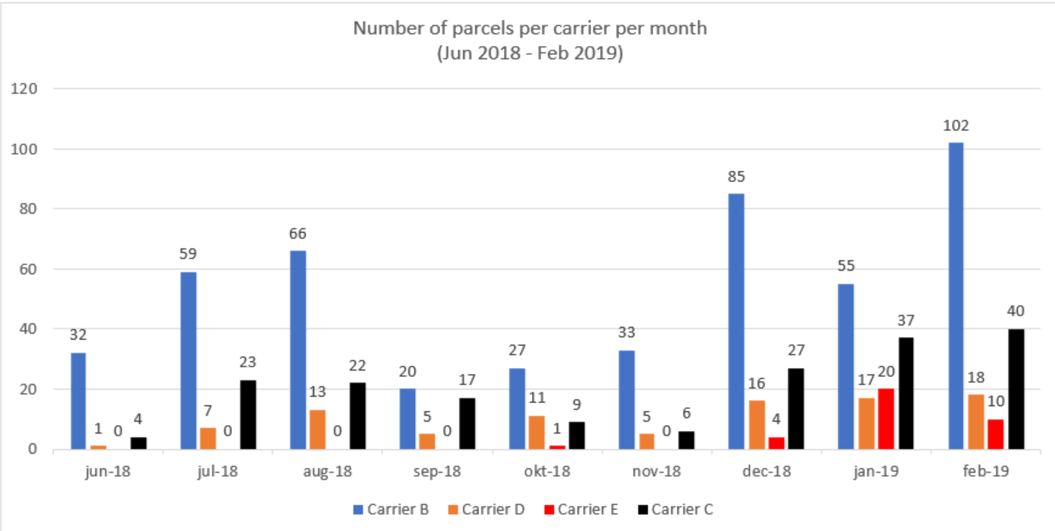

Figure 9: Number of parcels Carrier B, Carrier D, FastWay and Carrier C (Jun 2018 - Feb 2019)

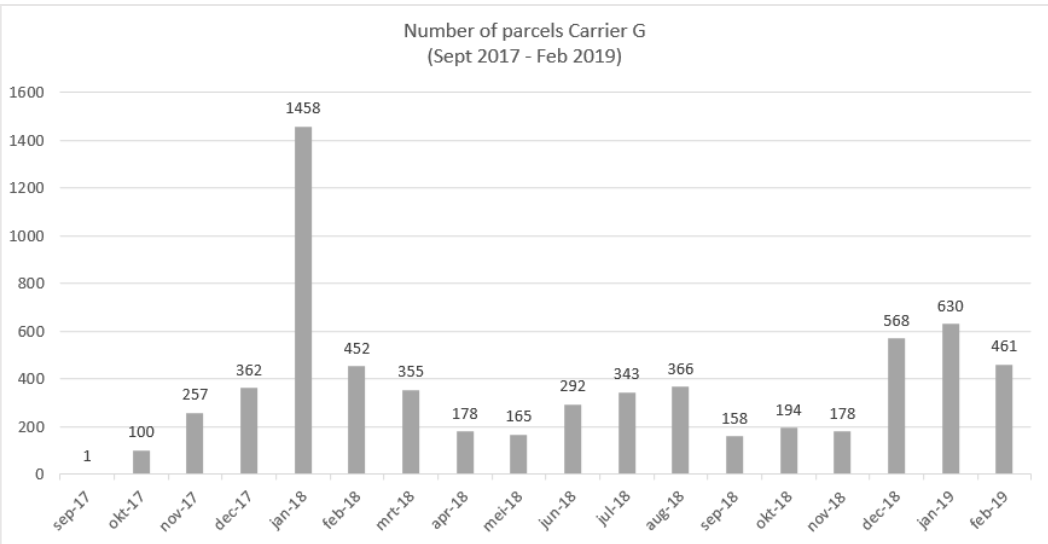

Figure 10: Number of parcels Carrier G per month (Sept 2017 – Feb 2019)

2.1.3 Number of parcels Client 3

Client 3 is another client of Company X. Data is available from April 2017 onwards. We consider five flows for this client:

- Parcels from France, collected by Carrier B
- Parcels from Spain, collected by Carrier D
- Parcels from Germany, collected by Carrier A
- Parcels from England, collected by Carrier L
- Parcels from Italy, collected by Carrier C

We do not consider the parcels from Carrier L, because this carrier delivers the parcels directly at the warehouse of the client. As we described in Section 1.3, this flow is a Type 1 flow and therefore outside the scope of this research. As a result, we consider four different flows of parcels in this research. Figure 11 shows the number of parcels of each carrier in the period April 2017 till February 2019.

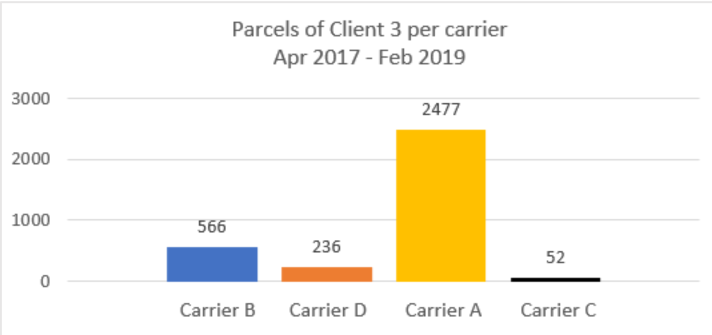

Figure 11: Number of parcels Client 3 per carrier (Apr 2017 - Feb 2019)

Figure 12 and Figure 13 show per month the number of parcels of the carriers Carrier B, Carrier D, and Carrier C. Figure 14 shows the number of parcels per month of the carrier with the most reverse parcels in this period, Carrier A.

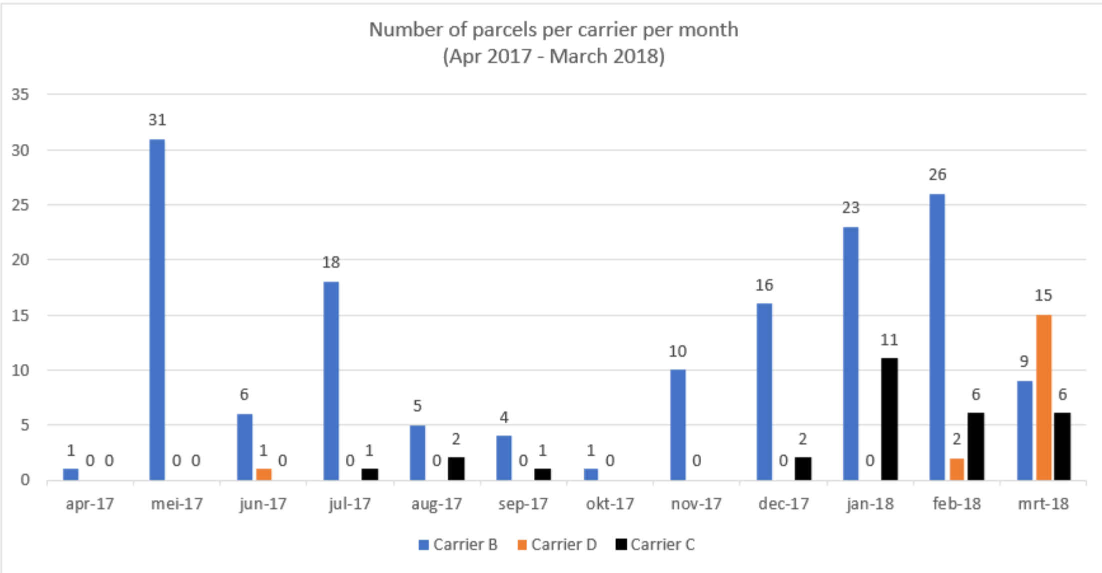

Figure 12: Number of parcels Carrier B, Carrier D, and Carrier C (Apr 2017 – March 2018)

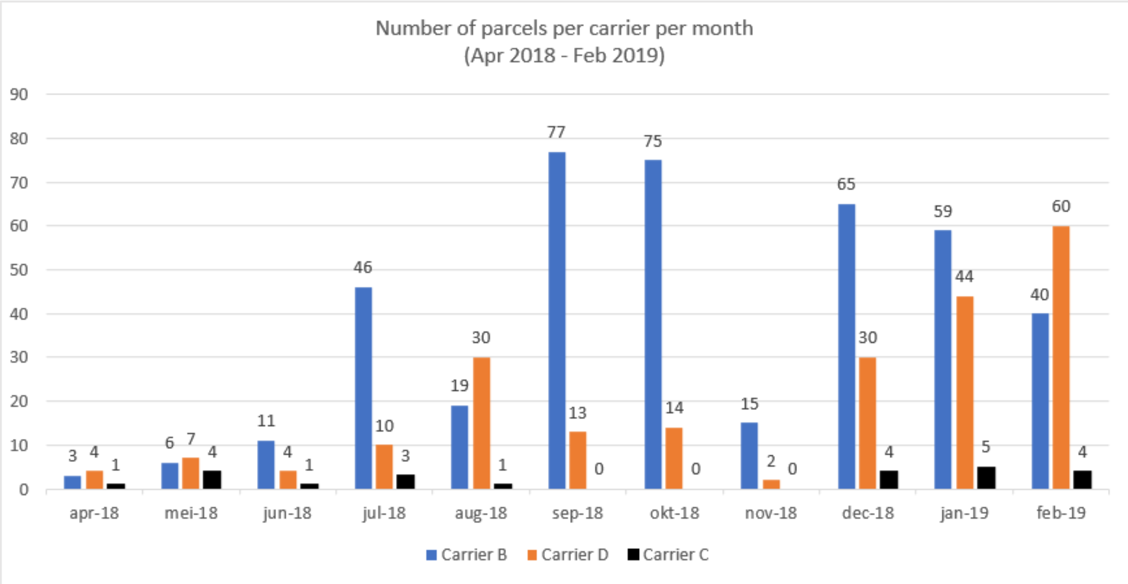

Figure 13: Number of parcels Carrier B, Carrier D, and Carrier C (Apr 2018 – Feb 2019)

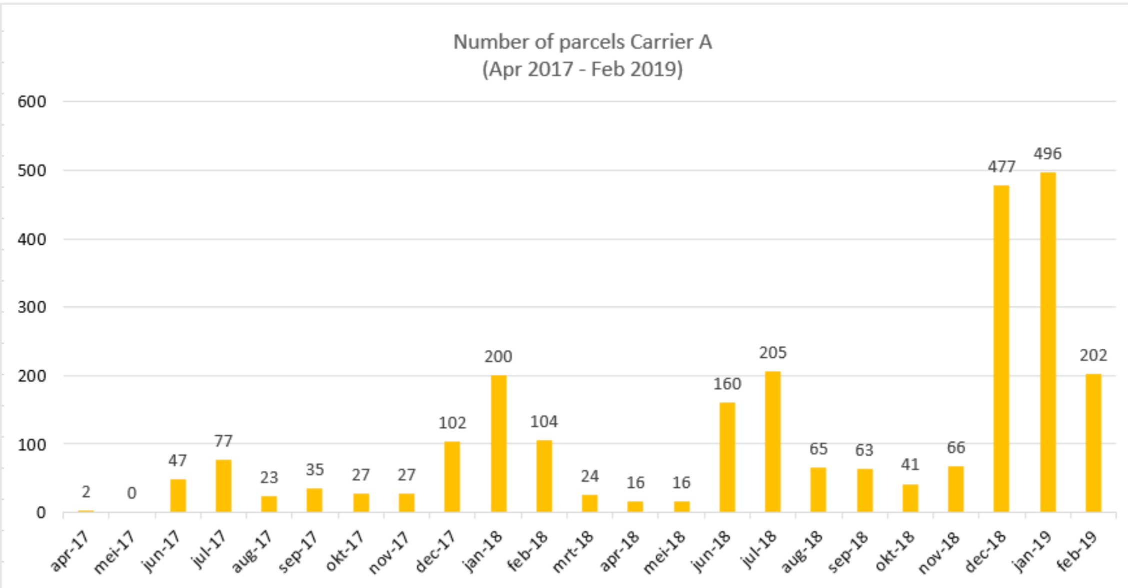

Figure 14: Number of parcels Carrier A per month (Apr 2017 – Feb 2019)

2.1.4 Number of parcels Client 4

Client 4 is another client of Company X. Data is available from April 2017 onwards. We consider eight flows for this client:

- Parcels from Belgium, collected by Carrier H
- Parcels from France, collected by Carrier B
- Parcels from Spain, collected by Carrier D
- Parcels from Germany, collected by Carrier A
- Parcels from Austria and Belgium, collected by Carrier L
- Parcels from England, collected by Carrier F
- Parcels from Germany, collected by Carrier I
- Parcels from other countries as stated above, collected by Carrier M

Carriers Carrier L and Carrier M picks up the parcels and delivers these directly at the warehouse of Client 4. This implies that Company X does not carry any transport in this reverse parcel flow. These flows are Type 1 flows and therefore outside the scope of this research, as we described in Section 1.3. As a result, we consider six flows in this research. Figure 15 shows the number of parcels of each carrier in the period April 2017 till February 2019.

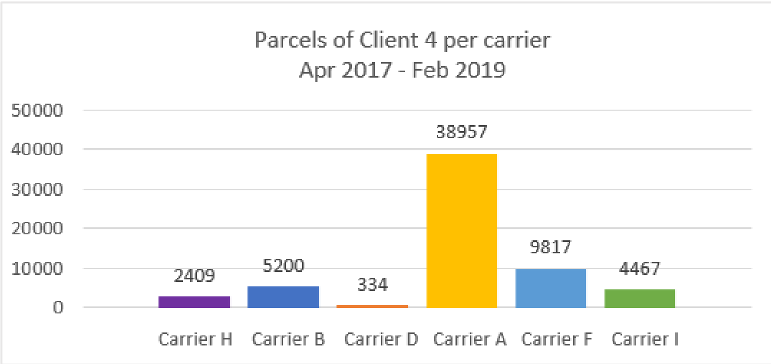

Figure 15: Number of parcels Client 4 per carrier (Apr 2017 - Feb 2019)

Figure 16 and Figure 17 show per month the number of parcels of the carriers Carrier H, Carrier B, Carrier D, Carrier F and Carrier I. Figure 18 shows the number of parcels per month of the carrier with the most reverse parcels, Carrier A.

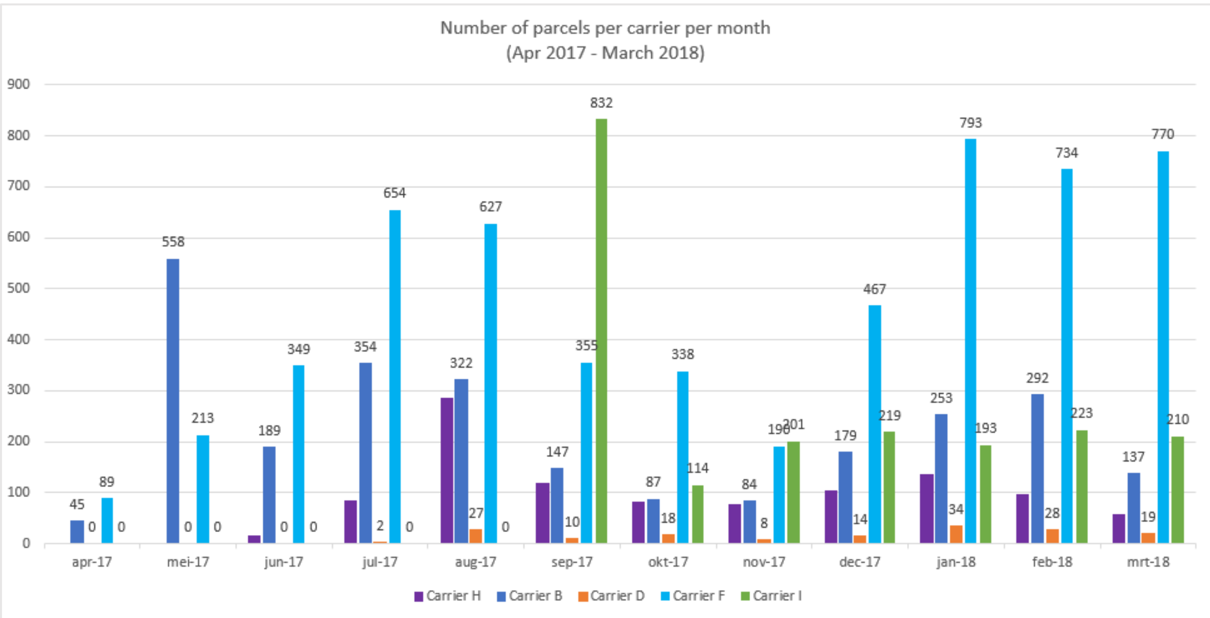

Figure 16: Number of parcels Carrier H, Carrier B, Carrier D, Carrier F and Carrier I (Apr 2017 – March 2018)

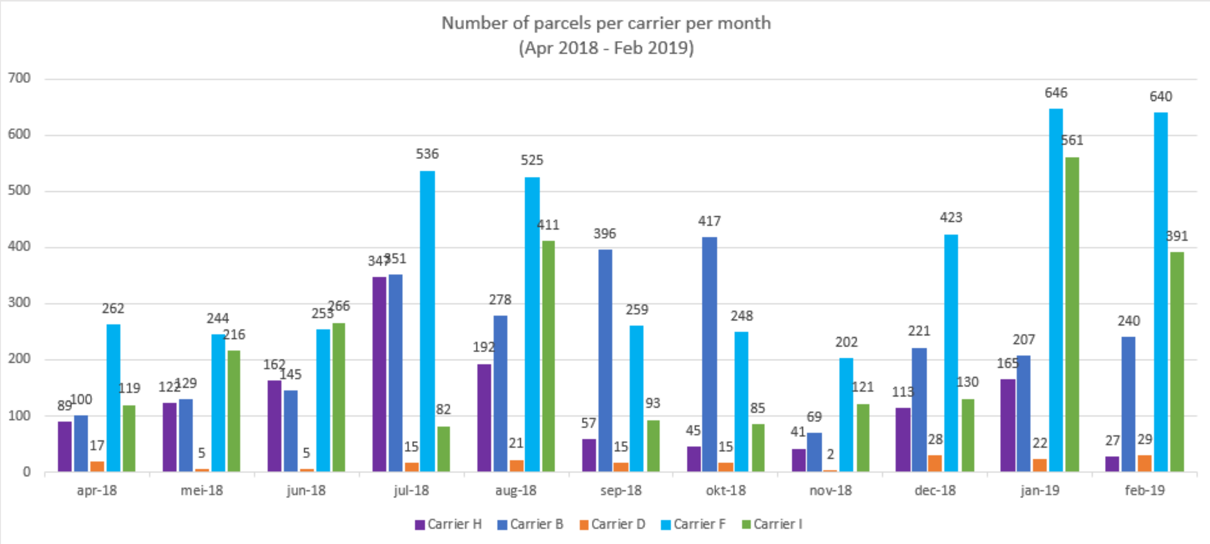

Figure 17: Number of parcels Carrier H, Carrier B, Carrier D, Carrier F and Carrier I (Apr 2018 - Feb 2019)

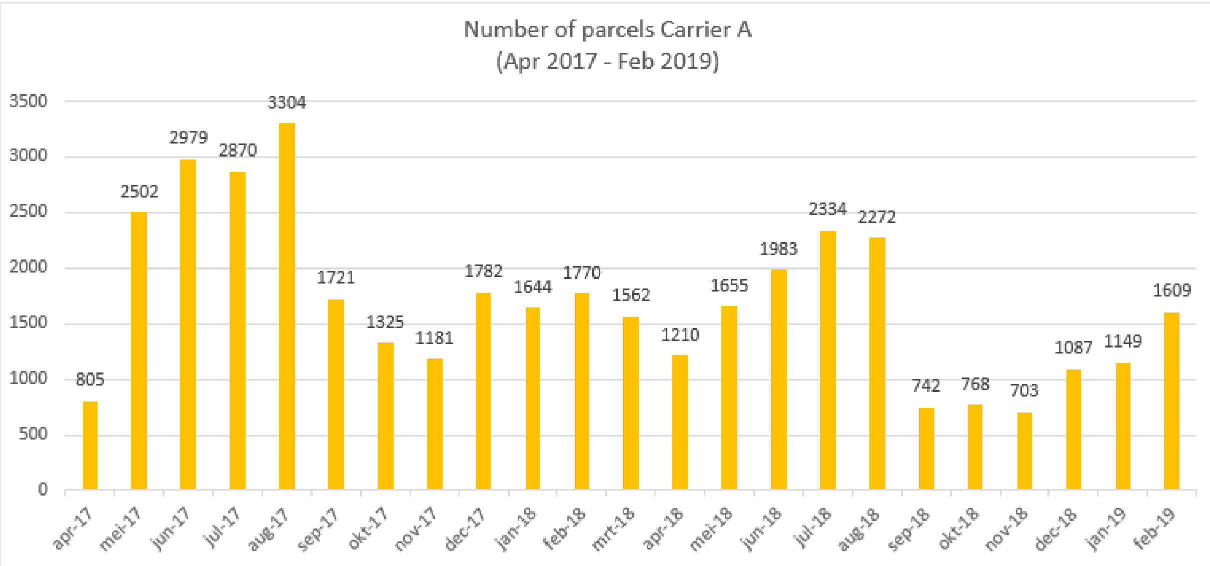

Figure 18: Number of parcels Carrier A per month (Apr 2017 - Feb 2019)

2.1.5 Number of parcels Client 5

Client 5 is a client of Company X. It is a relatively new client, because Company X started in December 2018 with its B2C activities for Client 5. This implies that limited data is available regarding the number of reverse parcels. For this client, we consider four flows of parcels:

- Parcels from Austria, Belgium, Czech Republic, Germany, Spain, and France, collected by Carrier L
- Parcels from England, collected by Carrier F
- Parcels from the Netherlands, collected by Carrier J
- Parcels from Czech Republic, Poland, and Italy, collected by Carrier M

The flow of reverse parcels of Carrier F is the only flow that we consider in this research, since this is a Type 2 flow. The other three flows are carriers that deliver directly at the warehouse of the client and therefore considered as Type 1 flow. Figure 19 shows the number of parcels per month of Carrier F.

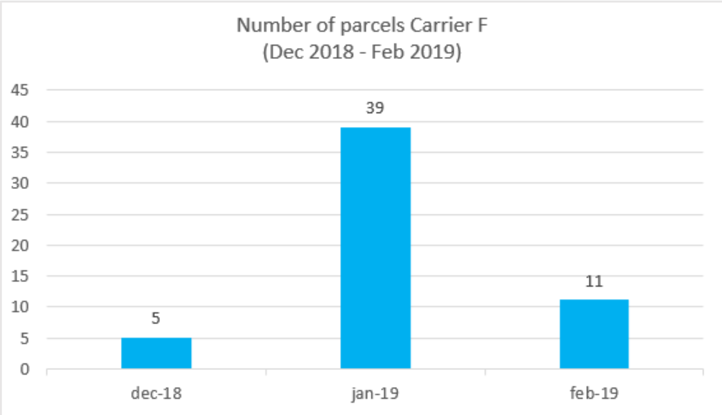

Figure 19: Number of parcels Carrier F (Dec 2018 - Feb 2019)

2.1.6 All flows together

Figure 20 contains a picture of all flows of the five clients. Company X does have two consolidation hubs in the current network, in Place C (England) and Place B (Belgium). These consolidation hubs are depicted by a blue circle in Figure 20. Place B (BL) serves as a consolidation hub for the reverse parcels of Carrier D, Carrier B, Carrier C, Carrier A, Carrier H and Carrier E. The consolidation hub in Place C (SW) process the parcels from Carrier F and Carrier G. In Figure 20, a green circle represents the warehouses in Place A, while the red dots represents places where the parcels are picked up at the carrier. Table 3 contains the pickup times and days at all carriers. We describe the pickup of all carriers in detail below the table.

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Figure 20: Flows of all carriers

Carrier	Clients	Via Hub Company X	When pickup?	Departure time truck at hub carrier	Arrival time truck at hub Company X (Place C/Place B)
Carrier B	Client 2 Client 3 Client 4	Yes, Place B	On a daily basis (Mon – Fri)	9:00 – 11:00 am	1:00 pm
Carrier D	Client 2 Client 3 Client 4	Yes, Place B	Only when Carrier D does have returns	Variable	Variable
Carrier E	Client 2	Yes, Place B	Based on info of carrier	Variable	Variable
Carrier C	Client 2 Client 3	Yes, Place B	Based on info of carrier	Variable	Variable
Carrier A	Client 1 Client 3 Client 4	Yes, Place B	On a daily basis (Mon – Fri)	4:00 pm	7:00 am (next day)
Carrier I	Client 4	No, directly to Place A	Once every two weeks	11:00 am	1:30 pm in Place A
Carrier H	Client 4	Yes, Place B	Carrier H delivers directly on a daily basis (Mon – Fri) at the hub in Place B Departure Place B: 10:00 am		
Carrier G	Client 2 Client 1	Yes, Place C	Carrier G delivers directly on a daily basis (Mon - Fri) at the hub in Place C Departure Place C: 10:00 pm		
Carrier F	Client 4 Client 5	Yes, Place C	Carrier F delivers directly on a daily basis (Mon – Fri) at the hub in Place C Departure Place C: 10:00 pm		

Table 3: Pickup and delivery of all carriers

Carrier B

Carrier B collects the parcels from France and delivers these at the hub of Carrier B in Place D (France). Company X picks up these parcels between 9:00 and 11:00 am on a daily basis, Monday to Friday. The truck arrives around 1:00 pm at the consolidation hub of Company X in Place B. The parcels have to wait one day in Place B before they are transported to the warehouses in Place A.

Carrier D

Carrier D collects the parcels from Spain and delivers these at the Company Y hub nearby Place E. Company X arranges by Company Y a transport from this hub to the Company Y hub in Place F (Netherlands). Next, the parcels are delivered at the consolidation hub in Place B. Only when there are returns at the Company Y hub, Company X arranges a pickup. So, the pickup and delivery day and time is variable.

Carrier E

Carrier E collects the parcels from Ireland and Carrier M delivers these at the consolidation hub in Place B. Only when there are returns from Carrier E, Company X arranges a pickup by Carrier M. So again, the pickup and delivery day and time is variable.

Carrier C

The same holds for the parcels from Italy. Carrier C takes care of the pickup of the parcels in Italy and delivers these at the hub of Company Z in Bergamo. Company Z informs Company X about the number of parcels they received and Company X arranges a pickup by Carrier M. Carrier M transports the parcels to the consolidation hub in Place B. Pickup and delivery occurs only when there are returns, so day and time are variable.

Carrier A and Carrier I

Carrier A and Carrier I collect the parcels from Germany. Carrier A delivers the parcels at the hub of Carrier A in Place H. Company X picks up on a daily basis and transports the parcels to Place B. The truck departs at Carrier A in Place H at 4:00 pm and arrives in Place B the next day at 7:00 am. The arrival is on the next day, because the truck has to wait an night at a parking area until the Company X hub in Place B opens at 7:00 am. Carrier I delivers the parcels at the hub of Carrier I in Place G. Company X picks up the parcels in Place G and delivers these at the warehouses in Place A, but only once every two weeks. The truck departs at Carrier I in Place G at 11:00 am and arrives around 1:30 pm in Place A. So, the parcels from Carrier I do not travel via the consolidation hub in Place B. However, in some periods in the past they did travel via Place B.

Carrier H

Carrier H collects the parcels from Belgium and delivers these directly at the consolidation hub in Place B. Delivery in Place B is on a daily basis, Monday to Friday, but not on a specified time. After the consolidation in Place B, Company X transports the parcels to the warehouses in Place A.

Carrier G and Carrier F

The parcels from England are consolidated in Place C. Both Carrier G and Carrier F deliver at this Company X hub on a daily basis, Monday to Friday. To deliver all the parcels at the warehouses in Place A, a truck departs every day, Monday to Friday, in Place C at 9:00 pm (UK time)/10:00 pm (Dutch time) with parcels from Carrier G and Carrier F and drives via Place B to Place A. Around 7:00 am the truck arrives in Place B and picks up the parcels from:

- Carrier B
- Carrier A
- Carrier D
- Carrier E
- Carrier C
- Carrier H

The truck in Place B departs at 10:00 am and arrives between 2:00 and 4:00 pm in Place A.

2.2 Lead time current situation

In this section, we make a distinction between Lead Time Carrier and Lead Time Company X, see Figure 21. Lead Time Carrier means the time the carrier does take to transport the parcel from the Pick Up Drop Off (PUDO) point to the hub of the carrier. Only carriers Carrier G, Carrier F, and Carrier H deliver the parcels direct at the hub of Company X in Place C and Place B. In this case is the Lead Time Carrier extended with the transport to the hub of Company X, see Lead Time Carrier group B in Figure 21. Lead Time Company X means the time Company X does take to transport the parcel from the hub of the carrier to the warehouse of the client. In case of carriers Carrier G, Carrier F, and Carrier H, the Lead Time Company X is the time required to transport the parcel from the hub of Company X to the warehouse of the client, see Lead Time Company X group B in Figure 21.

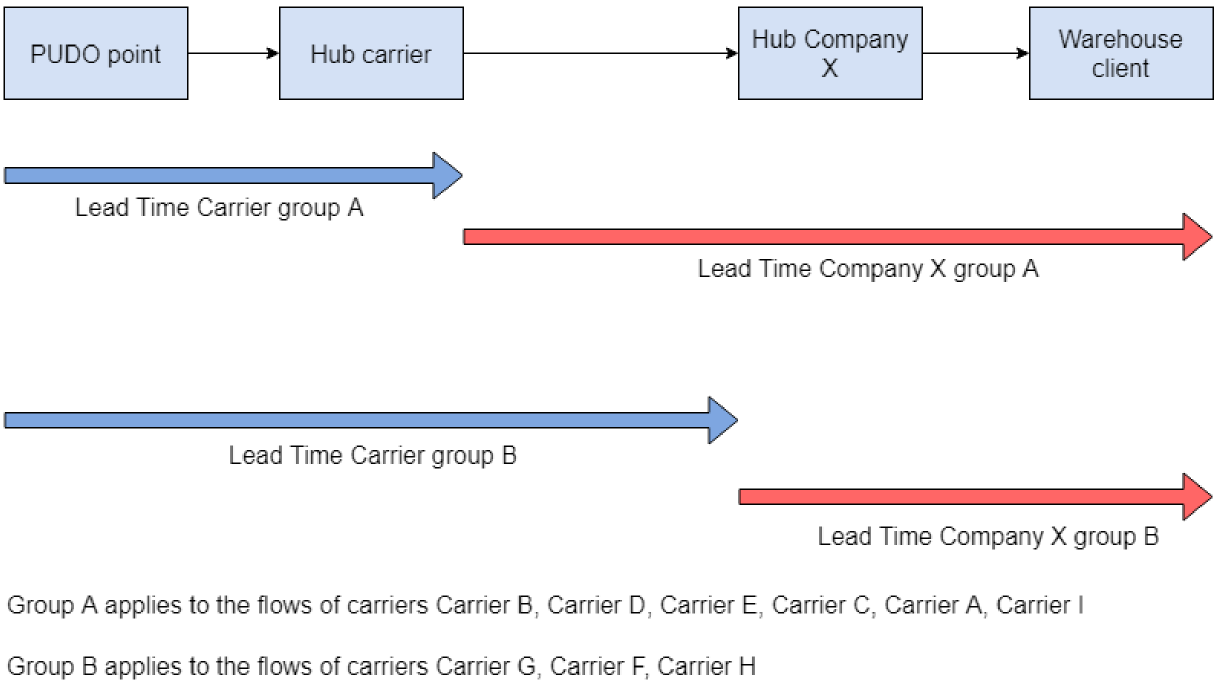

Figure 21: Lead time description

2.2.1 Current lead times of Client 2

Table 4 contains the lead times of Client 2 in the current situation. We see that the average total lead time is far more than the maximum lead time stated in the SLA, except from the flows of Carrier G and Carrier B. The lead times of these flows are close to the maximum lead time. In Figure 22, we see that the flows of Carrier D, Carrier E, and Carrier C face a high percentage of total parcels that have a lead time above the maximum lead time.

Carrier	Average of lead time carrier	Average of lead time Company X	Minimum of total lead time	Maximum of total lead time	Average of total lead time	Max lead time (SLA)
Carrier B	1.3 days	4.9 days	3 days	29 days	6.2 days	6
Carrier D	2.7 days	8.1 days	6 days	23 days	10.8 days	6
Carrier E	3.1 days	18.4 days	6 days	44 days	21.5 days	6
Carrier C	3.1 days	11.4 days	7 days	25 days	14.6 days	7
Carrier G	1.8 days	3.4 days	3 days	73 days	5.1 days	6

Table 4: Current lead times of Client 2

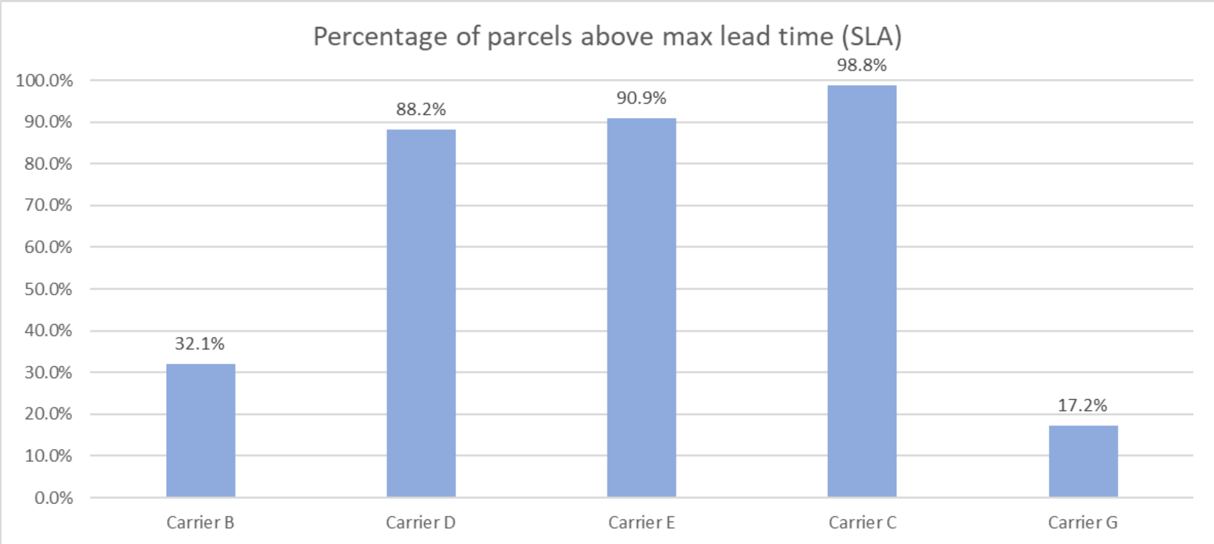

Figure 22: Client 2 - Percentage of parcels above max lead time (SLA)

2.2.2 Current lead times of Client 4

Table 5 contains the lead times of Client 4 in the current situation. We are not able to give a reliable lead time of the carrier and Company X for the flow of Carrier I, due to missing data. We again see that the lead time of the flow of Carrier D is far above the maximum lead time as stated in the SLA. The same holds for the flow of Carrier I. In Figure 23, we see that the flows of Carrier D and Carrier I face the highest percentage of total parcels above the maximum lead time.

Carrier	Average of lead time carrier	Average of lead time Company X	Minimum of total lead time	Maximum of total lead time	Average of total lead time	Max lead time (SLA)
Carrier H	1.6 days	2.2 days	2 days	21 days	3.8 days	4
Carrier B	1.3 days	3.0 days	3 days	25 days	4.3 days	6
Carrier D	2.9 days	6.0 days	6 days	25 days	8.9 days	7
Carrier A	1.3 days	3.0 days	3 days	49 days	4.3 days	5
Carrier F	1.4 days	4.2 days	3 days	77 days	5.6 days	6
Carrier I	No reliable data*	No reliable data*	2 days	71 days	8.6 days	5

Table 5: Current lead times of Client 4. Asterisks indicate that no reliable data could be given due to missing data

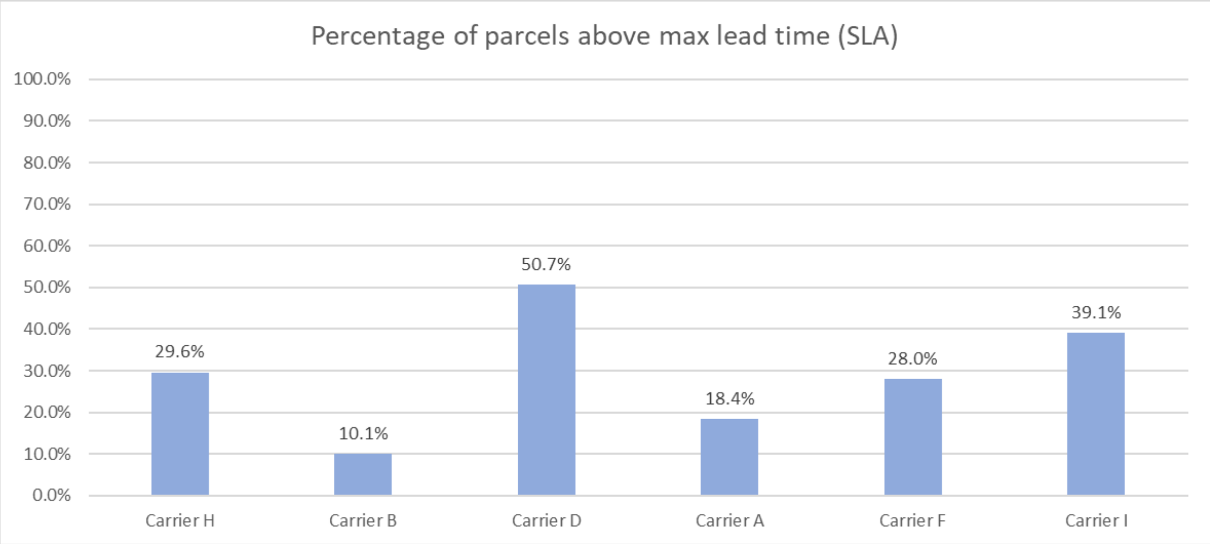

Figure 23: Client 4 - Percentage of parcels above max lead time (SLA)

2.2.3 Current lead times of Client 5

Table 6 contains the lead times of Client 5 in the current situation. We see that the average total lead time is far above the maximum lead time agreed in the SLA. Moreover, the percentage of parcels above the maximum lead time is 82.4 percent.

Carrier	Average of lead time carrier	Average of lead time Company X	Minimum of total lead time	Maximum of total lead time	Average of total lead time	Max lead time (SLA)
Carrier F	2.2 days	12.6 days	3 days	30 days	14.8 days	5

Table 6: Current lead times of Client 5

2.2.4 Current lead times of Client 3

Table 7 contains the lead times of Client 3 in the current situation. In Figure 24, we see that more than half of the total parcels of Carrier D, Carrier A, and Carrier C do have a lead time above the maximum lead time.

Carrier	Average of lead time carrier	Average of lead time Company X	Minimum of total lead time	Maximum of total lead time	Average of total lead time	Max lead time (SLA)
Carrier B	1.3 days	3.3 days	3 days	22 days	4.6 days	5
Carrier D	2.7 days	5.4 days	6 days	23 days	8.1 days	6
Carrier A	1.2 days	3.0 days	3 days	40 days	4.2 days	3
Carrier C	4.1 days	10.2 days	6 days	36 days	14.3 days	6

Table 7: Current lead times of Client 3

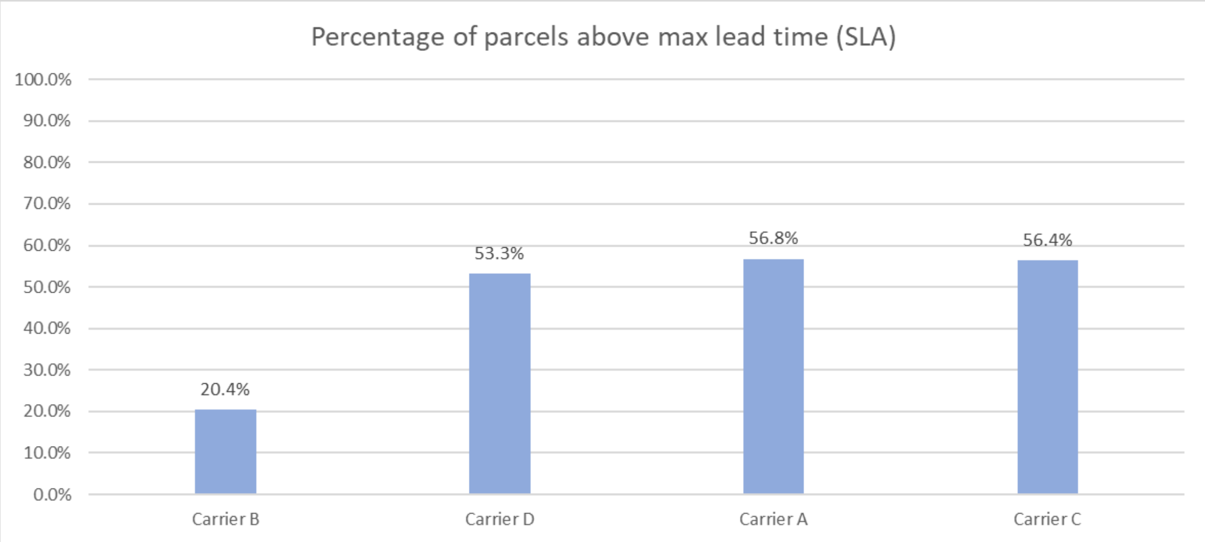

Figure 24: Client 3 - Percentage of parcels above max lead time (SLA)

2.2.5 Current lead times of Client 1

Table 8 contains the lead times of Client 1 in the current situation. We see that the average total lead time for both flows is close to the maximum lead time as agreed in the SLA. Figure 25 shows the percentage of parcels above the maximum lead time, which is for both flows around 40 percent. We left out the flow of Carrier B, because only one parcel is send in this period, as we described in Section 2.1.1.

Carrier	Average of lead time carrier	Average of lead time Company X	Minimum of total lead time	Maximum of total lead time	Average of total lead time	Max lead time (SLA)
Carrier A	2.3 days	2.2 days	3 days	27 days	4.5 days	4
Carrier G	2.9 days	2.6 days	3 days	11 days	5.5 days	5

Table 8: Current lead times of Client 1

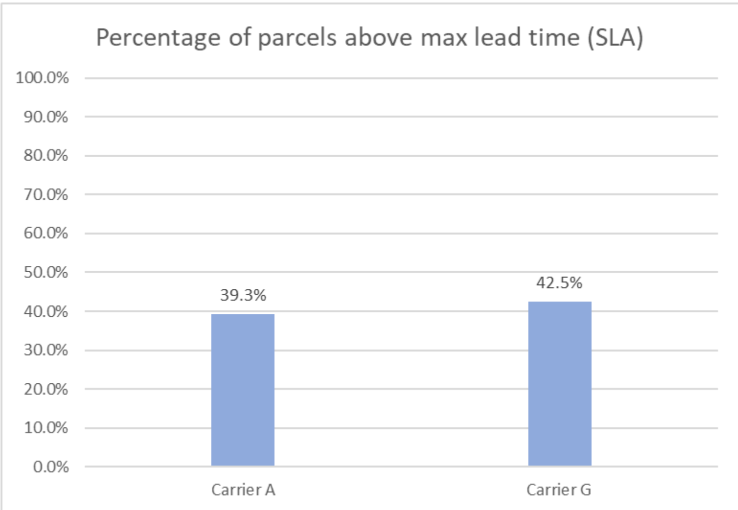

Figure 25: Client 1 - Percentage of parcels above max lead time (SLA)

2.2.6 Conclusion on lead times

From the previous sections on lead times, we conclude that the lead time of the flows of Carrier D, Carrier C, Carrier E and Carrier I is far above the maximum lead time as stated in the SLA. As we describe in Section 2.1.6 the parcels from these carriers are not picked up frequently which we see as a cause of this high lead time. In addition, we see that the average lead time of Carrier F for Client 5 is almost 15 days. By doing research, we see that many parcels of this flow stay some days at consolidation hub Place C for an unknown reason. Moreover, these parcels are also processed by consolidation hub Place B and stored for some time over there. This causes a high lead time. There are also a number of flows for which holds that the average lead time is slightly above the maximum lead time. This holds for the flows of Carrier B (Client 2), Carrier A (Client 3 and Client 1), and Carrier G (Client 1).

2.3 Causes of the high lead time

This section describes which causes exist for the high lead times. Causes are identified by the data analysis of the previous sections and interviews with several involved people within the company. Figure 26 shows the problem bundle, in which we mapped the causes of the high lead time. The root causes in the green boxes are explained in detail in the following sections. In Section 2.3.9, we describe which causes we do take into consideration in this research.

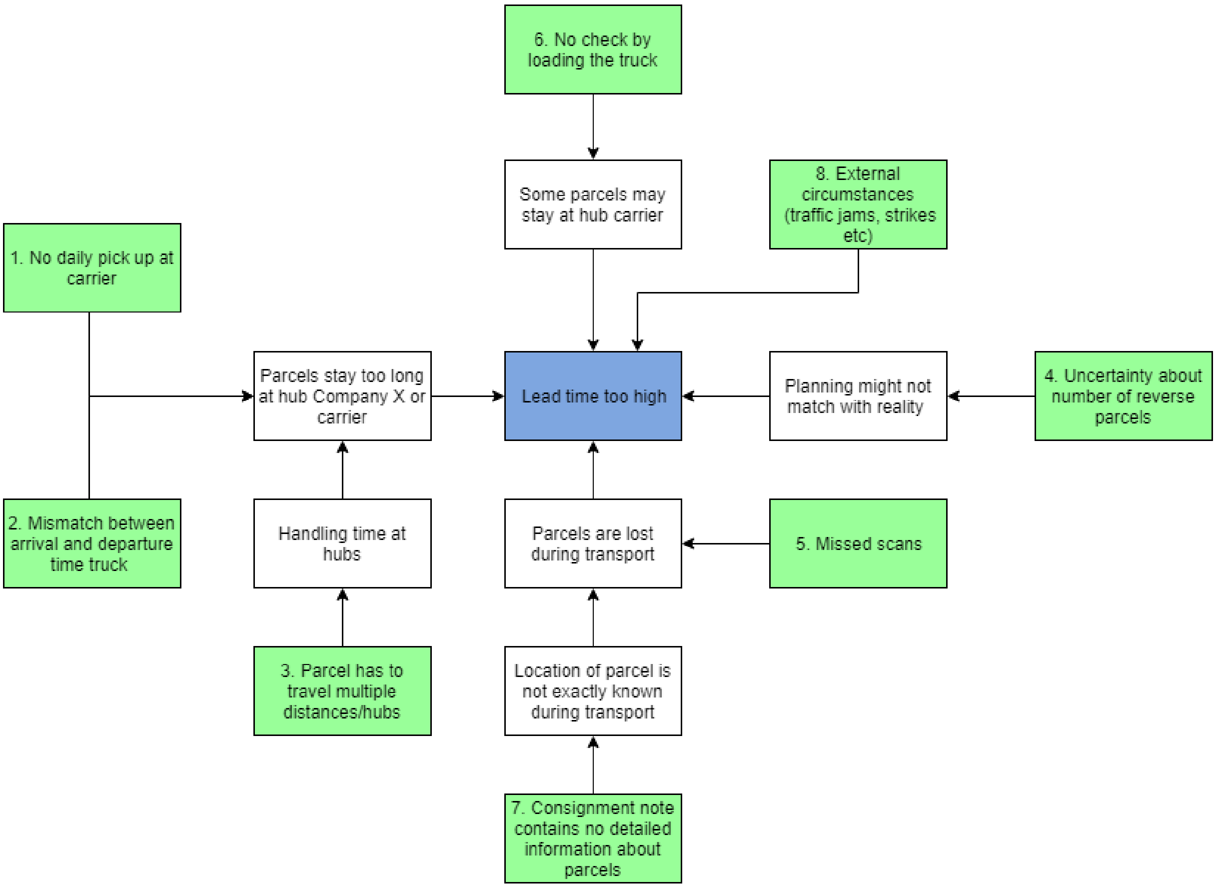

Figure 26: Problem bundle

2.3.1 Cause 1 - No daily pickup at carrier

From the previous section, we conclude that parcels from Carrier D, Carrier C, Carrier E, and Carrier I face an average lead time above the maximum lead time as agreed in the SLA. Pickup of these parcels is not done on a daily basis. As a consequence, parcels are stored at the hub of the carrier for some time when Company X arranges a pickup. Company X arranges a pickup by Carrier M if there are reverse parcels for Carrier E and Carrier C. When Carrier D does have returns, the pickup is done by transport companies Company Y or Company W. Pickup of the parcels from Carrier I is done once every two weeks, which implies that these parcels are also stored for some time at the hub of the carrier. So, in case the pickup is not done on a daily basis, it takes more time to transport the parcel back to the warehouse of the client.

2.3.2 Cause 2 - Mismatch between arrival and departure time truck

In Section 2.1.6, we see that the deliveries of parcels at the Company X hubs in Place C and Place B is throughout the day. Due to variability in transport travel times, the delivery is not exactly on the given time. It happens every weekday that the parcels from carriers Carrier B and Carrier A must be stored for a day at the hub of Place B before the parcels will be on the next truck to the warehouses in the region of Place A. These parcels have to be stored, because they arrive in the afternoon while the truck to Place A departs in the morning. Moreover, for some parcels the arrival at the Company X hubs in Place C and Place B is not on a specified day and time. This leads to variability in delivery and the chance that parcels must be stored at the consolidation hub for the next truck.

2.3.3 Cause 3 - Parcel has to travel multiple distances/hubs

A reverse parcel passes multiple hubs and has to travel multiple distances along the way from PUDO point to the warehouse of a client. At these hubs, parcels have to be sorted and consolidated according to their destination. Parcels stay at these hubs for transport to their next destination, which results in an increased lead time.

2.3.4 Cause 4 - Uncertainty about number of reverse parcels

By analysing the data of Section 2.1, we see that there exists often a high variability in number of reverse parcels per month. We can see that for some months it holds that the amount of reverse parcels is limited, but the next month shows a big increase. For example, this can be explained by a discount promotion of a client. When such a promotion is held in a certain month, we can expect an increase in the number of parcels in the next month. Another reason could be for example the Christmas period, in which people do their Christmas shopping. An increase in returns could be expected in the month January.

Due to this high variability in the number of parcels, it is difficult to plan and make sure that the parcels are returned to the warehouse within the required lead time. This makes the reverse logistics of parcels an uncertain and stochastic process, because you often do not know the amount of reverse parcels which has to be picked up. Moreover, this amount is highly variable per pickup.

2.3.5 Cause 5 - Missed scans

The Transport Management System is used to keep track of all parcels of the clients. We can select for each client the sent and received parcels in a given time period. Moreover, a track and trace overview is available, which shows all the scans the parcel received. We can, for example, see if the shipment is processed by the carrier and delivered at the hub of the carrier. Figure 27 shows a track & trace overview in which four scans are important:

- “Shipment delivered successfully”, which means that the parcel is delivered at the hub of the carrier.
- “Received in return warehouse (incoming scan)”, which means that the parcel is delivered at the Company X hub.
- “Left return warehouse (outgoing scan)”, which means that the parcel left the Company X hub.
- “Arrived in final warehouse (final scan)”, which means that the parcel is delivered back at the warehouse of the client.

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Figure 27: Track and trace overview

However, we are not able to see when the parcel left the hub of the carrier, because the parcel receives no outgoing scan at the hub of the carrier. Moreover, we are not able to see an exact location, like an address, in the track and trace overview. Besides that, it happens that parcels are not scanned when they enter or leave hubs by mistakes of employees. This means that in some cases we do not exactly know where the parcel is located. As a consequence, parcels are lost in the transportation network.

2.3.6 Cause 6 - No check by loading the truck

In most cases, Company X picks up the parcels at the hub of the carrier and delivers these at the Company X hubs in Place C or Place B. The carrier ensures that a trailer, which contains the parcels, is ready to be picked up. So, the loading of the trailer is the responsibility of the carrier. The truck driver of Company X does not check if all parcels that should be in the truck, are in the truck. As a consequence, there is a chance that parcels stay at the hub of the carrier. This leads to a higher lead time for these parcels, because they have to wait for the next pickup of Company X.

2.3.7 Cause 7 – Consignment note contains no detailed information about parcels

When the parcel is transported on a truck, the truck driver receives a consignment note of the freight he or she transports. Figure 28 shows a consignment note of a transport of reverse parcels. The description of what is transported is outlined with the red circle. In this case, the truck driver delivers one pallet with reverse parcels of Client 6 and one of Client 7. Client 6 and Client 7 are clients of Company X. On this consignment note, we are not able to see exactly which parcel is transported. For example, the barcodes of the parcels on the pallets are not mentioned. In this way, we are not able to keep track of the parcels completely during transport. Only when the parcel reached the destination, for example the warehouse of the client, it gets a scan and is therefore located at the destination.

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Figure 28: Consignment note

2.3.8 Cause 8 - External circumstances

When a parcel is transported from A to B several unexpected events may happen which disrupt the transport. For example, it is possible that a truck breaks down, which causes a delay for the parcels in the truck. Besides that, strikes on the roads may cause a transport delay, which for example recently happened in Belgium (The Bulletin, 2019). This may result in an increased lead time when such an event occurs.

2.3.9 Causes taken into consideration

In Table 9 we describe which causes we do take into consideration in this research.

Cause	Do we take this cause into consideration?	Explanation
Cause 1: No daily pickup at carrier	Yes	By analysing the data, we see that the lead time of the flows with no daily pickup (Carrier D, Carrier C, Carrier E, and Carrier I) is far above the maximum lead time as stated in the SLA. Therefore, we do take this cause into consideration.
Cause 2: Mismatch between arrival and departure time truck	Yes	This cause is directly related to a high lead time, because we see that the parcels of Carrier A and Carrier B have to wait at least one day at the hub in Place B. Moreover, for some flows it holds that the delivery is throughout the day at the hub in Place C and Place B. This implies that parcels have to wait for the next truck at these hubs. This results in a longer lead time.
Cause 3: Parcel has to travel multiple distances/hubs	Yes	This cause is directly related to a high lead time, because a parcel has to travel multiple hubs and this implies handling time. Parcels have to be stored for some time before they are on the next truck.
Cause 4: Uncertainty about number of reverse parcels	Yes	The data shows us that the number of reverse parcels is highly variable. Due to this variability, it is difficult to make a planning for the pickup of parcels at the hub. You often do not know how much parcels have to be picked up and when they will arrive at the hub of the carrier. This causes a high lead time, when the planning does not match with the reality.
Cause 5: Missed scans	Yes	Due to missed scans and lack of an address in the scan, the location of a parcel is not exactly known during transport. This results in lost parcels during transport. It happens more often that parcels do not get a scan at a location. Therefore, we consider this as a cause of the high lead time.
Cause 6: No check by loading the truck	No	This cause is simply solvable by giving an instruction to the truck driver to check if all parcels are in the truck. Moreover, parcels may stay at the hub of the carrier, but this is expected to be negligible. Therefore, out of scope for this research.
Cause 7: Consignment note contains no detailed information about parcels	No	The company is already working on a solution for this cause. Therefore, out of scope for this research.
Cause 8: External circumstances	No	These events happen unfrequently and are therefore out of scope for this research.

Table 9: Causes taken into consideration

2.4 Conclusion

In this chapter we answered the following research question: *What is the performance of the reverse process of parcels?* We present in the first section which flows exist for each client of Company X. By analysing historical data, we give an insight in the number of reverse parcels for each client. In addition, the current lead times are calculated to give a detailed overview of the performance of the reverse process for each client. Lastly, we describe that the following causes contributes to the high lead times:

- Cause 1: No daily pickup at carrier
- Cause 2: Mismatch between arrival and departure time truck
- Cause 3: Parcel has to travel multiple distances/hubs
- Cause 4: Uncertainty about number of reverse parcels
- Cause 5: Missed scans

The first four causes are all related to the planning of pickups and deliveries of parcels under uncertainty. The fifth cause, missed scans, contributes to a high lead time, because parcels get lost during transport if they do not get scans on locations. This results in a higher lead time. In the next chapter, we perform a literature review on models to analyse a truck schedule in a cross-docking network.

3. Literature review

This chapter provides an answer to the research question: *Which models exist to analyse a truck schedule in a cross-docking network, in the literature?* Section 3.1 describes the truck scheduling in a cross-docking centre, while Section 3.2 presents the vehicle routing problem in a cross-docking network. In Section 3.3, we describe the service network design models. Section 3.4 summarizes the findings from the previous sections. In Section 3.5, we describe different types of simulation models and describe how we conduct a simulation study. Section 3.6 concludes this chapter.

3.1 Truck scheduling in a cross-docking centre

As described in Section 2.1.6, Company X has two consolidation hubs, in which parcels are consolidated and moved to the next truck. This corresponds to the purpose of a cross-docking centre, because in a cross-docking centre, different sized shipments with the same destination are consolidated to full truckloads, such that transportation costs and inventory holding costs can be reduced (Boysen & Fliedner, 2010; Agustina et al., 2010; Maknoon & Laporte, 2017). Figure 29 shows a schematic representation of a cross-docking centre, in which the first step is to unload the inbound trucks at the dock doors. Next, the load is scanned and sorted according to their destination. And finally, the load is loaded into an outbound truck at the dock doors.

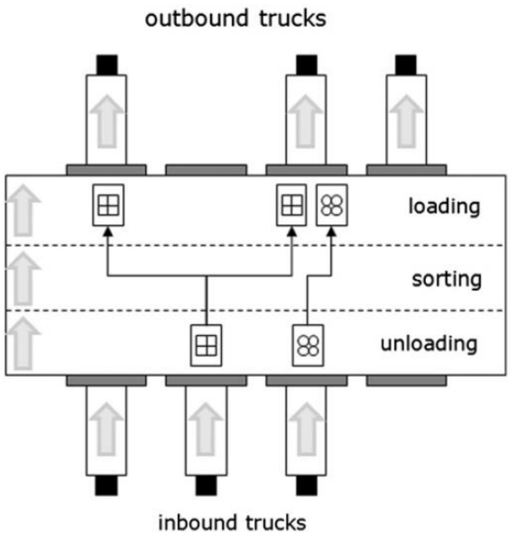


Figure 29: Layout of a cross-docking centre – adapted from: Boysen & Fliedner (2010)

Boysen & Fliedner (2010) and Belle et al. (2012) classify the cross-docking decision problems as follows:

- Location of cross-docking terminal(s)
- Layout of the terminal
- Assignment of destinations to dock doors
- Vehicle routing
- Truck Scheduling
- Resource scheduling inside the terminal
- (Un-) Packing loads into (from) trucks

For our research, the vehicle routing and truck scheduling are interesting decision problems, because these decision problems cover the planning of trucks in transportation networks. The truck scheduling problem decides on the assignment of the incoming and outgoing trucks to dock doors and determines the sequence in which the trucks are processed at each dock door (Boysen & Fliedner, 2010; Belle et al., 2012). So, truck scheduling is about *where and when* the trucks should be processed in a cross-docking centre. The truck scheduling problems are formulated as a mathematical model, such as an integer programming model, and solved by (meta-) heuristics. Moreover, the objective of the models is to minimize the costs or makespan, i.e., the transfer or operation time in a cross-docking centre. For examples of the truck scheduling problems in a cross- docking centre, see the papers of Cota et al. (2016), Keshtzari et al. (2016), and Vahdani & Zandieh (2010).

Ladier & Alpan (2016) propose robust models for the truck scheduling problem in a cross-docking centre. Robust truck scheduling means in this case that uncertainties are taken into account, such as truck arrival times, unload time of a pallet, transfer time of a pallet. The authors propose four robust optimization techniques: the minimax method; the minimization of expected regret; resource redundancy and time redundancy. Next, they test the robustness of the truck schedule by means of a simulation model, in which each source of uncertainty (arrival time, unloading time, transfer time) follows a random distribution. They found that minimizing the average number of trucks docked at a given door is a good way to ensure robustness in the schedule. However, this increases storage capacity. In addition, Konur & Golias (2013) use simulation to evaluate the performance of certain scheduling strategies. They consider the arrival time of an inbound truck as uncertain and generate multiple arrival scenarios to use in their simulation.

3.2 Vehicle routing in a cross-docking network

As stated by Boysen & Fliedner (2010), vehicle routing is a decision problem in a cross-docking centre and is closely related to truck scheduling. The vehicle routing schedule on the inbound side sets the arrival times of trucks at the cross-docking centre. In addition, on the outbound side, the vehicle routing schedule sets boundaries on the earliest and latest departure time of outbound trucks. A vehicle routing problem in a cross-docking network consists of a set of pickup and delivery nodes in which the product demand from each pickup node should be delivered to the corresponding delivery node through a cross-docking centre by a set of vehicles. Figure 30 shows an example of vehicle routings in a cross-docking network. The vehicle routes begin and end at the cross-docking centre. First, a vehicle drives to a set of pickup nodes and returns to the cross-docking centre. The goods are consolidated according to destination and after that, a vehicle delivers the goods to a set of delivery nodes. Finally, the vehicle comes back to the cross-docking centre.

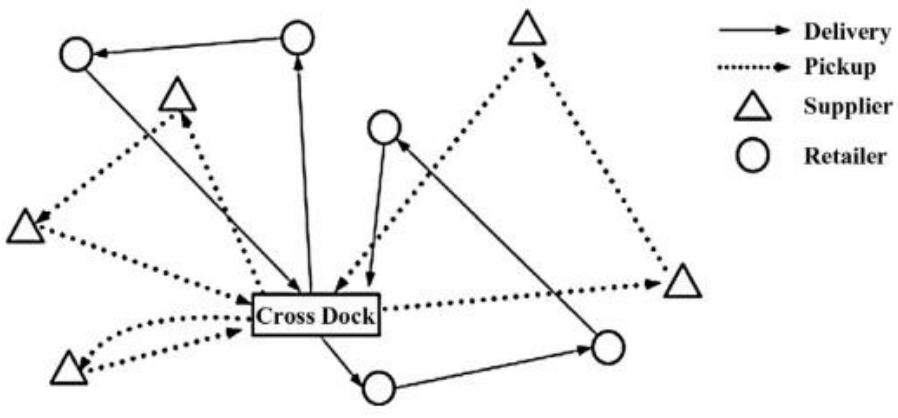


Figure 30: Vehicle routing in a cross-docking network - adapted from: Moghadam et al. (2014)

Moghadam et al. (2014) study the vehicle routing scheduling problem in a cross-docking network with time windows and split deliveries. They consider products that must be transferred from suppliers to the corresponding customers within their time windows by a set of homogenous vehicles. The authors give a mathematical formulation of the problem and solve it by a simulated annealing algorithm and a hybrid metaheuristic algorithm which combines ant colony system and simulated annealing algorithms. Maknoon & Laporte (2017) also present a vehicle routing problem in a cross-docking network, but they consider multiple cross-docking centres. This means that products can be consolidated with other products by transshipping at multiple cross-docking centres. As similar to all studies in vehicle routing problems in a cross-docking network, they consider two separate routes, pickup and delivery, for products transportation. The authors model the vehicle load synchronization by means of two planning levels. At the first level, they decide on which vehicles will travel between cross-docking centres and which request will be loaded on that vehicle. At the second level, an explicit routing decision is made for each vehicle. Maknoon & Laporte (2017) formulate the problem by means of a mathematical model and solve it by using an adaptive large neighborhood search (ALNS) heuristic, because the mathematical model cannot be solved exactly for large instances.

The stochastic vehicle routing problem includes random variables in the model. According to Juan et al. (2013), different stochastic parameters can be taken into account in a stochastic vehicle routing problem:

- The customer, i.e., if a customer is present with a certain probability or absent
- The demand of a customer
- The travel time of vehicles

The authors state that simulation seems the most suitable method to address the stochastic routing problem, because of its stochastic nature such that it can deal with a stochastic environment.

3.3 Service network design models

Another way of scheduling trucks in a transporation network is by using service network design models. Service network design models are part of the tactical planning level. Tactical planning refers to a set of interrelated decisions that aim to ensure an optimal allocation and utilization of resources to achieve the economic and customer service goals of the company (Crainic, 2000). For example, trucks are resources, which must be allocated to execute transport orders (Wieberneit, 2008). According to Crainic (2000) and Wieberneit (2008), service network design models include the following decisions:

- *Service selection:* Decisions about the offered services and their characteristics, for example, the frequency or scheduling of a service.
- *Traffic distribution:* Decisions about the routes used to move the traffic of each demand, such as service routes and hubs, terminals, i.e., cross-docking centres used.
- *General empty balancing:* Decisions about the repositioning of empty vehicles.
- *Vehicle and crew planning:* Decisions about which consolidation activities are performed in each terminal.

The frequency or scheduling of a service defines the level of service that is to be offered on that route during the planning period (Crainic & Roy, 1988). In the model, integer values are assigned to the frequency. For example, a zero value for the frequency indicates that a service is not offered. The trade-off in service network design models is between costs and customer service level, i.e., speed, flexibility, and reliability of services in the transportation network (Crainic, 2000). Wieberneit (2008) describes a generic Service Network Design Problem which contains decisions regarding service selection and traffic distribution. The model is formulated as a mathematical model and the objective is to minimize costs of all relevant decisions, which are fixed costs for each route and costs for the shipped goods. Crainic (2000) states that service network design models take the form of a mixed-integer network optimization problem for which no exact solution method exists. Heuristics are generally used to find a solution (Crainic, 2000; SteadieSeifi et al., 2014).

However, most research on service network design models concentrate on static, deterministic service network designs and do not incorporate uncertainty, in terms of demands, travel time, and vehicle breakdowns. Bai et al. (2014) state that optimal solutions in a deterministic setting might have poor quality or even lose feasibility if uncertain factors are taken into account. Therefore, the authors introduce a stochastic service network design model with vehicle rerouting options to handle uncertain demand. They model a stochastic programming model which contains two stages. The service network is determined in the first stage, while in the second stage a minimal cost flow is found based on the network obtained in the first stage. The rerouting is modelled by a set of integer variables in the second stage of the stochastic programming model. The objective of the model is to minimise the sum of the fixed network costs and the average costs, which includes both the rerouting and outsourcing costs.

Layeb et al. (2018) solve the stochastic service network design problem, while considering continous distributions of demand and travel time variabilities, by using a simulation-optimization approach. They first developed a simulation model and coupled this simulation model with an optimizer to solve the stochastic service network design probem. Simulation-optimization is successfull in solving stochastic problems, because simulation models incorporate uncertainties, and real stochastic nature of the environment.

3.4 Findings

In the previous sections, we described different models to analyse scheduling of trucks in a cross-docking network. We described truck scheduling, vehicle routing, and service network design models. We conclude that none of these models are fully applicable to our research, because of several reasons:

- The truck scheduling problem in a cross-docking centre only focuses on truck scheduling within a cross-docking centre. However, this research has a network-wide focus, which means that we consider the truck scheduling in the whole cross-docking network.
- The vehicle routing problem in a cross-docking network focuses on routes to be made between customer locations. In our research, we do not deal with customers as end nodes, but with hubs or terminals. Moreover, the routing aspect is not applicable in our research, since most locations of hubs are geographically dispersed such that a tour between hubs is not feasible.
- The objective of service network design models is minimizing costs while time plays no role in these models. However, the focus of this research is on reducing lead times of reverse parcels. Therefore, we conclude that service network design models are not applicable to our research.

Model	Type of model	Solved by	Pros	Cons
Truck scheduling model	Mathematical model	• (Meta-) heuristics	• It is solvable in reasonable amount of time • Detailed solution for truck scheduling within a cross-docking centre	• Deterministic • Objective is to minimize costs or transfer time within a cross-docking centre • Focus is on truck scheduling within a cross-docking centre
Vehicle routing model	Mathematical model	• (Meta-) heuristics • Algorithms	• It is solvable in reasonable amount of time • Routing scheme of vehicles in which distances or costs are minimized	• Deterministic • Demand must be known in advance • Routing between customer locations
Service network design model	Mathematical model	• Heuristics	• It is solvable in reasonable amount of time • Efficient allocation of existing resources • Determines frequency of services	• Deterministic • Objective is to minimize costs • Demand must be known in advance

Table 10: Details, pros, and cons of the models

In Table 10, we summarize the disadvantages and advantages of the different models. We also described stochastic and robust variants of the models in previous sections. The stochastic and robust variants do still have the disadvantage that the scope of the model is not applicable to our research, because of the reasons described earlier in this section. However, we conclude from these stochastic and robust variants that simulation is a good option to incorporate uncertainty for the planning of trucks in general. We conclude that uncertainty of the following aspects in truck scheduling are taken into account in these models:

- Arrival time of a truck
- Unload time of a pallet
- Transfer time of a pallet
- Arrival of demand
- Demand size
- Travel time of a truck

We identified in Section 2.4 that the number and arrival of reverse parcels are uncertain. Moreover, we also deal with uncertainties of travel time in our research, since the travel time of a truck might deviate due to traffic conditions. This leads to uncertain arrival times of trucks. In addition, simulation modelling is time based, which is suitable for our research since we deal with lead times. Hence, we conclude that simulation is a good approach for our research.

3.5 Simulation

3.5.1 Types of simulation

Law (2015) classifies simulation models along three dimensions:

- Static versus dynamic simulation models: A static simulation model is a representation of a system at a particular time, or one in which time plays no role. On the other hand, a dynamic simulation model represents a system as it evolves over time.
- Deterministic versus stochastic simulation models: A simulation model is called deterministic if it does not contain any random components. On the other hand, stochastic simulation models incorporate random input components.
- Continuous versus discrete simulation models: In a continuous simulation model the state changes continuously with respect to time. In a discrete simulation model, this only happens at discrete points in time. For example, by an arrival or departure event in the system.

Since the parcels are transported between hubs during time periods, we conclude that the system evolves over time and therefore time plays a role. In addition, the system contains stochastic elements, as we described in the previous section. Furthermore, parcels are transported at discrete points in time and therefore the state of the system changes at discrete points in time. Hence, a dynamic stochastic discrete event simulation, seems to be a logical choice in terms of simulation type. This simulation type is called shortly discrete-event simulation (DES). Moreover, discrete-event simulation seems to be frequently used to simulate issues in distribution & transportation planning, according to Tako & Robinson (2012). More specific, the papers of Magableh et al. (2005) and Arnaout et al. (2010) show that discrete-event simulation seems appropriate to analyse a cross-docking network.

Law (2015) classifies the type of simulation further in terminating and nonterminating simulations. We speak of a terminating simulation when a natural event specifies the end of a simulation run. The system is ‘cleaned out’ at that point in time. In our research, the state of the system at the end of the day, when the warehouse closes, is the state for the beginning of the next day. Hence, we conclude that there is no natural event that specifies the end of a simulation run. Therefore, we deal with a nonterminating simulation. Further, a distinction is made between transient system behaviour and steady state behaviour. In a transient system behaviour the performance does depend on initial conditions and in a steady state behaviour it does not. We assume that our simulation does not depend on initial conditions, because the system is never empty. Therefore, we are interested in the behaviour of the system in the long run, i.e., the steady state, which are the lead times of reverse parcels. For steady state behaviour, Law (2015) suggests to make use of a warmup period. This means that observations which depend on initial conditions are deleted at the beginning of the simulation. Law (2015) and Mes (2018) give two methods to determine the warmup period: Welch's graphical method and the Marginal Standard Error Rule (MSER) rule. In addition, since we are dealing with a stochastic process, the results of two simulation runs with the same configuration may vary. To smoothen out these deviations, Law (2015) suggests to determine the number of replications, i.e., simulation runs, and gives the following approach to determine the number of replications:

1. Make *n* independent replications with same initial conditions, same terminating event and different seed values per replication.
2. Measure the performance for each replication, i.e., the average over each replication.
3. Perform replications until the width of the confidence interval, relative to the average, is sufficiently small.
4. Seek for the minimal number of replications for which the estimated relative error is smaller or equal to the corrected target value. In formula form:

$$n^* = \min\left\{ i \geq n : \frac{t_{i-1,1-\alpha/2}\sqrt{S_n^2/i}}{\left|\bar{X}_n\right|} \leq \frac{\gamma}{1+\gamma} \right\}$$

Equation 1: Formula minimal number of replications

In which:

$n^* = minimal\ number\ of\ replications$

$t_{i-1,1-\alpha/2}$ = *Student's t-distribution for i-1 degrees of freedom and a probability of 1-(α/2)*

$S_n^2 =\ sample\ variance\ over\ n\ replications$

$i = number\ of\ replications$

$|\bar{X}_n| = cumulative\ mean\ of\ the\ output\ data$

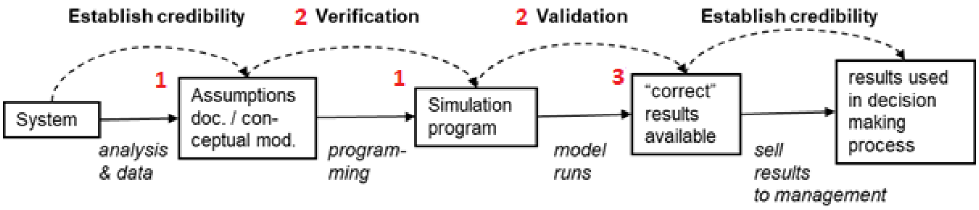
$\frac{\gamma}{1+\gamma} = corrected\ target\ value$

A relative error (γ) of 5% and a significance level of 95% are commonly used for these formulas.

3.5.2 Conducting a simulation study

Mes (2018) describes three main steps to conduct a simulation study: *Problem definition, model construction,* and *experimental design and analysis of results.* In the first step, the problem is identified and goals are formulated. In addition, the experimental factors are chosen and the scope and level of detail are determined. Moreover, a project specification is made, in which the previous aspects are stated.

The second step is model construction. In this step, a document of the model is made, in which all model elements, variables, inputs, processes and logics are explained. In addition, flowcharts are made, which are useful to represent decision processes. After the documentation is done, we can start with programming the model. According to Mes (2018), it is important to first construct a model with default functionality and add later on basic and detailed logic. During programming, we need to check if the programmed model corresponds with the conceptual model and with the reality. This is called verification and validation, respectively. These two concepts ensure credibility, i.e., that the decision maker accepts the model and output as being correct. Figure 31 shows these concepts and displays in which section of this thesis the different steps are described.



1. Section 4.1
2. Section 4.2
3. Section 5.1

Figure 31: Verification, validation and credibility– adapted from Mes (2018)

The third step is experimental design and analysis of results. In the experimental design, decisions about which configurations to simulate are taken. Three questions are important regarding the design of experiments:

1. Which factors to vary?
2. Which levels to choose for each factor?
3. Which combinations of factor levels to simulate?

Factors are the input parameters and structural assumptions in a simulation model. Levels refer to the values of these factors, i.e., which values the factors can take. After the experiments are designed, production runs are made. Lastly, the output of these production runs are analysed, documented, and presented.

3.6 Conclusion

In this chapter, we answered the following research question: *Which models exist to analyse a truck schedule in a cross-docking network, in the literature?* We described truck scheduling, vehicle routing, and service network design models. Truck scheduling models only focuses on truck scheduling problems within a cross-docking centre, and not on the cross-docking network. The vehicle routing models focuses on developing tours between customer locations. In our research, we deal with hub locations as end-nodes, instead of customer locations. Moreover, the routing aspect is not applicable to our research, since most locations of hubs are geographically dispersed such that a tour between hubs is not viable. Service network design models focuses on the whole cross-docking network, but the objective of these models is on minimizing costs. Since we focus on reducing lead times, we conclude that these models are not applicable to our research. However, the stochastic and robust variants of these models do take the following uncertainties into account in truck scheduling:

- Arrival time of a truck
- Unload time of a pallet
- Transfer time of a pallet
- Arrival of demand
- Demand size
- Travel time of a truck

These uncertainties are modelled with simulation. For our research, we conclude that a discrete-event simulation (DES) is the appropriate simulation type to model these uncertainties in truck scheduling. Moreover, simulation incorporates the stochastic nature of the environment and can be time based. We conclude that we deal with a nonterminating simulation and steady state behaviour. For this simulation type, it is important to determine a warmup period and the number of replications. To conduct a simulation study, we consider three main steps: *Problem definition, model construction,* and *experimental design and analysis of results.* In the problem definition, the problem is identified and goals are formulated. In the next step, model construction, we program the model and make sure that the model corresponds with the reality. In the last step, the experimental design is constructed and results are analysed.

4. Model design

This chapter provides an answer to the research question: *How can we design the model found in the literature?* Section 4.1 describes the components of the model. Section 4.2 describes how we verify and validate the model. In Section 4.3, we describe the experimental design. Finally, Section 4.4 concludes this chapter.

4.1 Components of the model

In this section, we answer the first question of research question 3: *What are the components of the model?* First, we describe the objective of the model. Second, the input and output of the model is described. Third, we describe the scope and assumptions of the model. Finally, we generally describe the simulation model.

4.1.1 Objective

The aim of the simulation model is to estimate the lead times of reverse parcels with a high degree of accuracy. Regarding the accuracy of the model, we refer to Section 4.2.3 in which the number of replications are determined with a relative error of 5 percent and a significance level of 95 percent. As we describe in Section 4.3, four scenarios are analysed for the pickup of parcels at each carrier. Within these scenarios, we would like to know the impact of several pickup days and times. The different departure days and times determines the number of experiments within each scenario. Based on the results of these experiments, the best departure days and times are given together with the corresponding lead times. In Chapter 5, conclusions are drawn based on these results.

4.1.2 Input data

Input data is required to simulate the transport of reverse parcels and to make sure that the simulation model is a representation of reality. Three approaches exist to specify random input data for a simulation: direct data use, an empirical distribution, and a theoretical distribution (Mes, 2018). A theoretical distribution is preferred to model random input data, while an empirical distribution should be used if it is hard to find a theoretical distribution that describes the data properly. The use of direct data is useful for model validation, which we describe in Section 4.2.2. Appendix A describes how we fitted a theoretical distribution on the available data. We create histograms and use a distribution fitting software to fit several distributions. Based on the results of two statistical tests, the Chi-Squared test and the Kolmogorov-Smirnov test, we conclude that the exponential distribution seems to have the best fit with the data of all carriers.

Besides the input data of arrivals, we need the input about how long it takes for a truck to drive from A to B. Table 11 shows the driving times from which we assume a lower and upper bound around ten percent of the average number of hours. For the flows of Carrier D, Carrier C, and Carrier E, we consult Carrier M to determine the driving times, since a pickup by a normal truck will be too costly due to the fact that the number of parcels per day is too low. For the other flows, it holds that we applied the rules of driving time and rest periods in the calculations (European Commission Mobility and Transport, 2019) and assume that a truck drives an average speed of 70 km/h. Based on this information and in consultation with a Transport Planner of the company, we compute the truck driving times as showed in Table 11. In the simulation model, we model the truck driving times as an uniform distribution between the lower and upper bound as displayed in Table 11.

Indirect Transport From/To	Hub Company X (Place B) - Average	Hub Company X (Place B) – Lower bound	Hub Company X (Place B) – Upper bound
Carrier B	0.75 hour	0.675 hour	0.825 hour
Carrier D	48 hours	43.2 hours	52.8 hours
Carrier C	48 hours	43.2 hours	52.8 hours
Carrier A	5.25 hours	4.7 hours	5.8 hours
Carrier E	72 hours	64.8 hours	79.2 hours
Carrier G	9 hours	8.1 hours	9.9 hours
Carrier F	9 hours	8.1 hours	9.9 hours
Direct Transport From/To	**Warehouse Place A - Average**	**Warehouse Place A – Lower bound**	**Warehouse Place A – Upper bound**
Carrier B	6.6 hours	5.95 hours	7.25 hours
Carrier D	48 hours	43.2 hours	52.8 hours
Carrier C	48 hours	43.2 hours	52.8 hours
Carrier A	3 hours	2.7 hours	3.3 hours
Carrier E	72 hours	64.8 hours	79.2 hours
Carrier G	13 hours	11.7 hours	14.3 hours
Carrier F	13 hours	11.7 hours	14.3 hours
Company X hub	5.8 hours	5.2 hours	6.4 hours

Table 11: Truck driving times according to the information of a Transport Planner and by consulting Carrier M

We also have to consider the opening hours of the warehouses and hubs of Company X, because this restricts when a truck can arrive and depart at these locations. We consider the following opening hours as input for the simulation model:

- Warehouses Place A: 7:30 am – 4:30 pm, from Monday to Friday
- Company X hub Place B: 7:00 am – 5:00 pm, from Monday to Friday
- Company X hub Place C: 6:00 am – 10:00 pm, from Monday to Friday

4.1.3 Output

In Section 1.3, we defined the following core problem of this research: *The lead times of the reverse logistics of parcels are higher than agreed in the Service Level Agreements (SLA) for the selected clients of Company X, resulting in a service level below the desired level of 95%.* As a consequence, we are interested in the lead time as output of the simulation model. Therefore, the simulation model has to compute the lead times of the parcels over one month and store it as Key Performance Indicators (KPIs). We choose for one month, since Company X has Monthly Business Reviews (MBRs) with their clients in which the performance over the past month is discussed. Table 12 shows the KPIs, a short description of each KPI and the reason why we select the KPI.

KPI	Description	Why do we select this KPI?
KPI 1 – Average Lead Time	The average lead time of all parcels arriving at the warehouse in one month	To be able to compare this data with the data in Section 2.2 for each scenario
KPI 2 – Percentage Parcels Above Max Lead Time	The percentage of parcels with a lead time above the maximum lead time as stated in the SLA, out of the total number of parcels in one month	Because this KPI is related to the core problem of this research
KPI 3 – Min Lead Time	The shortest lead time of all parcels in one month	To analyse the best case scenario
KPI 4 – Max Lead Time	The longest lead time of all parcels in one month	To analyse the worst case scenario

Table 12: Key Performance Indicators set as output of the simulation model

4.1.4 Scope

As explained in Section 1.3, a reverse parcel is delivered at a PUDO point and transported back to the warehouses around Place A. The logistic process from PUDO point to the hub of the carrier is outside the scope of the model, since the lead time of this part depends on the service of the carrier. So, Company X does not have influence on this lead time. To be able to compute the lead time of the whole logistic process, which is PUDO point to the warehouses, we use the average values of the lead time of the clients from Section 2.2. We use an average value of the lead time of the carrier in the simulation model, because we found that minimal 90 percent of these lead times are within plus or minus 0.2 day from the actual average. This applies to all carriers. Therefore, we assume that an average value is sufficient here. Multiple clients make use of the same carrier, for example clients Client 1, Client 3, and Client 4 use Carrier A. The lead time of the carrier is calculated proportionally to the number of parcels for each client. As a result, Table 13 shows that the lead time PUDO to hub Carrier A is 1.3 days. These calculations are done for each carrier.

Client	Number of parcels (Section 2.1)	Percentage	Lead time Carrier A in days (Section 2.2)	Percentage * Lead time carrier
Client 1	497	1.2 %	2.3	0.03
Client 3	2477	5.9 %	1.2	0.07
Client 4	38957	92.9 %	1.3	1.21
SUM	41931	100 %		1.3

Table 13: Calculations of the lead time PUDO - hub Carrier A

Second, instead of incorporating the flows of all carriers in one simulation model, we choose to consider only one flow in the simulation model. We are able to adjust the simulation model to the carrier, by changing:

- The input distribution of the corresponding carrier

- The truck driving times, as explained in Section 4.1.2
- The value of the lead time PUDO – hub carrier, as explained above

We make this decision, because we want to advice Company X per flow on the best departure days and times in each scenario. An overall solution, with multiple flows in one model is therefore not required in this case.

Third, we do not consider the transport of reverse parcels from Carrier I, because Company X does not use this carrier anymore for the selected clients. So, this carrier is outside the scope of the model.

4.1.5 Assumptions

To prevent the model becoming unnecessarily complex, we make assumptions. Table 14 lists several assumptions we make and describes why these assumptions are made.

Assumption	Description	Why do we make this assumption?
Assumption 1 - Warehouses of the clients	The three warehouses of the clients in Place A are modelled as one warehouse in which all reverse parcels are coming in. In reality, the truck visits the three warehouses, which are less than two kilometres from each other, in a tour.	In consultation with my supervisors of the company, we conclude that it is not necessary to model this in detail. Compared to the driving times which we take as input in the simulation model, the driving times between the warehouses are negligible.
Assumption 2 – Time needed to (un)load the truck	We model the (un)loading time as a constant time of 10 minutes and add them to the truck driving times.	This assumption was made following the advice of a Transport Planner of the company by measuring the time of the (un)loading of five trucks at the warehouse. All the measurements have a duration of 9 or 10 minutes and some seconds. For simplicity, we take a constant of 10 minutes.
Assumption 3 – Departure times of trucks at the top of a hour	In the simulation model, the truck can depart at the top of a hour. Departure on a quarter or half an hour is not possible.	Since most of the trucks at Company X are scheduled at the top of a hour, we choose to model only departure times at the top of a hour.
Assumption 4 – Process at the hubs and warehouses	The scanning and sorting of parcels at the hubs and warehouses is not taken into consideration in the model.	As defined in the scope of this research, Section 1.4.3, the process within a warehouse or hub is outside the scope of this research.

Table 14: Assumptions made in the simulation model

4.1.6 Description of the model

We construct our simulation model in Tecnomatix Plant Simulation 13 developed by Siemens PLM Software. As explained in Section 4.1.4, the simulation model covers the logistic process from the hub of the carrier to the warehouses of the clients. Currently, the parcels from the different carriers are routed back to the warehouses in the way we described in Section 2.1.6. In the simulation model, the parcels arrive at the hub of the carrier and from this location they are transported via the hub of Company X to the warehouses (indirect transport) or direct to the warehouses of the clients (direct transport). To move the parcels through the simulation model, a method is called every hour of simulation. Figure 32 shows a flowchart of this method. The method contains several decision processes, presented by a diamond shape in Figure 32. An example of a decision process is whether a truck arrives during opening hours or not. If a truck arrives during opening hours at a warehouse or hub, the parcels are moved to that location. If a truck arrives outside the opening hours, the arrival of the parcels is scheduled at the time the warehouse or hub opens again. The square boxes in Figure 32 represent an activity or process, which is for example the movement of parcels to a warehouse or hub. The circles represent start and end events. Another routing flowchart at the hub of Company X contains the same logic as the flowchart in Figure 32. Appendix B displays that flowchart. For clarification of the dashboard and objects in the simulation model, we refer to Appendix C.

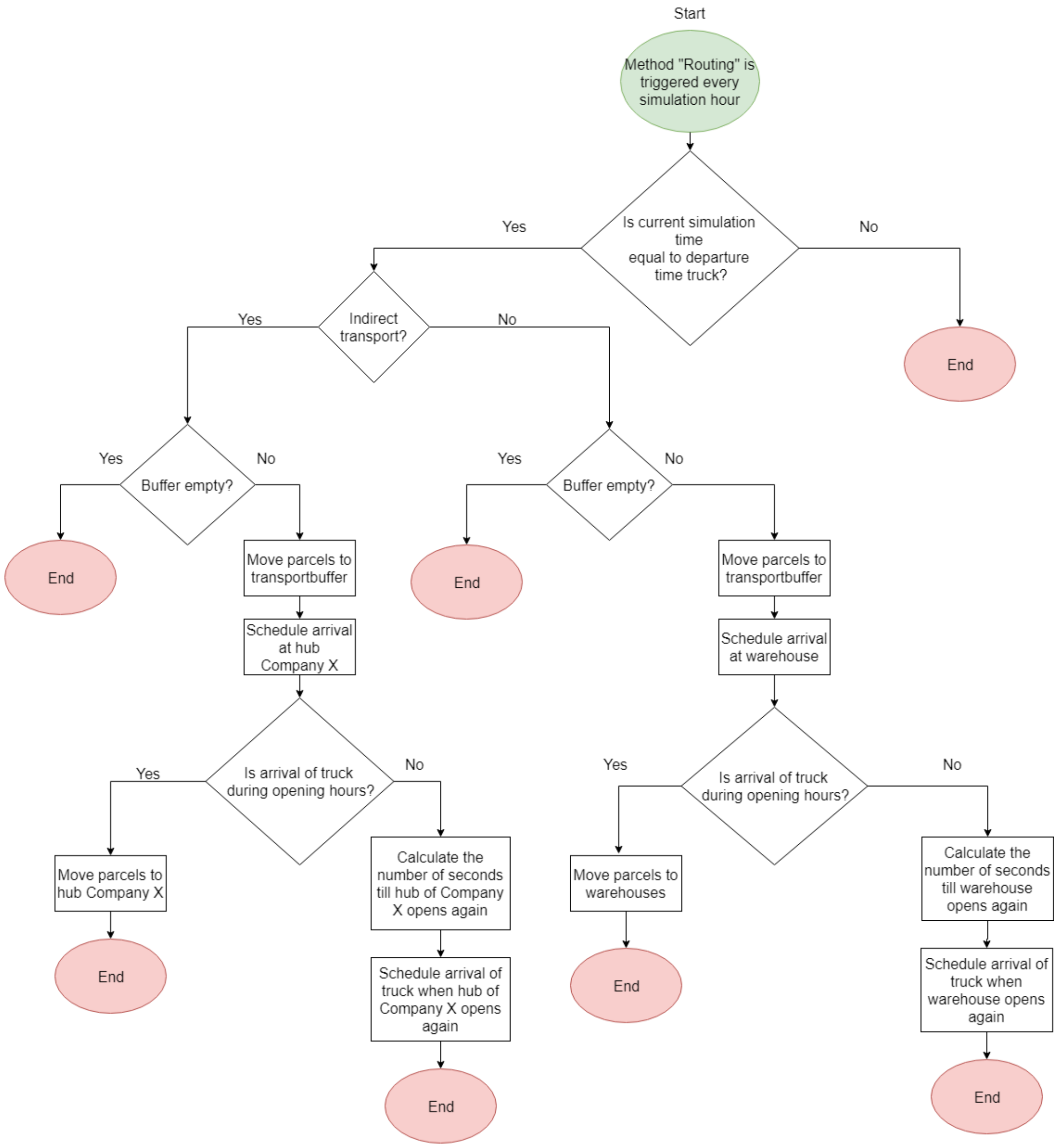


Figure 32: Flowchart routing method "Routing"

4.2 Model verification and validation

To make sure that the simulation model is an accurate representation of the reality, we have to verify and validate the programmed model. Verification means that we check if the programmed model corresponds with the conceptual model on paper. Validation is the process of determining whether a simulation model is an accurate representation of the system being studied. Moreover, the run length, number of replications and warmup period of the simulation model are determined. Therefore, we address the second question of research question 3: *How do we ensure that the simulation model meets the reality accurately enough?* in this section.

4.2.1 Verification

Law (2015) describes multiple techniques to verify a computer program of a simulation model. Instead of writing the entire computer program before debugging, we write and debug the computer program in modules. This means that after we write a module in lines of code, we immediately debug the code by stepping through the code lines. By doing this, we check if the programmed code does what it is supposed to do. Another technique we use is running the model under a variety of settings. We run the simulation model under a variety of settings of the input parameters, such as the input of arriving parcels, truck driving times, and opening hours. Next, we check if the output seems reasonable. Moreover, we make use of the animation technique. We looked at the animation in the model while the model is running. By doing so, we verify if the model does what it is supposed to do.

4.2.2 Validation

We validate the model by comparing the simulation model output with real data, which is the data presented in Section 2.2. Instead of validating the flows of all carriers, we choose to validate the model only on the flows of carriers Carrier F, Carrier G, Carrier H, Carrier A, and Carrier B. The reason for this is that these trucks depart on fixed days, Monday to Friday, and fixed times from the hub of the carrier or the Company X hub. For the flows Carrier C, Carrier E, and Carrier D it holds that the truck departure days and times are not on a fixed day and times. This makes it impossible to compare the simulation output with the real data, since we do not exactly know when the truck departed in the past. As a result, we cannot validate the model for these flows. Nevertheless, based on the validation of the other flows, we assume that our model is also valid for the flows of Carrier C, Carrier E, and Carrier D. We validate the model by using the departure days and times in the current situation, which are:

- Carrier F/Carrier G: 10:00 pm at the Company X hub (Place C), 10:00 am next day at the Company X hub (Place B), Monday to Friday
- Carrier H: 10:00 am at the Company X hub (Place B), Monday to Friday
- Carrier A: 4:00 pm at Carrier A hub, 10:00 am, next day, at the Company X hub (Place B), Monday to Friday
- Carrier B: 9:00-11:00 am at Carrier B hub, and 10:00 am, next day, at the Company X hub (Place B), Monday to Friday

Moreover, indirect transport and the current opening hours are used for all flows. We validate the model on two key performance indicators: the minimum lead time a parcel faced and the percentage of parcels above the maximum lead time according to the SLA. Table 15 shows the comparison of the simulation model with real data on the first performance indicator. We see some differences between the output of the simulation model and the real data, but based on these numbers we conclude that the output of the model meets the real data accurately enough.

Min lead time	Carrier F (Client 4)	Carrier F (Client 5)	Carrier G (Client 2)	Carrier G (Client 1)	Carrier H (Client 4)	Carrier A (Client 1)
Real data	3 days	3 days	3 days	3 days	2 days	3 days
Simulation model output	2 days, 17 hours, 53 minutes	3 days, 5 hours, 51 minutes	3 days, 2 hours, 42 minutes	2 days, 19 hours, 5 minutes	1 day, 22 hours, 16 minutes	3 days, 5 hours, 2 minutes
Difference in %	-8.50 %	8.13 %	3.75 %	-6.83 %	-3.61%	6.99 %
	Carrier A (Client 3)	**Carrier A (Client 4)**	**Carrier B (Client 2)**	**Carrier B (Client 3)**	**Carrier B (Client 4)**	
Real data	3 days	3 days	3 days	3 days	3 days	
Simulation model output	3 days, 3 hours, 26 minutes	2 days, 20 hours, 24 minutes	2 days, 21 hours, 32 minutes	3 days, 6 hours, 21 minutes	3 days, 2 hours, 16 minutes	
Difference in %	4.77 %	-5.00 %	-3.43 %	6.04 %	3.15 %	

Table 15: Validation on the minimum lead time

Table 16 shows the comparison of the simulation model with real data on the second performance indicator. Again, we see some differences between the output of the simulation model and the real data, but based on these numbers we conclude that the output of the model meets the real data accurately enough.

Percentage of parcels above max lead time (SLA)	Carrier F (Client 4)	Carrier F (Client 5)	Carrier G (Client 2)	Carrier G (Client 1)	Carrier H (Client 4)	Carrier A (Client 1)
Real data	28.0 %	82.4 %	17.2 %	42.5 %	29.6 %	39.3 %
Simulation model output	26.3 %	86.5 %	21.5 %	35.1 %	27.0 %	42.7 %
Difference	1.7 %	4.1 %	4.3 %	7.4 %	2.6 %	3.4 %
	Carrier A (Client 3)	**Carrier A (Client 4)**	**Carrier B (Client 2)**	**Carrier B (Client 3)**	**Carrier B (Client 4)**	
Real data	56.8 %	18.4 %	32.1 %	20.4 %	10.1 %	
Simulation model output	59.7 %	14.5 %	37.0 %	21.0 %	7.5 %	
Difference	2.9 %	3.9 %	4.9 %	0.6 %	2.6 %	

Table 16: Validation on the Percentage of parcels above max lead time (SLA)

4.2.3 Warmup period, run length, and number of replications

In Section 3.5.1, we concluded that we deal with a nonterminating simulation with steady state behaviour. Therefore, one needs to determine the warmup period before the model reaches its steady state. Appendix D shows that the system needs two days to get in the steady state. Therefore, the warmup period of the simulation model is two days.

Because we are dealing with a nonterminating simulation, we also have to determine the run length. Since Company X has Monthly Business Reviews (MBRs) with their clients in which the key performance indicators over the past month are discussed, we choose a run length of one month. We need to specify the run length as number of days in the simulation model, so we take 31 days as input.

To determine the number of replications, we use the approach as described in the literature review. We conclude from the calculations in Appendix D that three replications are required.

4.3 Experimental design

In this section, we address the third question of research question: *How does the experimental design look?* To obtain results from the simulation model, we have to clarify what kind of factors are used and how we vary them. Moreover, the scenarios, which we are going to simulate, are presented. This all includes our experimental design. The experimental design is developed in consultation with my company supervisors.

Table 17 shows the experimental design, which contains four scenarios. These four scenarios are a result of the combination of the factors 1 and 2:

- Factor 1: ***Direct and indirect transport.*** Direct transport means that the parcels are going directly from the hub of the carrier to the warehouses, without a stop at the hub of Company X. Indirect transport means that the parcel is first transported to the Company X hub and from that location to the warehouses around Place A.
- Factor 2: ***Current and extend opening hours.*** Current opening hours means that the current opening hours of the Company X hubs and the warehouses are used. Extend opening hours means that the opening hours are extended and the weekend is included.

Within each scenario, four factors are varied:

- Factor A: ***Departure time carrier.*** This factor describes the departure time at the hub of the carrier.
- Factor B: ***Departure day carrier.*** This factor describes the departure day at the hub of the carrier.
- Factor C: ***Departure time Company X hub (Place B/Place C).*** This factor describes the departure time at the Company X hub.
- Factor D: ***Departure day Company X hub (Place B/Place C).*** This factor describes the departure day at the Company X hub.

Scenario	Factor 1 – indirect/direct transport	Factor 2 – current/extend opening hours	Factor A: departure time carrier Factor B: departure day carrier Factor C: departure time Company X hub (BL/SW) Factor D: departure day Company X hub (BL/SW)
Scenario 1	**Indirect** transport	**Current** opening hours: • Hub Company X Place B: 7:00 am – 5:00 pm (Monday to Friday) • Warehouses: 7:30 am – 4:30 pm (Monday to Friday)	To vary the departure time and days **See Table 18**
Scenario 2	**Indirect** transport	**Extend** opening hours: • Hub Company X Place B: 6:00 am – 10:00 pm (Monday to Sunday) • Warehouses: 6:00 am – 10:00 pm (Monday to Sunday)	To vary the departure time and days **See Table 18**
Scenario 3	**Direct** transport	**Current** opening hours: • Warehouses: 7:30 am – 4:30 pm (Monday to Friday)	To vary the departure time and days **See Table 18**
Scenario 4	**Direct** transport	**Extend** opening hours: • Warehouses: 6:00 am – 10:00 pm (Monday to Sunday)	To vary the departure time and days **See Table 18**

Table 17: Experimental design with four scenarios

The number of experiments within each scenario depends on each carrier and are determined by the factors A, B, C, and D. Table 18 shows the number of experiments for Carrier A. In the current situation, Company X picks up the parcels from Carrier A five days per week, Monday to Friday. We do not consider pickup of one, two, three, and four times a week in this case, since less pickups than in the current situation results in an increase in lead time. So, starting point is the number of pickups in the current situation.

Carrier A	FACTOR A Departure time carrier	FACTOR B Departure day carrier	FACTOR C Departure time Company X hub: BL	FACTOR D Departure day Company X hub: BL	Nr Exp
Scenario 1	7 am, 11 am, 3 pm, 7 pm	To choose from: Mo,Tu,Wed,Thu,Fri,Sat	7 am, 10 am, 1 pm, 4 pm	Mon to Fri	
5 x week	4 x	$\binom{6}{5}$= 6 x	4 x	$\binom{5}{5}$= 1	=96
6 x week	4 x	$\binom{6}{6}$= 1 x	4 x	$\binom{5}{5}$= 1	=16
Scenario 2	7 am, 11 am, 3 pm, 7 pm	To choose from: Mo,Tu,Wed,Thu,Fri,Sat	8 am, 12 pm, 4 pm, 8 pm	Mon to Sun	
5 x week	4x	$\binom{6}{5}$=6x	4x	$\binom{7}{7}$=1	=96
6 x week	4x	$\binom{6}{6}$=1x	4x	$\binom{7}{7}$=1	=16
Scenario 3	7 am, 11 am, 3 pm, 7 pm	To choose from: Mo,Tu,Wed,Thu,Fri,Sat	N/A	N/A	
5 x week	4x	$\binom{6}{5}$=6			=24
6 x week	4x	$\binom{6}{6}$=1			=4
Scenario 4	7 am, 11 am, 3 pm, 7 pm	To choose from: Mo,Tu,Wed,Thu,Fri,Sat	N/A	N/A	
5 x week	4x	$\binom{6}{5}$=6			=24
6 x week	4x	$\binom{6}{6}$=1			=4

Table 18: Number of experiments Carrier A

At first, factor A describes the departure time at the hub of the carrier. The pickup of parcels must be done during the opening hours as we present in Table 19. For Carrier A, this means that pickup must be done between 7 am and 8 pm, Monday to Saturday. We do not consider departure times of every hour during opening hours, since the number of experiments will grow rapidly. Instead, we choose to distribute the departure times evenly over the opening hours of the carrier, with departure four times a day. So 7 am, 11 am, 3 pm, and 7 pm for Carrier A.

Carrier	Opening hours	Opening days
Carrier A	7:00 am – 8:00 pm	Monday to Saturday
Carrier B	9:00 am – 5:00 pm	Monday to Saturday
Carrier E	9:00 am – 5:00 pm	Monday to Friday
Carrier D	8:00 am – 6:00 pm	Monday to Friday
Carrier C	8:30 am – 12:00 am and 2:00 pm – 6:00 pm	Monday to Friday
Carrier F	6:00 am – 10:00 pm[1]	Monday to Friday
Carrier G	6:00 am – 10:00 pm[1]	Monday to Friday
Carrier H	7:00 am – 5:00 pm[2]	Monday to Friday

Table 19: Opening hours hub carriers

[1] Parcels of Carrier F and Carrier G are delivered at the Company X hub in Place C, so opening hours are equal to opening hours of the Company X hub in Place C.
[2] Parcels of Carrier H are delivered at the Company X hub in Place B, so opening hours are equal to opening hours of the Company X hub in Place B.

Second, factor B describes the departure day at the hub of the carrier. Since Carrier A is open from Monday to Saturday, there are six days to choose from. By a pickup schedule of five times a week, $\binom{6}{5}$= 6 combinations are possible.

Third, factor C describes the departure time at the Company X hub. Again, the departure times are evenly distributed over the opening hours of the Company X hub. In this case 7 am, 10 am, 1 pm, and 4 pm.

Fourth, factor D describes the departure day at the Company X hub. Since in the current situation, a truck already departs five days a week at the Company X hub in Place B (Monday to Friday), $\binom{5}{5}$= 1 combination is possible. More departures than five days a week is not possible, because in Scenario 1 we restricts ourselves to the current opening hours.

As a result, we consider 96 experiments in Scenario 1 when pickup is done five times a week:

$$4 * 6 * 4 * 1 = 96 \text{ experiments}$$

Appendix E contains tables with the description of the experiments for the other carriers. For the carriers Carrier A, Carrier B, Carrier G, Carrier F, and Carrier H we simulate all scenarios a second time in which pickup is done twice a day. Appendix F contains tables with the description of the experiments when pickup is done twice a day. For the carriers Carrier C, Carrier E, and Carrier D, it is not viable to have twice a day a pickup, since the number of parcels per day is too low. So, this means that it would be too costly to have a second transport on the same day.

4.4 Conclusion

In this chapter, we answered the following research question: *How can we design the model found in the literature?* The objective of the model is to estimate the lead times of the reverse parcels in different scenarios. We need input for the model, which are the input distributions for arrivals of parcels, truck driving times, and opening hours of the warehouses and the hubs of Company X. We showed that an exponential distribution seems to have the best fit with the interarrival times of all carriers. In addition, Key Performance Indicators are defined to gather output from the simulation model. The following KPIs are selected:

- Average lead time
- Percentage of parcels above the maximum lead time as stated in the SLA
- Minimum lead time
- Maximum lead time

We also described the scope and assumptions of the model in Section 4.1.4 and 4.1.5. Regarding the scope of the model, we choose to simulate the logistic process starting at the hub of the carrier and ending at the warehouses. We do not consider the logistic process from the PUDO point to the hub of the carrier, since the lead time of that part depends on the service of the carrier.

To ensure that the model represents the reality well enough, we verify and validate our model. Verification is done by three techniques: writing and debugging the computer program in modules; running the model with different settings and see if the output seems reasonable; and using the animation of the model to check if the model does what it is supposed to do. To validate the model, we compared the simulation model output with real data. Based on the comparison in Section 4.2.2, we conclude that our model is valid. Moreover, we have determined the warmup period and the number of replications of our simulation model in order to give reliable output data. We need two days of warmup before the system is in steady state. The required number of replications is three.

Since in the MBR(s) the performance of the reverse parcel process over the past month is discussed, we conclude that an appropriate run length is one month of simulation.

Finally, we present the experimental design. For each carrier, we simulate four scenarios:

- **Scenario 1**: *Indirect transport* and the *current opening hours* of the hubs of Company X and warehouses.
- **Scenario 2**: *Indirect transport* and the *extending opening hours* of the hubs of Company X and warehouses.
- **Scenario 3**: *Direct transport* and the *current opening hours* of the warehouses.
- **Scenario 4**: *Direct transport* and the *extending opening hours* of the warehouses.

Within these scenarios, we vary the departure days and times of trucks. The simulation model shows then which pickup days and times are the best in each scenario. The following chapter presents the results of the experimental design.

5. Analysis of results

This chapter provides an answer to the research question: *What are the results of the experiments conducted with the model?* Section 5.1 describes the results per carrier, while Section 5.2 discusses the results for the clients and Company X itself. We conclude this chapter in Section 5.3

5.1 Results experiments

This section presents the results of the experiments per carrier. A short recap, we would like to estimate the lead times per carrier in four different scenarios:

- **Scenario 1**: *Indirect transport* and the *current opening hours* of the hubs of Company X and warehouses.
- **Scenario 2**: *Indirect transport* and the *extending opening hours* of the hubs of Company X and warehouses.
- **Scenario 3**: *Direct transport* and the *current opening hours* of the warehouses.
- **Scenario 4**: *Direct transport* and the *extending opening hours* of the warehouses.

Within these scenarios, we vary the number of pickup days a week, as explained in Section 4.3. This depends on the carrier. The estimated lead times in these sections are lead times for all clients that make use of that specific carrier. Moreover, we also present results regarding the percentage of parcels above the maximum lead time as stated in the Service Level Agreement (SLA). As described in the problem description, Company X has the desire to reach a service level of 95 percent. This means that 95 percent of the reverse parcels must be back in the warehouse within the maximum lead time. As a result, a maximum of 5 percent of the reverse parcels might be above the maximum lead time. We use these 5 percent threshold by describing the results in the following sections.

5.1.1 Carrier A

Three clients of Company X make use of Carrier A to collect the reverse parcels in Germany: Client 4, Client 3, and Client 1. We used for all experiments in this section a lead time of 1.3 days for the logistic part from Pick Up Drop Off (PUDO) point to the hub of Carrier A. This lead time is based on a calculation of the average lead time carrier proportionally to the number of parcels for these three clients. Moreover, we identified in Section 2.2 an average total lead time of 4.3, 4.2, and 4.5 days for the parcels of Client 4, Client 3, and Client 1 respectively. Figure 33 and Table 20 display the results after running the experiments defined in Table 18 in Section 4.3. Since in the current situation, the pickup of parcels is done on five days during a week, we do not simulate scenarios with less than five pickup days during the week. Moreover, the Carrier A hub is open six days a week. So, we simulate a five- and six-days pickup frequency during a week.

We draw several conclusions from the results in Figure 33. At first, in Scenario 1, a reduction of the average lead time is possible when we select other departure times compared to the current situation. In Scenario 1, we apply the current opening hours and indirect transport, which is identically to the current situation. A reduction of the lead time to 3.3 or 3.2 days on average, for five- or six-days pickup respectively, is possible when we change the departure times to the times as showed in Appendix G. Second, Scenario 2 shows that a reduction to 2.5 or 2.4 days on average is possible when the current opening hours of the hub of Company X and the warehouses are extended. In this scenario, we still applied indirect transport. Third, in Scenario 3, reduction to 2.2 or 2.1 days on average is possible when direct transport is used instead of indirect transport. The current opening hours are used in this scenario. Lastly, in Scenario 4, we can reduce the average lead time to 1.9 or 1.8 days, for five or six days a pickup respectively. In this scenario, we use direct transport and extend the opening hours of the warehouses.

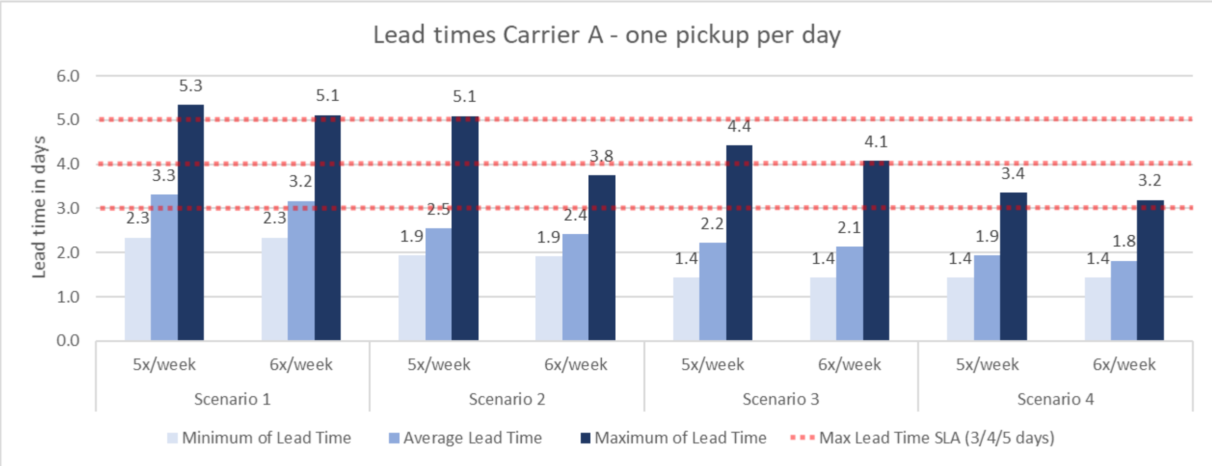


Figure 33: Lead time results Carrier A - one pickup per day

Table 20 shows the results concerning the percentage of parcels above the maximum lead time as stated in the SLA of these three clients. Clients Client 3, Client 1, and Client 4 do have different maximum lead times in their SLAs, respectively three, four, and five days. In case Company X wants to reach the service level of 95 percent with a maximum SLA lead time of 3 days, Scenario 4 with five or six days pickup seems appropriate. If Company X wants to reach the service level of 95 percent with a maximum SLA lead time of 4 days, it should go for Scenario 2, 3, or 4. Lastly, if Company X chooses for a maximum SLA lead time of 5 days, it can apply all scenarios, since the 95 percent service level is reached in all scenarios. Appendix G displays the best departure times and days of for these four scenarios.

Max Lead Time	Scenario 1		Scenario 2		Scenario 3		Scenario 4	
	5x/ week	6x/ week	5x/ week	6x/ week	5x/ week	6x/ week	5x/ week	6x/ week
% > Max Lead Time SLA (3 days)	38.3 %	32.5 %	11.5 %	5.5 %	16.5 %	16.3 %	2.7 %	0.9 %
% > Max Lead Time SLA (4 days)	21.5 %	20.8 %	3.6 %	0.0 %	3.9 %	1.4 %	0.0 %	0.0 %
% > Max Lead Time SLA (5 days)	4.4 %	1.3 %	0.6 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %

Table 20: Results Carrier A - Percentage of parcels above max lead time SLA - one pickup per day

Figure 34 and Table 21 show the results after running experiments with two pickups a day at the hub of Carrier A. Table 44 in Appendix F shows the defined experiments for these simulations. Again, we investigate five and six pickup days a week, resulting in ten or twelve pickups a week. By comparing Table 20 and Table 21, we see that the percentages above the maximum SLA lead time are lower when pickup is done twice a day. If Company X wants to reach the service level of 95 percent with a maximum SLA lead time of 3 days, it can go for pickup of twelve times a week in Scenario 2 and Scenario 4. In addition, pickup of ten times a week in Scenario 4 also results in a service level above the 95 percent. When a service level of 95 percent with a maximum SLA lead time of 4 days is desired, Company X should go for Scenario 2, 3, or 4. Lastly, if a 95 percent service level with a maximum SLA lead time of 5 days is desired, Company X can choose all scenarios. Appendix G shows the best departure days and times in each scenario.

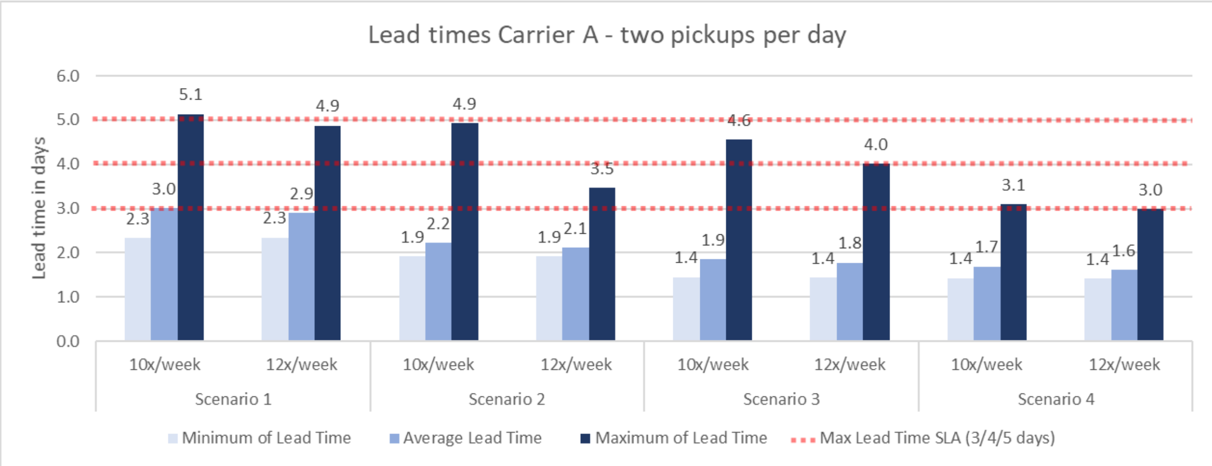


Figure 34: Lead time results Carrier A - two pickups per day

Max Lead Time	Scenario 1		Scenario 2		Scenario 3		Scenario 4	
	10x/ week	12x/ week	10x/ week	12x/ week	10x/ week	12x/ week	10x/ week	12x/ week
% > Max Lead Time SLA (3 days)	30.7 %	22.4 %	6.5 %	1.9 %	8.0 %	6.5 %	0.6 %	0.4 %
% > Max Lead Time SLA (4 days)	15.7 %	11.9 %	1.6 %	0.0 %	1.8 %	0.3 %	0.0 %	0.0 %
% > Max Lead Time SLA (5 days)	1.2 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %

Table 21: Results Carrier A - Percentage of parcels above max lead time SLA - two pickups per day

5.1.2 Carrier B

Three clients of Company X make use of Carrier B to collect the reverse parcels in France: Client 2, Client 4, and Client 3. We used for all experiments in this section a lead time of 1.3 days for the logistic part from PUDO point to the hub of Carrier B. This lead time is based on a calculation of the average lead time carrier proportionally to the number of parcels for these three clients. Figure 35 and Table 22 show the results after running the experiments displayed in Table 37 in Appendix E. Again, we investigate five- and six-days a pickup in a week, because five days is equal to the current situation and six days is the maximum since the hub of Carrier B is open six days a week.

We identified in Section 2.2 an average total lead time of 6.2, 4.3, and 4.6 days for the parcels of Client 2, Client 4, and Client 3 respectively. At first, Figure 35 shows that in Scenario 1, the average lead time can be reduced to 3.1 and 3.0 days on average, for five and six times a week a pickup respectively. Scenario 1 is equal to the current situation with indirect transport and the current opening hours. However, compared to the current situation, we need to change the pickup times, to reach an average lead time of 3.1 or 3.0 days. Second, the average lead time is reduced to 2.4 or 2.2 days on average in case the opening hours of the Company X hub and warehouses are extended (Scenario 2). Third, the average lead time is reduced to 3.0 or 2.9 days on average in Scenario 3. In this scenario, direct transport and the current opening hours are used. Lastly, a reduction to an average lead time of 2.3 or 2.2 days is possible when direct transport and an extension of the opening hours of the warehouses are applied (Scenario 4). Appendix G shows the best departure days and times for each scenario.

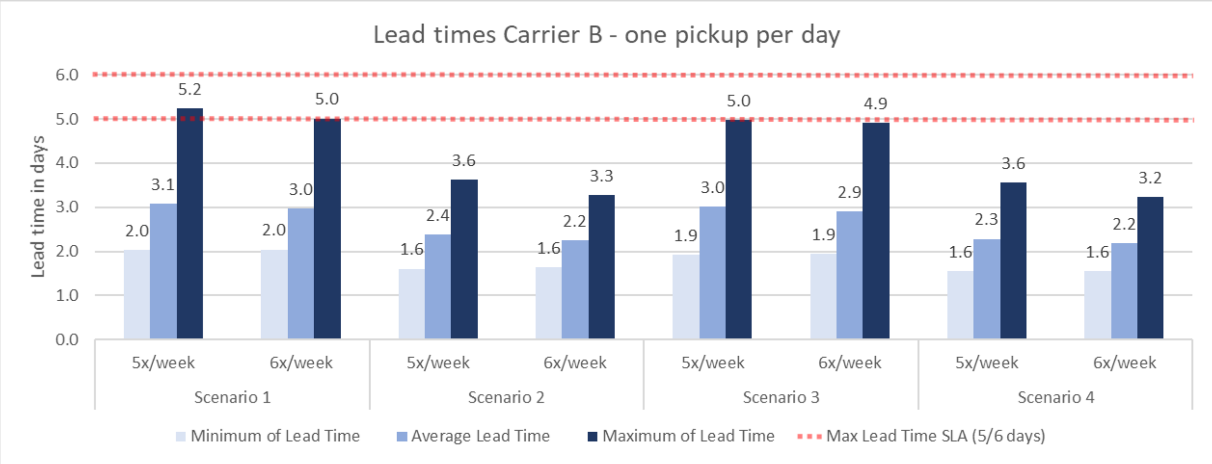


Figure 35: Lead time results Carrier B - one pickup per day

Table 22 shows the results regarding the percentage of parcels above the maximum lead time as stated in the SLA of these clients. The clients Client 2, Client 4, and Client 3 do have a different maximum lead time in their SLA. The maximum lead time in the SLA of Client 3 is five days, while the maximum of Client 2 and Client 4 is six days. For all scenarios and both maximum lead times, we conclude from Table 22 that the percentage of parcels above the maximum lead time is below 5 percent, which means that the service level is above 95 percent.

Max Lead Time	Scenario 1		Scenario 2		Scenario 3		Scenario 4	
	5x/ week	6x/ week	5x/ week	6x/ week	5x/ week	6x/ week	5x/ week	6x/ week
% > Max Lead Time SLA (5 days)	1.4 %	0.4 %	0.0 %	0.0 %	0.2 %	0.0 %	0.0 %	0.0 %
% > Max Lead Time SLA (6 days)	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %

Table 22: Results Carrier B - Percentage of parcels above max lead time - one pickup per day

Figure 36 displays the results when pickup is done twice a day. Table 45 in Appendix F contains the table with the description of the experiments for these scenarios. Again, we investigate five- and six-days a pickup during the week, resulting in ten or twelve pickups a week. The percentage of parcels above the maximum SLA lead time is for all scenarios zero percent, which means that the 95 percent service level is reached in all scenarios. Appendix G shows the best departure days and times in each scenario.

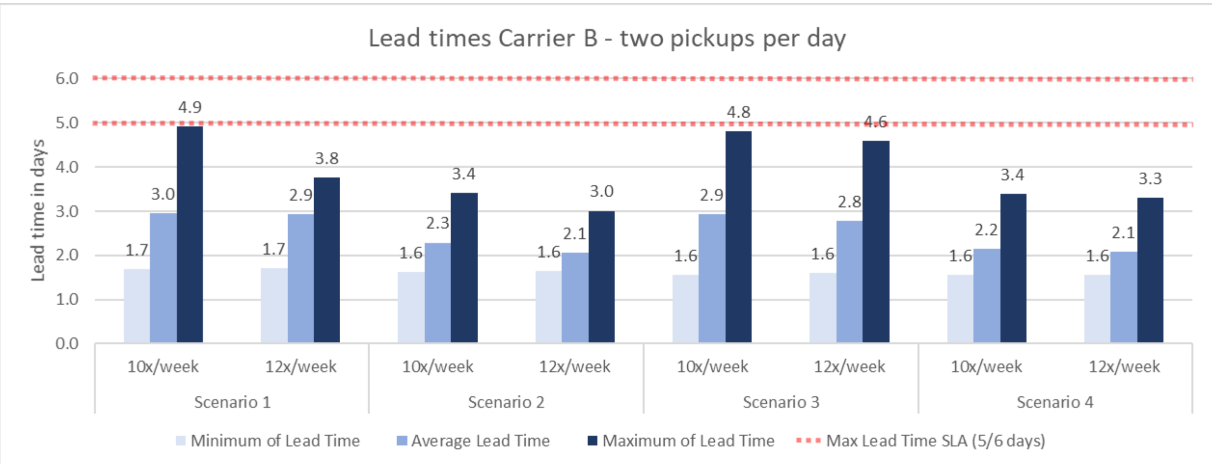


Figure 36: Lead time results Carrier B - two pickups per day

5.1.3 Carrier C

Client 2 and Client 3 make use of Carrier C to collect the reverse parcels in Italy. We used for all experiments in this section a lead time of 3.2 days for the logistic part from PUDO point to the hub of Company Z in Bergamo. This lead time is based on a calculation of the average lead time carrier proportionally to the number of parcels for these two clients. Figure 37 and Table 23 show the results for Scenario 1 and 2 after running the experiments defined in Table 41 in Appendix E. Since parcels of Carrier C are not picked up on fixed days and times, we investigate a pickup frequency from 1 to 5 days a week for each scenario. More than 5 days a week is not possible, due to the opening days of the hub of Company Z, which is Monday to Friday.

We identified in Section 2.2 an average lead time of 14.6 days for Client 2 and 14.3 days for Client 3. Figure 37 shows an average lead time of 8.9 days when pickup is done once a week with indirect transport and the current opening hours (Scenario 1). This lead time can be further reduced in the same scenario to an average of 6.8 days when pickup is done five times a week. In Scenario 2, an average lead time of 8.1 days is reached when pickup is done once a week, while the average lead time becomes 6.5 days when Company X arranges a pickup of five times a week. The risk, defined as the difference between the minimum and the maximum lead time, becomes smaller if pickup is done more frequently. From the results in Table 23 we conclude that all pickup frequencies in Scenario 1 and 2 do have a percentage above the 5 percent by a maximum lead time of 6 and 7 days. This would indicate that other defining components like the maximum SLA lead time or the lead time PUDO to the hub of the carrier should change. We conclude that the lead time PUDO to hub carrier is already three days on average, which is high compared to carriers in other countries, which have an average lead time ranging from one to two days.

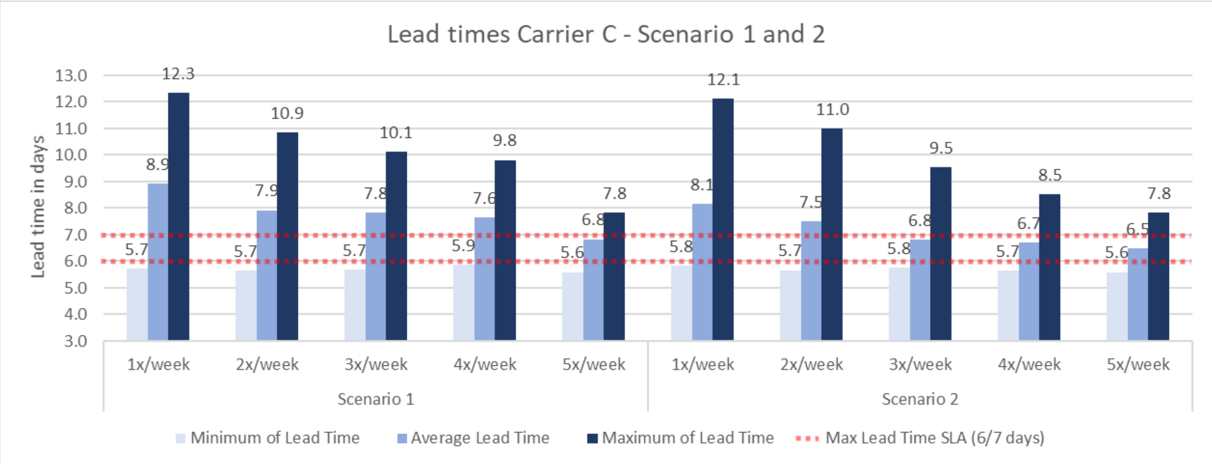


Figure 37: Lead time results Carrier C - Scenario 1 and 2

Max Lead Time	Scenario 1					Scenario 2				
	1x/ week	2x/ week	3x/ week	4x/ week	5x/ week	1x/ week	2x/ week	3x/ week	4x/ week	5x/ week
% > Max Lead Time SLA (6 days)	90.5 %	85.7 %	84.2 %	80.7 %	78.7 %	88.2 %	71.4 %	70.0 %	66.7 %	64.3 %
% > Max Lead Time SLA (7 days)	81.0 %	75.3 %	73.7 %	58.3 %	50.0 %	70.6 %	50.0 %	33.3 %	30.0 %	28.6 %

Table 23: Results Carrier C - Percentage of parcels above max lead time SLA - Scenario 1 and 2

Figure 38 and Table 24 show the results for Scenario 3 and 4 after running the experiments defined in Table 41 in Appendix E. In case pickup is done once a week in Scenario 3, an average lead time of 7.9 days is obtained. The average lead time is further reduced to 6.4 days on average if pickup is done five times a week. In Scenario 4, an average lead time of 7.3 days is reached by a once a week pickup. By a pickup of five days a week, an average lead time of 5.9 days is obtained. Again, we conclude that the risk becomes smaller when the pickup is done more frequently. The results in Table 24 shows that we are not able to reach a service level of 95 percent in Scenario 3 and 4 with a maximum lead time of 6 or 7 days. This would indicate that Company X should change other components, such as the maximum lead time in the SLA or the lead time PUDO to the hub of the carrier. The lead time PUDO to hub carrier is already more than three days on average, so a reduction of this lead time will also decrease the percentages in Table 23. Nevertheless, the percentages of Scenario 4, where we use four- and five-pickups a week, are close to the threshold of 5 percent to reach a service level of 95 percent. Appendix G displays the best departure times and days for all scenarios.

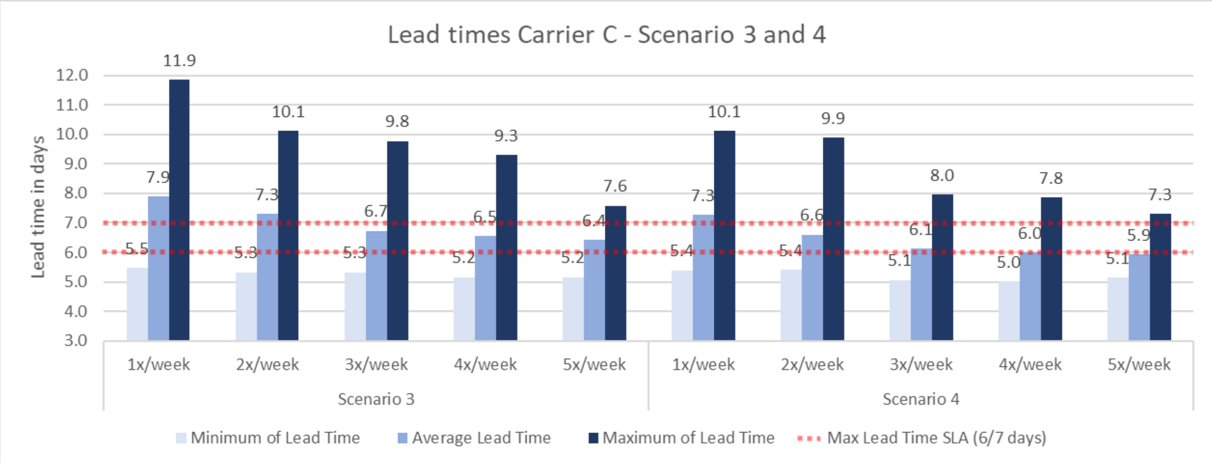


Figure 38: Lead time results Carrier C - Scenario 3 and 4

Max Lead Time	Scenario 3					Scenario 4				
	1x/ week	2x/ week	3x/ week	4x/ week	5x/ week	1x/ week	2x/ week	3x/ week	4x/ week	5x/ week
% > Max Lead Time SLA (6 days)	87.0 %	68.3 %	64.3 %	60.0 %	58.4 %	70.6 %	61.5 %	36.8 %	33.3 %	29.6 %
% > Max Lead Time SLA (7 days)	78.3 %	42.9 %	32.9 %	20.0 %	10.5 %	58.8 %	30.8 %	10.5 %	7.4 %	7.1 %

Table 24: Results Carrier C - Percentage of parcels above max lead time SLA - Scenario 3 and 4

5.1.4 Carrier D

Client 2, Client 3, and Client 4 make use of Carrier D to collect their reverse parcels in Spain. We used for all experiments in this section a lead time of 2.8 days for the logistic part from PUDO point to the hub of Company Y nearby Place E. This lead time is based on a calculation of the average lead time carrier proportionally to the number of parcels for these three clients. Figure 39 and Table 25 show the results of Scenario 1 and 2 after running the experiments described in Table 42 in Appendix E. We investigate a pickup frequency from one to five days a week, since these parcels are not picked up on a regular basis and the hub of the carrier is open five days a week.

In Section 2.2, we identified an average total lead time of 10.8, 8.1, and 8.9 days for Client 2, Client 3, and Client 4 respectively. At first, Figure 39 displays that in Scenario 1, with indirect transport and the current opening hours, the average lead time ranges from 8.7 to 6.3 days. The average lead time in Scenario 2 ranges from 8.5 to 5.9 days. We see that the difference between the minimum and maximum of the lead time becomes smaller when pickup is done more times during the week. Table 25 displays the percentage of parcels above the maximum lead time. We conclude that none of the scenarios reach the service level of 95 percent with a maximum lead time of 6 or 7 days, since all percentages are above 5 percent. This would indicate that other defining components like the maximum lead time stated in the SLA or the lead time PUDO to hub carrier should change.

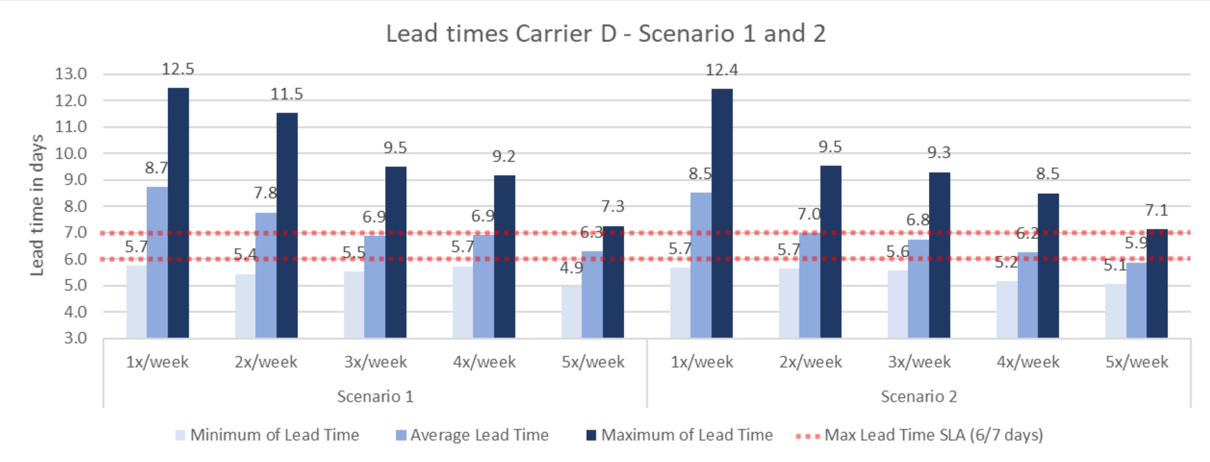


Figure 39: Lead time results Carrier D - Scenario 1 and 2

Max Lead Time	Scenario 1					Scenario 2				
	1x/ week	2x/ week	3x/ week	4x/ week	5x/ week	1x/ week	2x/ week	3x/ week	4x/ week	5x/ week
% > Max Lead Time SLA (6 days)	77.8 %	70.0 %	53.3 %	50.1 %	40.0 %	76.5 %	57.1 %	40.0 %	31.3 %	28.6 %
% > Max Lead Time SLA (7 days)	50.0 %	40.0 %	36.4 %	30.8 %	10.0 %	70.6 %	35.7 %	33.3 %	30.8 %	11.1 %

Table 25: Results Carrier D - Percentage of parcels above max lead time SLA - Scenario 1 and 2

Figure 40 shows the lead times of Scenario 3 and 4. In Scenario 3, the average lead time ranges from 7.8 to 5.7 days. We conclude that the difference between the minimum and maximum decreases when the number of pickups per week increases. The same holds for the lead times in Scenario 4. In Scenario 4, the average lead time ranges from 7.1 to 5.3 days. By a pickup frequency of five times a week, the difference between the minimum and maximum is the smallest. From the results in Table 26, we conclude that a 95 percent service level is reached when pickup is done four or five times a week in Scenario 4 by a maximum lead time of 7 days. In addition, we reach the 95 percent service level by a pickup frequency of five times a week in Scenario 4 and a maximum lead time of 6 days. Appendix G displays the best departure times and days for all scenarios.

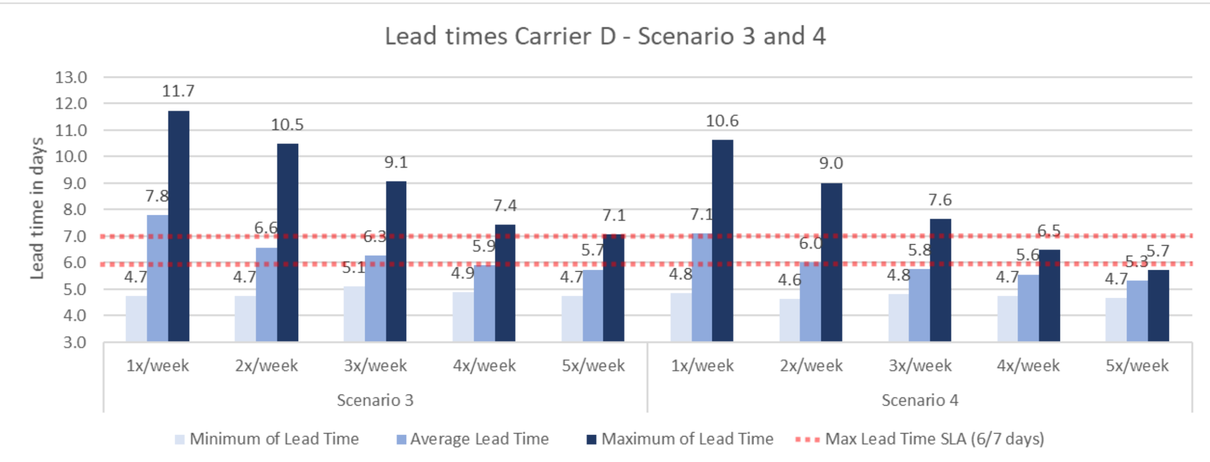


Figure 40: Lead time results Carrier D - Scenario 3 and 4

Max Lead Time	Scenario 3					Scenario 4				
	1x/ week	2x/ week	3x/ week	4x/ week	5x/ week	1x/ week	2x/ week	3x/ week	4x/ week	5x/ week
% > Max Lead Time SLA (6 days)	70.6 %	47.4 %	30.0 %	23.1 %	12.8 %	54.5 %	29.4 %	28.6 %	20.0 %	0.0 %
% > Max Lead Time SLA (7 days)	58.8 %	36.8 %	20.0 %	10.0 %	8.5 %	36.4 %	17.6 %	14.3 %	0.0 %	0.0 %

Table 26: Results Carrier D - Percentage of parcels above max lead time SLA - Scenario 3 and 4

5.1.5 Carrier E

Client 2 makes use of Carrier E to collect the reverse parcels in Ireland and agreed a maximum SLA lead time of 6 days. We used for all scenarios in this section a lead time of 3.1 days for the logistic part from PUDO point to the hub of Carrier E. This lead time is obtained from Section 2.2. Figure 41 and Figure 42 show the results of the simulations of Scenario 1 to 4. Table 43 in Appendix E displays the defined experiments for these scenarios. The pickup of the parcels from Carrier E is not done on a regular basis, which also holds for the parcels from Carrier D and Carrier C. Therefore, we investigate a pickup frequency of one to five days a week. Five days is the maximum, because the hub of Carrier E is open from Monday to Friday.

In Section 2.2, we identified an average total lead time of 21.5 days. Figure 41 shows that the average lead time in Scenario 1 ranges from 8.5 days, for a once a week pickup, to 6.8 days, when pickup is done five days a week. In Scenario 2, the average lead time ranges from 8.1 to 6.7 days. For both scenarios, we conclude that the difference between the minimum and maximum becomes smaller when pickup is done more times a week. The percentage of parcels above the maximum lead time of 6 days is for all scenarios 100 percent, because the minimum lead time is always above the maximum lead time according to the SLA of Client 2, which is 6 days. This indicates that other defining components like the maximum lead time as stated in the SLA or the lead time PUDO to hub carrier should change.

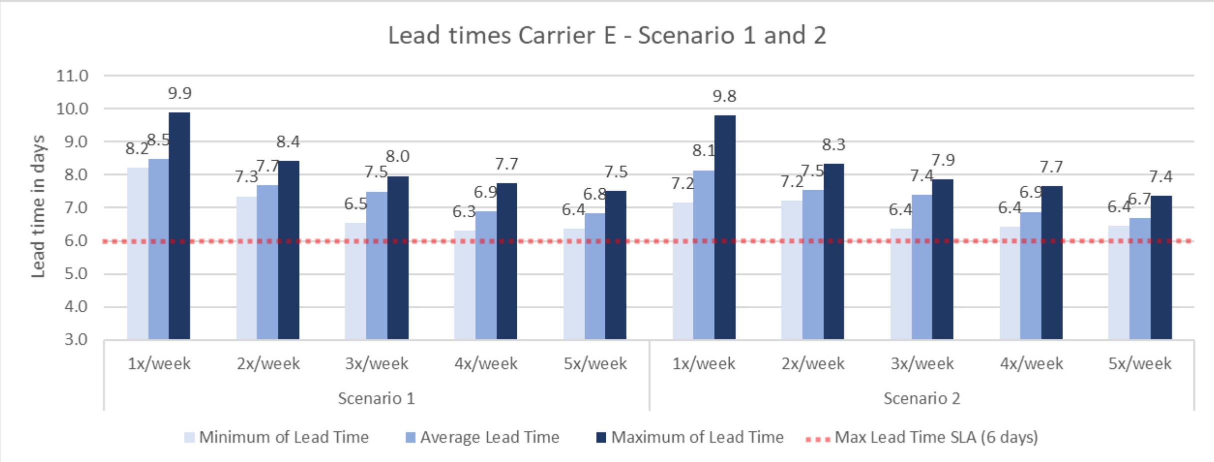


Figure 41: Lead time results Carrier E - Scenario 1 and 2

Figure 42 shows the lead times for Scenario 3 and 4. In Scenario 3, the average lead time ranges from 8.0 to 6.5 days, while in Scenario 4, the average ranges from 7.9 to 6.4 days. Again, for both scenarios we see that the difference between the minimum and maximum lead time becomes smaller if pickup is done more frequently. Appendix G displays the best departure times and days for all scenarios.

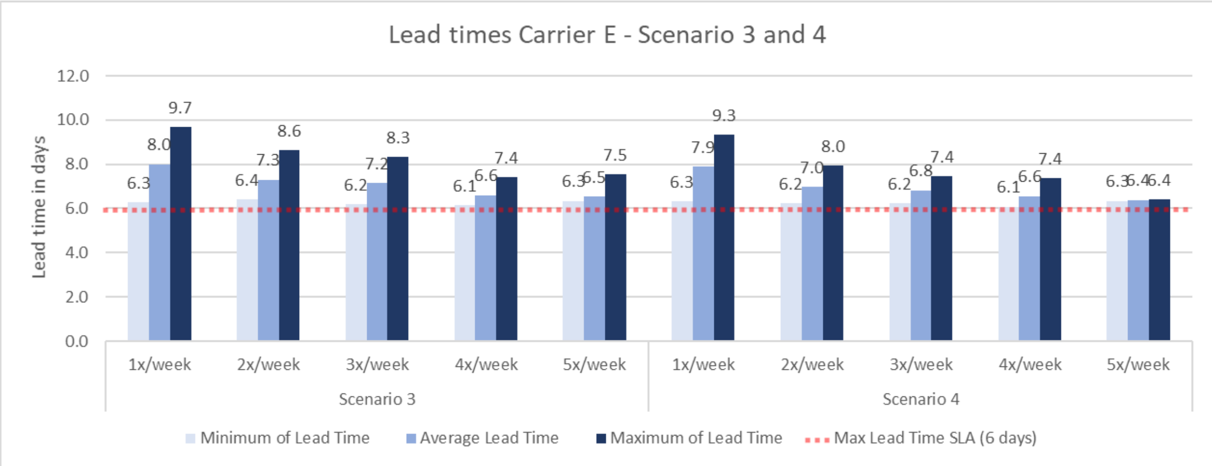


Figure 42: Lead time results Carrier E - Scenario 3 and 4

5.1.6 Carrier F

Client 4 and Client 5 make use of Carrier F to collect their reverse parcels in England. We used for all its corresponding scenarios a lead time of 1.8 days for the logistic part from PUDO point to the hub of Company X in Place C. This lead time is based on a calculation of the average lead time carrier proportionally to the number of parcels for these two clients. Carrier F delivers the parcels directly at the Company X hub in Place C, instead of delivery at the hub of Carrier F. Therefore, we consider in the simulations the Company X hub in Place C as the hub of the carrier. Scenario 1 and 2 contains indirect transport, which means in this case that the parcels are transported from Place C to the Company X hub in Place B, followed by a transport to the warehouses. On the other hand, Scenario 3 and 4 means that the parcels are directly transported from the Company X hub in Place C to the warehouses around Place A. In this case, there is no stop in Place B.

Figure 43 and Table 27 show the results when pickup is done five days a week and if there is one pickup per day. Table 39 in Appendix E lists the experiments for these four scenarios. In the current situation, pickup is already done five days a week. Since the Company X hub in Place C is open five days a week, we only simulate a pickup frequency of five days a week. As we identified in Section 2.2, the average total lead time is 5.6 days for the parcels of Client 4 and 14.8 days for the parcels of Client 5. Figure 43 shows that, in Scenario 1, an average lead time of 4.0 days is obtained. In Scenario 2, 3, and 4, the average lead time is lower, respectively 3.6, 3.3, and 3.2 days on average. Table 27 displays that the 95 percent service level is reached in Scenario 4 by a maximum lead time of 5 days. However, if the maximum lead time is 6 days, the service level of 95 percent is reached in all scenarios. Appendix G displays the best departure times for all scenarios.

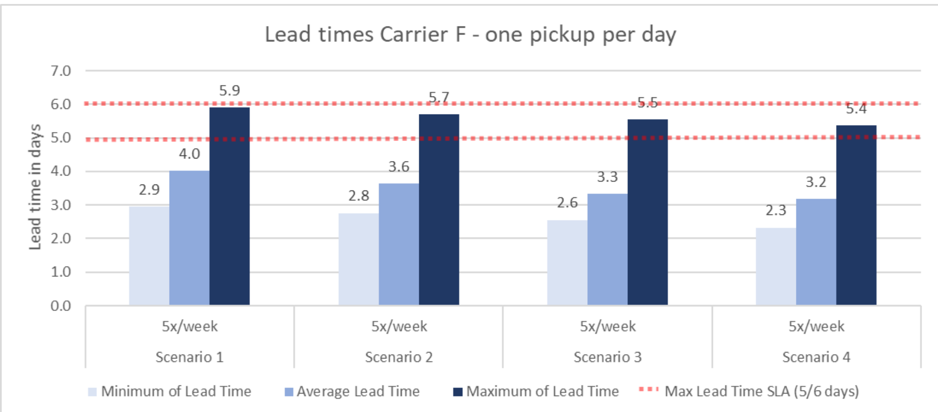


Figure 43: Lead time results Carrier F - one pickup per day

Max Lead Time	Scenario 1	Scenario 2	Scenario 3	Scenario 4
	5x/week	5x/week	5x/week	5x/week
% > Max Lead Time SLA (5 days)	20.8 %	5.6 %	9.0 %	3.8 %
% > Max Lead Time SLA (6 days)	0.0 %	0.0 %	0.0 %	0.0 %

Table 27: Results Carrier F - Percentage of parcels above max lead time SLA - one pickup per day

Figure 44 and Table 28 display the results when pickup is done twice a day. Table 47 in Appendix F contains the table with the description of the experiments for these scenarios. Again, we investigate five days a pickup during the week, resulting in ten pickups a week. We conclude from Table 28 that we reach a service level of 95 percent in Scenario 3 and 4 with a maximum lead time of 5 days. If Company X chooses a maximum lead time of 6 days, all scenarios have a service level above 95 percent. Appendix G displays the best departure times for all scenarios.

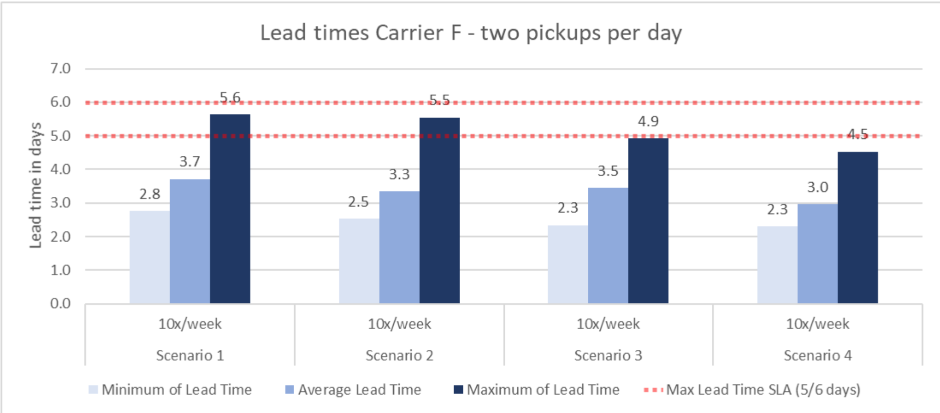


Figure 44: Lead time results Carrier F - two pickups per day

Max Lead Time	Scenario 1	Scenario 2	Scenario 3	Scenario 4
	10x/week	10x/week	10x/week	10x/week
% > Max Lead Time SLA (5 days)	11.4 %	5.3 %	0.0 %	0.0 %
% > Max Lead Time SLA (6 days)	0.0 %	0.0 %	0.0 %	0.0 %

Table 28: Results Carrier F - Percentage of parcels above max lead time SLA - two pickups per day

5.1.7 Carrier G

Client 2 and Client 1 make use of Carrier G to collect the reverse parcels in England. We used for all scenarios in this section a lead time of 1.9 days for the logistic part from PUDO point to the hub of Company X in Place C. This lead time is based on a calculation of the average lead time carrier proportionally to the number of parcels for these two clients. As similar to the flow of Carrier F, the parcels of Carrier G are delivered at the Company X hub in Place C. So, in this case means indirect transport in Scenario 1 and 2 the transport of parcels from Place C via Company X hub in Place B to the warehouses. Direct transport in Scenario 3 and 4 means the transport of parcels from the hub in Place C directly to the warehouses. In this case, there is no stop in Place B. As similar to the situation of Carrier F, we simulate five days per week a pickup.

Figure 45 and Table 29 display the results and Table 38 in Appendix E shows the defined experiments for these scenarios. In Section 2.2, we identified an average total lead time of 5.1 days for the parcels of Client 2 and 5.5 days for the parcels of Client 1. Figure 45 shows an average lead time of 4.2 days in Scenario 1, while the average lead times are further reduced to 3.5, 3.3, and 3.0 days on average, for respectively Scenario 2, 3, and 4. In Table 29, we see that a 95 percent service level is reached in Scenario 3 and 4 with a maximum lead time of 5 days. In case Company X selects a maximum lead time of 6 days, the 95 percent service level is reached in all scenarios. Appendix G displays the best departure times for all scenarios.

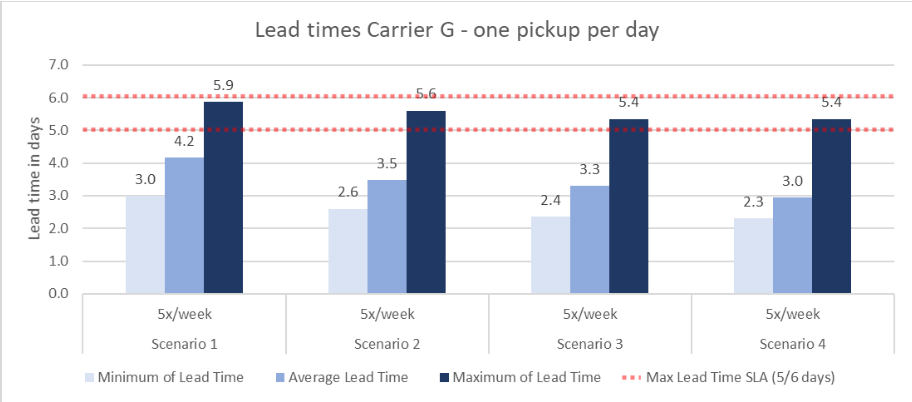


Figure 45: Lead time results Carrier G - one pickup per day

Max Lead Time	Scenario 1	Scenario 2	Scenario 3	Scenario 4
	5x/week	5x/week	5x/week	5x/week
% > Max Lead Time SLA (5 days)	23.7 %	7.5 %	2.9 %	2.4 %
% > Max Lead Time SLA (6 days)	0.0 %	0.0 %	0.0 %	0.0 %

Table 29: Results Carrier G - Percentage of parcels above max lead time SLA - one pickup per day

Figure 46 and Table 30 show the results when pickup is done twice a day. Table 46 in Appendix F displays the defined experiments for these scenarios. As equal to the situation of Carrier F, we investigate five days a week a pickup, resulting in ten pickups a week when pickup is done twice a day. Table 30 shows that the 95 percent service level is reached in all scenarios with a maximum lead time of 5 and 6 days. Appendix G contains the best departure times in all scenarios.

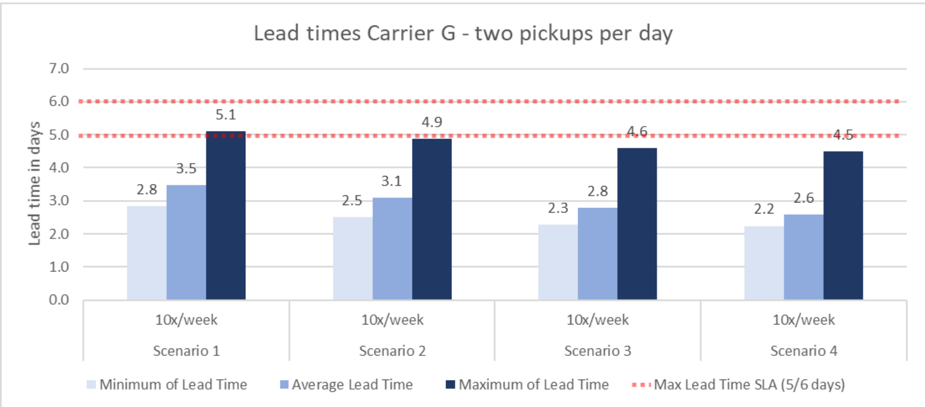


Figure 46: Lead time results Carrier G - two pickups per day

Max Lead Time	Scenario 1	Scenario 2	Scenario 3	Scenario 4
	10x/week	10x/week	10x/week	10x/week
% > Max Lead Time SLA (5 days)	1.6 %	0.0 %	0.0 %	0.0 %
% > Max Lead Time SLA (6 days)	0.0 %	0.0 %	0.0 %	0.0 %

Table 30: Results Carrier G - Percentage of parcels above max lead time SLA - two pickups per day

5.1.8 Carrier H

Client 4 makes use of Carrier H to collect the reverse parcels in Belgium. We used for all scenarios in this section a lead time of 1.6 days for the logistic process from PUDO point to the Company X hub in Place B. This lead time is obtained from Section 2.2. Carrier H delivers the parcels directly at this Company X hub, instead of delivery at the hub of Carrier H themselves. So, in this case, we consider the Company X hub in Place B as the hub of the carrier. Only direct transport is considered, since there is no stop at the Company X hub. As a consequence, we simulate Scenario 3 and 4. In the current situation, Carrier H delivers from Monday to Friday in Place B. The hub is closed during the weekends. Therefore, we only simulate a five days per week pickup.

Figure 47 shows the results of lead times when pickup is done once a day. Table 40 in Appendix E shows the defined experiments for the scenarios. We conclude that there is almost no difference between the lead times if the opening hours of the warehouses are extended, Scenario 4, compared to the lead times with current opening hours, Scenario 3. The 95 percent service level is only reached in Scenario 4 with a maximum lead time of 4 days, since the percentage of parcels above the maximum lead time is 5.0 percent in this scenario. Appendix G shows the best departure times for both scenarios.

Figure 48 displays the results when pickup is done twice a day, resulting in 10 pickups a week. Table 48 in Appendix F contains the description of the experiments for these scenarios. We reach the service level of 95 percent in both scenarios, since the percentage of parcels above the maximum lead time is 4.6 and 3.8 percent, for Scenario 3 and Scenario 4 respectively. Appendix G shows the best departure times for both scenarios.

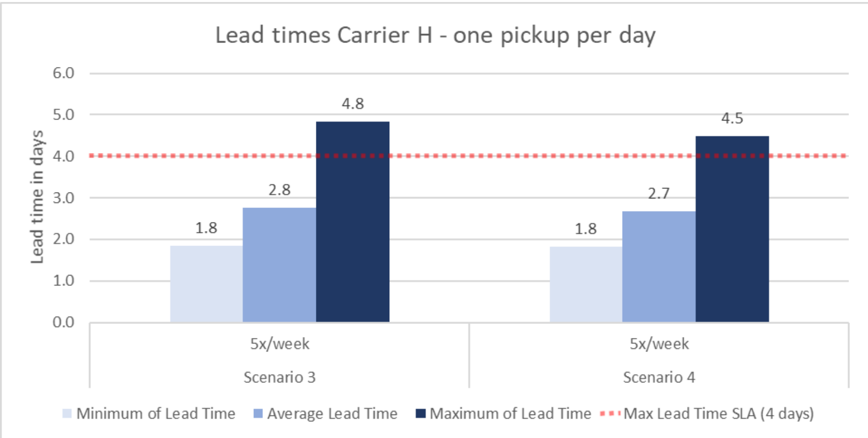


Figure 47: Lead time results Carrier H - one pickup per day

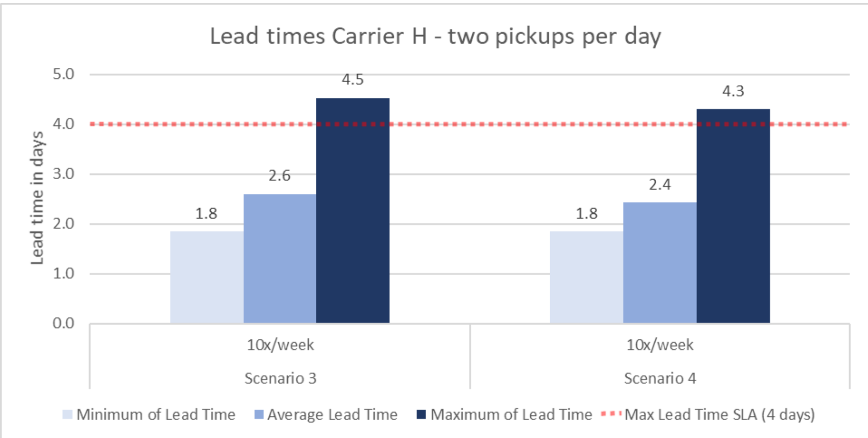


Figure 48: Lead time results Carrier H - two pickups per day

5.2 Discussion of the results

The previous section shows several scenarios to reduce the lead times for the reverse parcels of each carrier. The clients of Company X have an interest in a short lead time, since a shorter lead time means that items can be quickly sold again. Moreover, they are able to proceed the refund of the returned items earlier. From a customer perspective, this results in a positive image of the client. In addition, a shorter lead time contributes to a positive image of Company X as well, since the client experiences that Company X achieves the agreed performance.

The scenarios, which we evaluate with the simulation model, are structured in a way that Scenario 1 contains the least changes compared to the current situation and Scenario 4 the most. According to my company supervisors, it is preferable to apply Scenario 1 first. If it turns out that the service level in this scenario is below the required 95 percent, we consider Scenario 2. If the service level is still below the 95 percent in Scenario 2, we consider Scenario 3 et cetera. Moreover, we conclude that Scenario 1 is considered as the least costly and Scenario 4 as the most costly. This is due to the fact that direct transport will be more costly than indirect transport, because there is no consolidation option if we apply direct transport. This means that we are not able to combine different sized shipments in one single shipment at the Company X hub anymore, which results in less full truckloads and an increase in transport costs per parcel. Moreover, extending the opening hours is estimated to be less costly than direct transport. As a result, this implies a ranking of the scenarios according to their number, which applies to all carriers:

- Scenario 1, most preferred scenario
- Scenario 2, second most preferred scenario
- Scenario 3, third most preferred scenario
- Scenario 4, fourth most preferred scenario

Based on this ranking, we present in Table 31 the minimal required scenario for each maximum SLA lead time, on the condition that the 95 percent service level is obtained. Moreover, the table shows the percentage of parcels above the maximum lead time the corresponding scenario. In addition, it presents the reduction in average lead time compared to the current situation. The minimum, average, and maximum lead times are given as well.

We draw several conclusions from the results in Table 31. At first, for some carriers we also evaluate the scenarios when pickup is done twice a day at the carrier. This results in two options to reach the desired service level of 95 percent by a given maximum SLA lead time. For example, with a maximum lead time of five days in the case of Carrier G, we recommend to implement Scenario 3 when pickup is done once a day at the carrier and Scenario 1 when pickup is done twice a day. In general, picking up twice a day results in higher service level, but also results in more transportation costs compared to a pickup of once a day. Company X should consider this and decides which scenario fits best with regard to costs, lead times, and service level. Second, the results of carriers Carrier C and Carrier E show that none of the scenarios reach a service level of 95 percent. This indicates that other components like the maximum SLA lead time or the lead time of PUDO point to the hub of the carrier should change. We conclude that the maximum SLA lead time should increase or the lead time of PUDO point to the hub of the carrier should decrease. The lead time PUDO point to hub carrier is already three days on average for these carriers. Third, for Carrier D, we conclude that Scenario 4 with a pickup frequency of four or five days per week reaches the service level. Because there are not every day parcels from this carrier, it could happen that the truck drives empty on some days in the week. If Company X do think that this is not acceptable, it should do the same as in the situation of Carrier C and Carrier E. Therefore, a solution is to increase the maximum SLA lead time or to decrease the lead time from PUDO point to the hub of the carrier.

Carrier – Max SLA Lead Time	Minimal required scenario	Percentage of parcels above max lead time SLA	Min Lead Time (days)	Average Lead Time (days)	Max Lead Time (days)	% Reduction in Average Lead Time
Carrier A	Pickup *once* a day					
3 days	Scenario 4 - 5x/week	2.7 %	1.4	1.9	3.4	54.8 %
4 days	Scenario 2 - 5x/week	3.6 %	1.9	2.5	5.1	44.4 %
5 days	Scenario 1 - 5x/week	4.4 %	2.3	3.3	5.3	23.3 %
Carrier A	Pickup *twice* a day					
3 days	Scenario 2 - 12x/week	1.9 %	1.9	2.1	3.5	50.0 %
4 days	Scenario 2 - 10x/week	1.6 %	1.9	2.2	4.9	51.1 %
5 days	Scenario 1 - 10x/week	1.2 %	2.3	3.0	5.1	30.2 %
Carrier B	Pickup *once* a day					
5 days	Scenario 1 – 5x/week	1.4 %	2.0	3.1	5.2	32.6 %
6 days	Scenario 1 – 5x/week	0.0 %	2.0	3.1	5.2	27.9 %
Carrier B	Pickup *twice* a day					
5 days	Scenario 1 – 10x/week	0.0 %	1.7	3.0	4.9	34.8 %
6 days	Scenario 1 – 10x/week	0.0 %	1.7	3.0	4.9	30.2 %
Carrier C	None of the scenarios reach the 95 percent service level					
Carrier D	Pickup *once* a day					
6 days	Scenario 4 - 5x/week	0.0 %	4.7	5.3	5.7	34.6 %
7 days	Scenario 4 – 4x/week	0.0 %	4.7	5.6	6.5	37.1 %
Carrier E	None of the scenarios reach the 95 percent service level					
Carrier F	Pickup *once* a day					
5 days	Scenario 4 - 5x/week	3.8 %	2.3	3.2	5.4	78.4 %
6 days	Scenario 1 - 5x/week	0.0 %	2.9	4.0	5.9	28.6 %
Carrier F	Pickup *twice* a day					
5 days	Scenario 3 - 10x/week	0.0 %	2.3	3.5	4.9	76.4 %
6 days	Scenario 1 - 10x/week	0.0 %	2.8	3.7	5.6	33.9 %
Carrier G	Pickup *once* a day					
5 days	Scenario 3 - 5x/week	2.9 %	2.4	3.3	5.4	40.0 %
6 days	Scenario 1 - 5x/week	0.0 %	3.0	4.2	5.9	17.6 %
Carrier G	Pickup *twice* a day					
5 days	Scenario 1 - 10x/week	1.6 %	2.8	3.5	5.1	36.4 %
6 days	Scenario 1 - 10x/week	0.0 %	2.8	3.5	5.1	31.4 %
Carrier H	Pickup *once* a day					
4 days	Scenario 4 – 5x/week	5.0 %	1.8	2.7	4.5	28.9 %
Carrier H	Pickup *twice* a day					
4 days	Scenario 3 – 10x/week	4.6 %	1.8	2.6	4.5	31.6 %

Table 31: Minimal required scenario for each maximum SLA lead time

Before Company X implements the chosen scenario, it should arrange several things in general. Scenario 1, which consists of indirect transport and the current opening hours, has the least changes compared to the current situation. Only the pickup days and times at the hub of the carrier, as well as the Company X hub, should change. In case Company X implements this scenario for the pickup at a carrier, it should consult the carrier about the desired pickup days and times. Scenario 2 contains an extension of the opening hours. This means that the hubs of Company X and warehouses are open from 6 am to 10 pm every day, so weekend as well. In case Company X implements this scenario, it should think of arranging extra staff for these opening hours. Moreover, shift work is necessary. In Scenario 3, we applied direct transport and used the current opening hours. In the current situation, the sorting process of reverse parcels according to clients is done at the Company X hub in Place C or Place B. For direct transport, Company X should arrange this sorting process at the hub of the carrier. They have to consult the carrier to see if this is possible. In case Company X choses Scenario 4 for the pickup at a carrier, it should think of all mentioned things before.

5.3 Conclusion

In this chapter, we answered the following research question: *What are the results of the experiments conducted with the model?* We present the lead times of the defined scenarios for each carrier. Further, we show results regarding the percentage of parcels above the maximum SLA lead time in each scenario. Since the wish is to obtain a service level of 95 percent, the percentage of parcels above the maximum SLA lead time should not exceed 5 percent in a scenario. In consultation with my company supervisors, we conclude that Scenario 1 is the most preferred scenario to apply, since this scenario requires the least changes compared to the current situation and it is considered as the least costly scenario. Further, Scenario 2 is the second most preferred scenario, and Scenario 3 and 4, the third and fourth most preferred scenario, respectively. So, this implies a ranking of the scenarios according to their number. The ranking with respect to costs of the scenarios is the same. We select for each maximum SLA lead time a minimal required scenario, based on this ranking, and on the condition that the 95 percent service level is obtained in the corresponding scenario. Table 31 on the previous page, shows the minimal required scenarios for each maximum SLA lead time of the corresponding carrier.

6. Conclusions and recommendations

In this final chapter, we conclude our research. In Section 6.1, we present the conclusions of this research. Section 6.2 provides recommendations and Section 6.3 addresses the limitations of this research. In Section 6.4, we describe how this research contributes to literature and the practical environment. Finally, Section 6.5 presents suggestions for further research.

6.1 Conclusions

The reverse process of parcels at Company X often takes more time than agreed in the Service Level Agreements (SLAs), which are contracts between Company X and the clients of Company X. These contracts defines the level of service expected from Company X. Company X has the desire to reach a service level of 95 percent, which means that 95 percent of the reverse parcels must be back within the maximum lead time as stated in the SLA. In other words, the main research question that we formulate is:

How could Company X shorten its lead times of the reverse parcels, such that the desired service level of 95 percent is reached?

To answer this question we first analyse the current situation and the performance of the reverse process. We conclude that the following causes contribute to a high lead time:

- *Cause 1 - No daily pickup at carrier*: The parcels from carriers Carrier D, Carrier E, and Carrier C are not picked up on a daily basis. As a consequence, parcels are stored at the hub of these carriers for some time, before they are transported back to the warehouses.
- *Cause 2 - Mismatch between arrival and departure time truck*: The delivery of parcels at the Company X hubs in Place C and Place B is throughout the day. This implies that sometimes parcels have to wait at these hubs for the next truck. As an example, the parcels of Carrier A and Carrier B have to wait a day in Place B before they are on the next truck.
- *Cause 3 - Parcel has to travel multiple distances/hubs*: Parcels have to be cross-docked at hubs, which causes handling time. In addition, it happens that parcels must be stored at hubs, waiting for the next truck.
- *Cause 4 - Uncertainty about number of reverse parcels*: We conclude that the number of reverse parcels is highly variable. Moreover, it is not exactly known when parcels arrive at the hub of the carrier. Due to this variability, it is difficult to make a planning for the pickup of the parcels. This causes a high lead time, when the planning does not match with the reality.
- *Cause 5 - Missed scans*: Due to missed scans at hubs and lack of an address in the scan, the location of a parcel is not exactly known during transport. This results in lost parcels. As a result, the lead time of these parcels increases.

We conclude that the first four causes relates to the scheduling of pickups and deliveries of parcels under uncertainty. The fifth cause is a quality issue, which causes a high lead time. Therefore, we take this cause into consideration. A literature review is performed on models to analyse a truck schedule in a cross-docking network. We found that simulation is a suitable approach to evaluate the reverse process of parcels at Company X, since it incorporates uncertainty of travel times and arrival times of trucks. Moreover, simulation modelling is time based, which is suitable for our research, since we deal with lead times. With the simulation model, we evaluate four scenarios for the parcels of each carrier:

- **Scenario 1**: *Indirect transport* and the *current opening hours* of the hubs of Company X and warehouses.
- **Scenario 2**: *Indirect transport* and the *extending opening hours* of the hubs of Company X and warehouses.
- **Scenario 3**: *Direct transport* and the *current opening hours* of the warehouses.

- **Scenario 4**: *Direct transport* and the *extending opening hours* of the warehouses.

Within each scenario, we vary the number of pickup days and times. We conclude that Scenario 1 is the most preferred scenario to apply, since this scenario requires the least changes compared to the current situation and it is considered as the least costly scenario. Further, Scenario 2 is the second most preferred scenario, and Scenario 3 and 4, the third and fourth most preferred scenario, respectively. In consultation with my company supervisors, we conclude that the costs of the scenarios results in the same ranking. Thus, we rank the scenarios according to their number: Scenario 1 is the most preferred scenario, while Scenario 4 is the least preferred scenario. For each maximum lead time, we select the minimal required scenario, which satisfies the condition of the 95 percent service level. Since Company X wishes to reach a service level of 95 percent, a maximum of five percent of the parcels might have a lead time above the maximum lead time. We also evaluated the four scenarios when pickup is done twice a day at the carriers Carrier A, Carrier B, Carrier F, Carrier G, and Carrier H. For the other carriers, it is not viable to have a second pickup on the same day, since the number of parcels per day is low. As a consequence, it would be too costly to have a second truck on the same day which picks up the parcels.

Table 32 presents the minimal required scenario for each maximum SLA lead time, based on the ranking of the scenarios. Moreover, it shows the percentage of parcels above the maximum SLA lead time. In addition, the table shows the minimum, average, and maximum lead time of each scenario, as well as the reduction in average lead time compared to the current situation. Appendix G displays the best departure days and times in each scenario. We conclude that none of the scenarios reach the 95 percent service level for carriers Carrier C and Carrier E. Therefore, other components should change, like the maximum SLA lead time or the lead time PUDO point to the hub of the carrier. We conclude that the lead time PUDO point to the hub of these carriers is already three days, which is high compared to carriers in other countries.

Carrier – Max SLA Lead Time	Minimal required scenario	Percentage of parcels above max lead time SLA	Min Lead Time (days)	Average Lead Time (days)	Max Lead Time (days)	% Reduction in Average Lead Time
Carrier A	Pickup *once* a day					
3 days	Scenario 4 - 5x/week	2.7 %	1.4	1.9	3.4	54.8 %
4 days	Scenario 2 - 5x/week	3.6 %	1.9	2.5	5.1	44.4 %
5 days	Scenario 1 - 5x/week	4.4 %	2.3	3.3	5.3	23.3 %
Carrier A	Pickup *twice* a day					
3 days	Scenario 2 - 12x/week	1.9 %	1.9	2.1	3.5	50.0 %
4 days	Scenario 2 - 10x/week	1.6 %	1.9	2.2	4.9	51.1 %
5 days	Scenario 1 - 10x/week	1.2 %	2.3	3.0	5.1	30.2 %
Carrier B	Pickup *once* a day					
5 days	Scenario 1 – 5x/week	1.4 %	2.0	3.1	5.2	32.6 %
6 days	Scenario 1 – 5x/week	0.0 %	2.0	3.1	5.2	27.9 %
Carrier B	Pickup *twice* a day					
5 days	Scenario 1 – 10x/week	0.0 %	1.7	3.0	4.9	34.8 %
6 days	Scenario 1 – 10x/week	0.0 %	1.7	3.0	4.9	30.2 %
Carrier C	None of the scenarios reach the 95 percent service level					
Carrier D	Pickup *once* a day					
6 days	Scenario 4 – 5x/week	0.0 %	4.7	5.3	5.7	34.6 %
7 days	Scenario 4 – 4x/week	0.0 %	4.7	5.6	6.5	37.1 %
Carrier E	None of the scenarios reach the 95 percent service level					
Carrier F	Pickup *once* a day					
5 days	Scenario 4 - 5x/week	3.8 %	2.3	3.2	5.4	78.4 %
6 days	Scenario 1 - 5x/week	0.0 %	2.9	4.0	5.9	28.6 %
Carrier F	Pickup *twice* a day					
5 days	Scenario 3 - 10x/week	0.0 %	2.3	3.5	4.9	76.4 %
6 days	Scenario 1 - 10x/week	0.0 %	2.8	3.7	5.6	33.9 %
Carrier G	Pickup *once* a day					
5 days	Scenario 3 - 5x/week	2.9 %	2.4	3.3	5.4	40.0 %
6 days	Scenario 1 - 5x/week	0.0 %	3.0	4.2	5.9	17.6 %
Carrier G	Pickup *twice* a day					
5 days	Scenario 1 - 10x/week	1.6 %	2.8	3.5	5.1	36.4 %
6 days	Scenario 1 - 10x/week	0.0 %	2.8	3.5	5.1	31.4 %
Carrier H	Pickup *once* a day					
4 days	Scenario 4 – 5x/week	5.0 %	1.8	2.7	4.5	28.9 %
Carrier H	Pickup *twice* a day					
4 days	Scenario 3 – 10x/week	4.6 %	1.8	2.6	4.5	31.6 %

Table 32: Minimal required scenario for each maximum SLA lead time

6.2 Recommendations

To obtain a service level of 95 percent for the parcels from each carrier, we recommend Company X to first consider the maximum SLA lead times it will offer to their clients. Based on the chosen maximum lead times, we recommend the financial department of Company X to make a detailed cost-benefit analysis of the corresponding scenarios presented in Table 32. For some carriers it holds that two possible scenarios are given to reach the service level by a given maximum lead time. For example, with a maximum lead time of five days in the case of Carrier G, we recommend to implement Scenario 3 when pickup is done once a day at the carrier and Scenario 1 when pickup is done twice a day. Picking up twice a day would be more costly, but also results in a higher service level in general. We recommend that the financial department takes these two options into account and make a cost-benefit analysis of both scenarios.

After the financial department of Company X made the cost-benefit analysis of the corresponding scenarios, Company X should conclude if the scenarios are still feasible with respect to costs and revenues.

Before Company X implements the chosen scenario, it should arrange several things. In case Company X wants to implement Scenario 1, it should consult the carrier about the desired pickup days and times. Scenario 1 is equal to the current situation, except from the fact that the departure days and times have to change. In Scenario 2, Company X should think of arranging extra staff for the warehouses and hubs, because in this scenario the opening hours are extended. In addition, shift work is necessary. In Scenario 3, Company X should arrange the sorting process of parcels at the hub of the carrier, since we applied direct transport in this scenario. In case Company X implements Scenario 4, it should think of all mentioned things before.

The results of carriers Carrier C and Carrier E in Table 32 show that none of the scenarios reach a service level of 95 percent. This indicates that other components like the maximum SLA lead time or the lead time of PUDO point to the hub of the carrier should change. We recommend to increase the maximum SLA lead time for the parcels from these carriers. Another option is to select another carrier in the corresponding country to pick up the reverse parcels, since we conclude that the lead time of these carriers is high compared to carriers in other countries. Moreover, for the pickup at Carrier D, we recommend to implement Scenario 4 with a pickup frequency of four or five days a week. Since it turns out that on some days there are no parcels to be picked up, it could happen that the truck drives empty on some days. In case this is not desired, we recommend the same solutions as we propose for the parcels from Carrier C and Carrier E. Therefore, we advise to increase the maximum SLA lead time. A second option is selecting another carrier in Spain in order to shorten the lead time of PUDO point to the hub of the carrier.

Finally, we conclude in the previous section that missed scans are a cause of the high lead time. Due to missed scans and a lack of an exact location in the scan, the location of a parcels is not exactly known, which results in lost parcels. This contributes to an increased lead time of these parcels. We recommend to actually scan the parcels if they leave or enter a certain warehouse or hub. Moreover, we advise to add a scan point when parcels leave the hub of the carrier. In the current situation, parcels of all carriers do not receive a scan at that moment.

Company X already introduces a scan app for scanning the reverse parcels at the hubs of Company X and warehouses. With this system, we are able to scan the barcode of a pallet, instead of scanning the parcels case-by-case. This reduces the chance on missed scans. However, we still recommend to take care of scanning all parcels when they enter or leave a certain location. In addition, we advise to add an exact location, like an address, in the scans. We expect that these changes might improve the trackability of the parcels. This results in a reduction of the number of parcels being lost and therefore contributes to a shorter lead time.

6.3 Limitations

This research has several limitations, which we discuss in this section. First, we could question the quality of data used to calculate the lead times in the current situation. We observed more often that scans were missing for parcels of some carriers, which let us exclude these parcels by calculating the lead times. Moreover, across the clients, differences exists in how the lead times are tracked in the returns rapports. This makes it difficult to analyse the lead times in the same way for all clients. However, given the available data, we tried to calculate the lead times as accurately as possible.

Second, the scope of this research is the reverse parcel process of five clients of Company X. However, Company X has more clients that make use of the carriers as presented in this research. Since we only focused on the five clients, we do not exactly know how the proposed recommendations affect other clients of Company X in terms of costs, performance, and lead times.

Third, we made some decisions regarding the number of experiments in each scenario. To keep a reasonable amount of experiments, we decided to vary the departure times between experiments, but within an experiment we keep the same departure time for all weekdays. For example, we let a truck depart at 9 pm from Monday to Friday, instead of investigating a departure of 9 pm on Monday, 11 am on Tuesday, 5 pm on Wednesday, etcetera. In addition, we decided to evaluate every scenario when pickup is done once and twice a day for some carriers. For example, we did not design experiments with twice a pickup on Monday, once a pickup on Tuesday, twice a pickup on Wednesday, etcetera. It is either twice a pickup or once a pickup for all days. We made this decision, because otherwise the number of experiments to simulate will grow rapidly.

6.4 Contributions to literature and practice

As concluded in the literature study of this research, simulation modelling is a good approach to model uncertainties in travel times and arrival times of trucks. Moreover, it is time based and therefore applicable to the problem of Company X, since we deal with lead times. Discrete-event simulation is a suitable type of simulation to model the reverse logistics of Company X, since the system evolves over time and it contains stochastic elements. Therefore, we implemented the case of Company X in a discrete-event simulation model and evaluated the consequences of various scenarios on lead times. Our contribution to the literature is that we showed how a practical problem in the area of reverse logistics and cross-docking networks can be modelled with simulation. Our contribution to the practical environment of Company X is that we proposed recommendations how Company X could shorten the lead times of the reverse parcels process of each carrier, based on the results of the simulations.

6.5 Further research

We recommend to do further research on the following topics:

- *The sorting and consolidation process in a warehouse or hub.* We left this part outside the scope of our research, since we only focused on the transport of reverse parcels. However, improvements in the sorting and consolidation process could contribute to a shorter lead time.
- *The effects of seasonality on the lead times*. Since the clients of Company X are merely fashion and lifestyle brands, they face seasonality of their products. We recommend to study the effects of seasonality on the lead times.
- *The effects of the recommend scenarios on other clients of Company X.* Since more clients of Company X make use of the same carriers as presented in this research, the recommend scenarios can affect these clients as well on costs, lead times, and performance. Therefore, we recommend to study these effects on other clients of Company X.
- *The effect of an experiment with different departure times on days during the week.* In this research, we kept the departure time within an experiment equal for all days during the week. However, we recommend to study the effects of different departure times on the days during the week. For example, a possible experiment could contain a departure time of 9 pm on Monday, 11 am on Tuesday, 5 pm on Wednesday, etcetera. These additional experiments could have a positive effect on the lead times, which will become clear by doing further research.

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Appendix A – Input distributions

In this appendix, we determine the input distributions of all carriers. For Carrier A, we count the number of arrived parcels per hour of the day. This is done for every day of the week, except from Sunday because the Carrier A hub is closed on this day. Based on the number of observations per hour on each day, we choose the busiest hour and calculate the interarrival times during this hour. Figure 49 to Figure 54 shows the histograms of the busiest hour on each day. Next, a chi-square test is performed to calculate the cumulative error, which is the sum of the difference between the observed number of observations in an interval and the expected number of observations in that interval. We find that the cumulative error is smaller than the chi-square test statistic for each day and thus we cannot reject the null hypothesis, which implies that the observed interarrival times statistically are not significantly different than that from an exponential distribution. We now showed that the interarrival times are exponentially distributed and the arrival process can be modelled as a nonstationary Poisson process. We use the thinning algorithm, presented by Shedler & Lewis (1979), to model this in the simulation model. The thinning algorithm generates an arrival rate throughout the whole day that is equal to that of the busiest hour. It then throws out arrivals during hours different than that of the busiest hour. We 'thin out' if the following equation holds: $\frac{\lambda^*}{\lambda(t_i^*)} < random\ number\ between\ 0\ and\ 1$, in which λ^* is the arrival rate of the busiest hour and $\lambda(t_i^*)$ the arrival rate of the current hour. Otherwise, the parcel is accepted. Table 33 shows the arrival rates per hour for Carrier A.

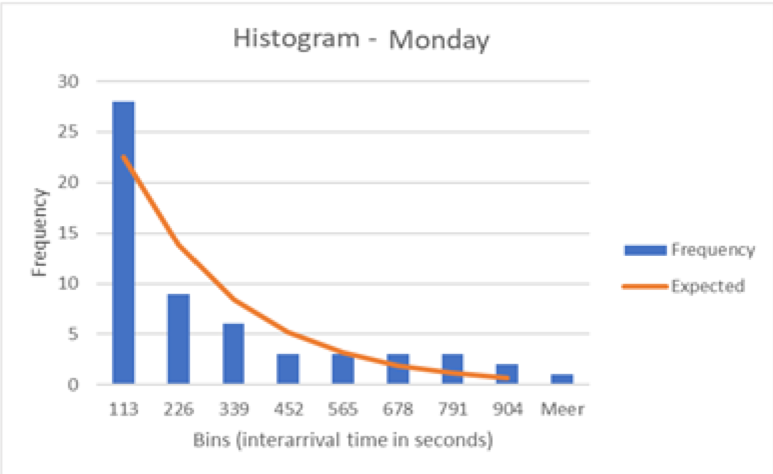

Figure 49: Histogram - Carrier A Monday

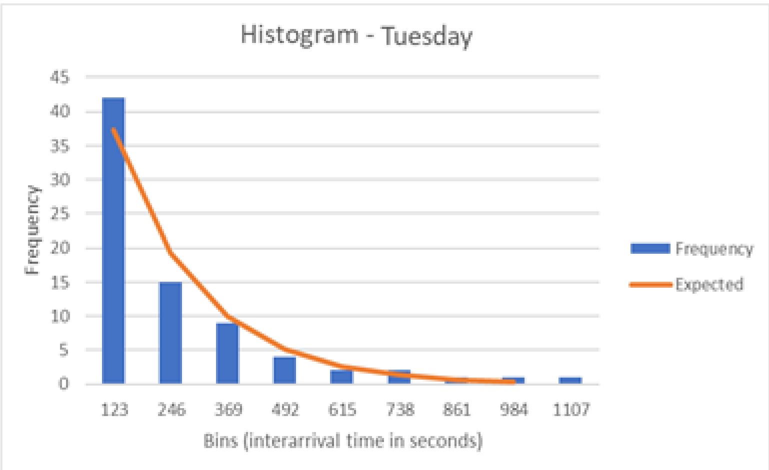

Figure 50: Histogram - Carrier A Tuesday

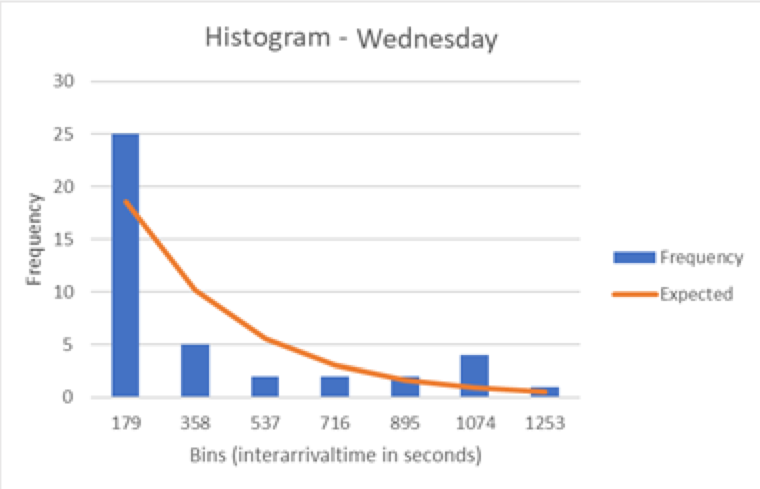

Figure 51: Histogram - Carrier A Wednesday

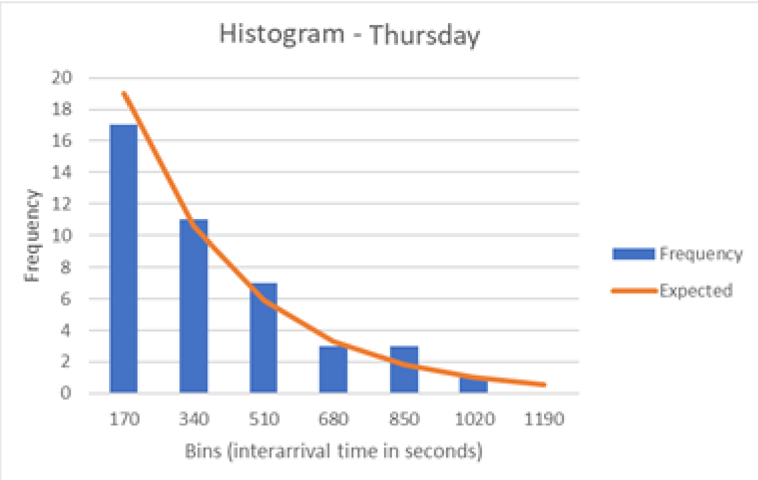

Figure 52: Histogram - Carrier A Thursday

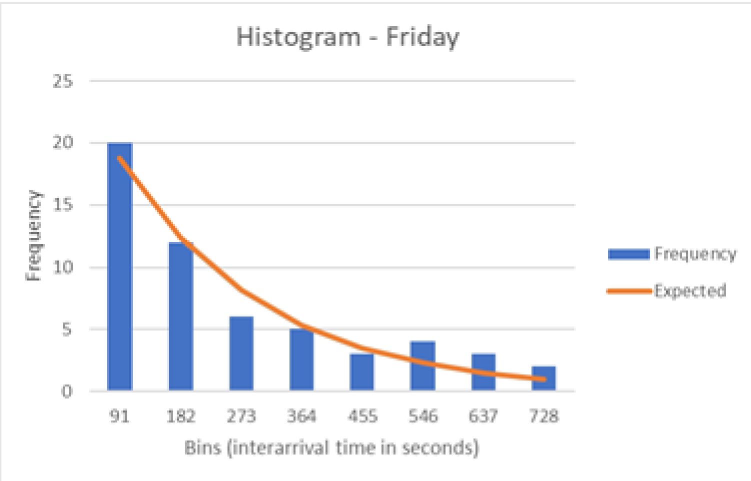

Figure 53: Histogram - Carrier A Friday

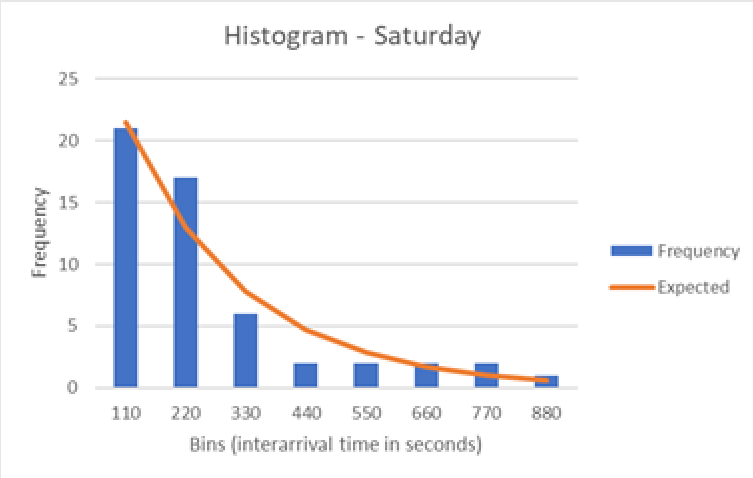

Figure 54: Histogram - Carrier A Saturday

Hour	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
0-1	10.4	14.7	9.2	12.3	12.9	16.6	0.0
1-2	14.9	14.4	10.0	11.0	14.9	14.6	0.0
2-3	13.9	18.9	11.4	11.5	16.6	11.8	0.0
3-4	1.7	19.4	11.4	12.3	15.7	16.0	0.0
4-5	0.0	0.2	0.8	0.0	0.3	0.0	0.0
5-6	0.2	0.0	0.0	0.0	0.0	0.0	0.0
6-7	0.0	1.4	0.0	0.0	0.0	0.0	0.0
7-8	1.0	0.0	0.8	0.0	0.3	0.0	0.0
8-9	1.0	0.9	2.2	0.0	0.0	0.0	0.0
9-10	1.5	0.7	0.3	1.8	0.6	0.0	0.0
10-11	0.7	1.2	1.6	0.5	0.6	0.0	0.0
11-12	1.5	0.9	2.4	0.3	1.4	1.1	0.0
12-13	0.5	1.2	0.8	1.3	0.6	1.4	0.0
13-14	1.2	0.9	0.8	1.8	0.6	2.8	0.0
14-15	1.0	0.2	1.6	0.5	0.6	2.5	0.0
15-16	2.0	0.7	0.3	1.0	2.0	2.5	0.0
16-17	1.5	0.7	0.8	1.6	1.7	0.6	0.0
17-18	3.7	0.2	1.4	2.1	2.2	0.0	0.0
18-19	0.2	4.5	0.3	0.0	0.0	0.0	0.0
19-20	11.2	11.4	1.1	0.0	0.0	0.0	0.0
20-21	10.4	10.6	7.6	4.2	10.9	0.0	0.0
21-22	7.5	8.5	12.2	9.2	10.1	0.0	0.0
22-23	14.7	14.0	11.6	11.0	15.7	0.0	0.0
23-24	15.6	14.9	9.5	8.9	10.1	12.4	0.0

Table 33: Arrival rates Carrier A

For the other carriers, there is limited data available such that we are not able to fit a distribution in such a detailed way we do for Carrier A. However, we fit theoretical distributions on the historical data available, which is interarrival time between parcel arrivals. The following distributions are available in Plant Simulation and therefore used for the fitting procedure:

- Beta distribution (continuous)
- Binomial distribution (discrete)
- Erlang distribution (continuous)
- Gamma distribution (continuous)
- Geometric distribution (discrete)
- Lognormal distribution (continuous)
- Normal distribution (continuous)
- Negative exponential distribution (continuous)
- Poisson distribution (discrete)
- Triangular distribution (continuous)
- Uniform distribution (continuous)
- Weibull distribution (continuous)
- Hypergeometric distribution (discrete)

We use the tool Easyfit, which ranks the distributions based on two different tests, the Chi-Squared (CS) test and the Kolmogorov-Smirnov (KS) test:

- Chi-Squared (CS) test: The data is divided into k adjacent intervals and the number of observations in each interval is computed. The Chi-Square test statistic is calculated by the following formula:

$$X^2 = \sum_{j=1}^{k} \frac{\left(N_j - np_j\right)^2}{np_j}$$

Equation 2: Chi-Square test (Law, 2015)

In which N_j is the number of observations in interval j and np_j is the expected number of observations followed from the fitted theoretical distribution. We reject the null hypothesis, which is: the data follows the specified distribution, if the test statistic is larger than the critical value. For the critical value, we use a significance level of 5%, which is common in statistics.

- Kolmogorov-Smirnov (KS) test: This test compares an empirical distribution function with the distribution function of the hypothesized distribution. The null hypothesis is not rejected if the following equation holds:

$$D = \max_{1 \leq i \leq N} \left(F(Y_i) - \frac{i-1}{N}, \frac{i}{N} - F(Y_i) \right)$$

Equation 3: Kolmogorov-Smirnov test (Law, 2015)

In which $F(Y_i)$ is the fitted distribution function. We reject the null hypothesis if the test statistic is larger than the critical value. Again, we use a significance level of 5% for the critical value.

Table 34 shows the Kolmogorov-Smirnov and Chi-Square test statistic and critical value for the carriers. We select for each flow the best ranked distribution(s) based on the test statistics. Sometimes, two distributions are selected as best. This is due to the fact that one distribution is selected as best on the KS test and the other on the CS test. The test statistic in Table 34 is marked green if the value is lower than the critical value. For Carrier H, we see that the KS test statistic is slightly above the critical value for the exponential distribution. However, the CS test statistic is below the critical value. Based on this and the fact that the input of all other carriers can be described by an exponential distribution, we assume an exponential distribution here as well. Table 35 shows the parameters of the distributions for all carriers.

		KS test statistic	Critical value KS test	CS test statistic	Critical value CS test
Carrier F	Beta	0.054	0.0795	N/A	
	Exponential	0.065	0.0795	16.057	21.026
Carrier B	Exponential	0.042	0.0751	12.751	16.679
	Gamma	0.034	0.0751	22.578	19.675
Carrier D	Exponential	0.054	0.0830	13.316	15.507
Carrier E	Exponential	0.149	0.2640	2.620	5.992
Carrier H	Exponential	0.101	0.0942	11.871	12.592
	Weibull	0.098	0.0942	16.087	14.067
Carrier C	Exponential	0.048	0.0645	7.541	14.067
Carrier G	Exponential	0.032	0.0524	9.784	21.026

Table 34: KS test and CS test

Carrier	Parameter
Carrier F - Exponential	λ = 0.00016296
Carrier B - Exponential	λ = 0.000086891
Carrier D – Exponential	λ = 0.0000046587
Carrier E – Exponential	λ = 0.0000018113
Carrier H – Exponential	λ = 0.000045294
Carrier C - Exponential	λ = 0.0000073671
Carrier G - Exponential	λ = 0.00011716

Table 35: Parameters distributions

Appendix B – Flowchart of routing method

Flowchart method "RoutingBLtoOL" (hub Company X - warehouses)

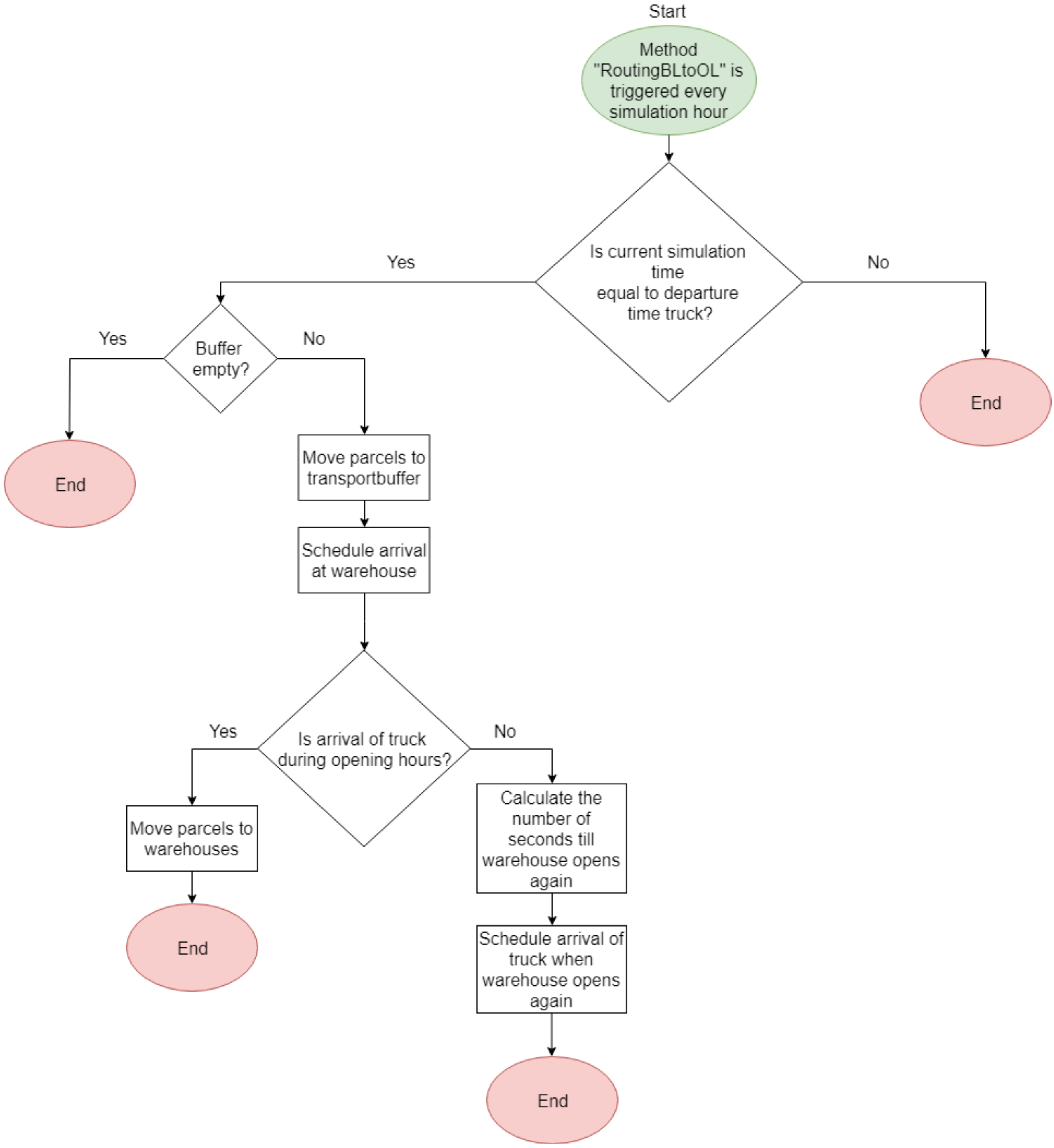

Figure 55: Flowchart routing method "RoutingBLtoOL"

Appendix C – Description simulation model

Figure 56 displays the dashboard of the simulation model. Below, we describe part A to F in detail.

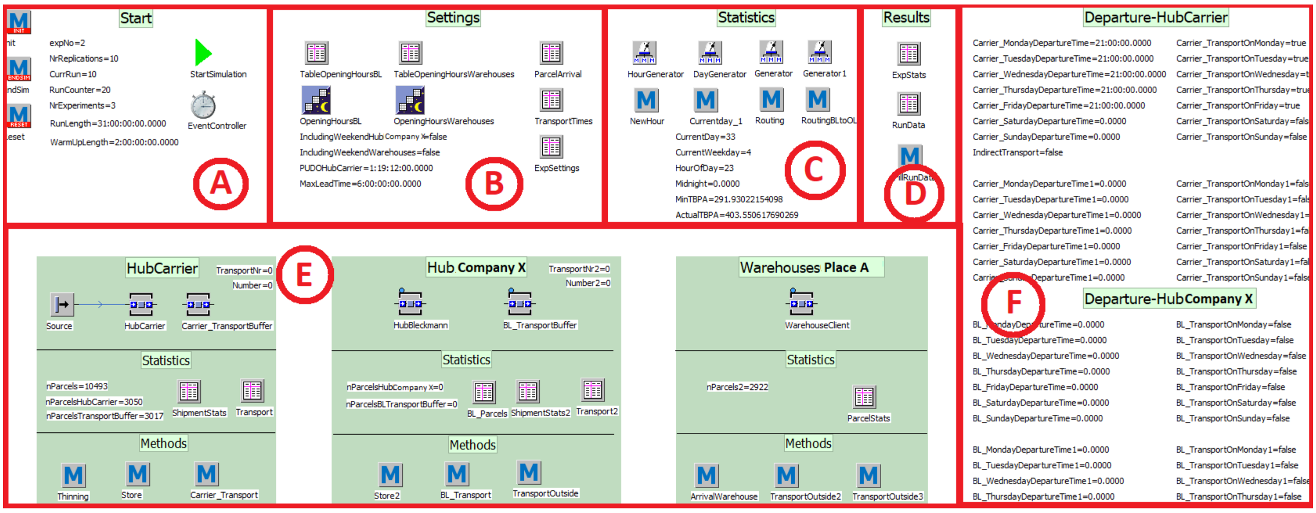

Figure 56: Dashboard simulation model

Start (A)

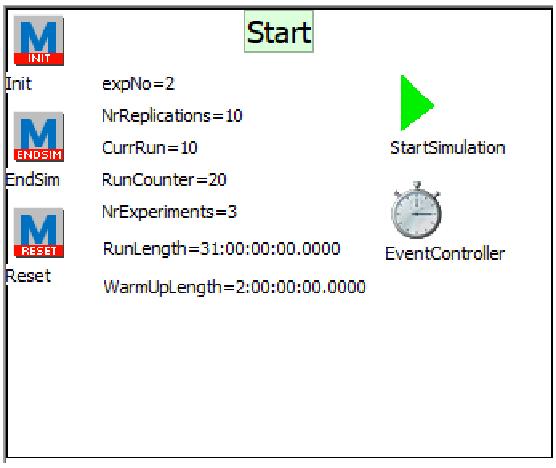

Figure 57: Start

This box contains the following objects:

- Method *Init:* This method is called at the beginning of each simulation run. With this method, the settings of the current experiment are applied: departure times, days, and opening hours.
- Method *EndSim:* This method is called at the end of each simulation run. It calculates the statistics and determines if a new simulation run must be executed.
- Method *Reset:* This method is called at the beginning of each simulation run and deletes content of tables and variables of the previous simulation run.
- Variable *expNo:* Displays the current experiment number in the simulation.
- Variable *NrReplications:* Sets the number of replications of each experiment. Three replications are sufficient, as concluded in Appendix D.
- Variable *CurrRun:* Displays the replication number within an experiment.
- Variable *RunCounter:* Displays the total number of replications of all experiments.
- Variable *NrExperiments:* Sets the number of experiments that must be executed.

- Variable *RunLength:* Sets the run length of one simulation run. We determined a run length of 31 days.
- Variable *WarmUpLength:* Sets the warmup period of the simulation. Two days of warmup is sufficient, as concluded in Appendix D.
- Button *StartSimulation:* We start the simulation by clicking this button.
- Button *EventController:* With the EventController, we are able to run the simulation faster or slower.

Settings (B)

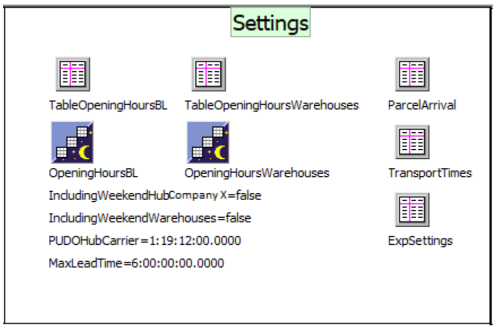

Figure 58: Settings

This box contains the following objects:

- TableFile *TableOpeningHoursBL:* In this table, we set the opening hours of the hub of Company X.
- ShiftCalendar *OpeningHoursBL:* Applies the opening hours from the TableFile *TableOpeningHoursBL* to the hub of Company X.
- TableFile *TableOpeningHoursWarehouses:* In this table, we set the opening hours of the hub of warehouses.
- ShiftCalendar *OpeningHoursWarehouses:* Applies the opening hours from the TableFile *TableOpeningHoursWarehouses* to the warehouses.
- TableFile *ParcelArrival:* In this table, we set the arrival rate of parcels at the corresponding carrier.
- TableFile *TransportTimes:* In this table, we set the truck driving times of the corresponding carrier.
- TableFile *ExpSettings:* In this table, we set the settings of the experiments.
- Variable *IncludingWeekendHubCompany X:* This variable determines if the hub of Company X is open in the weekend or not.
- Variable *IncludingWeekendWarehouses:* This variable determines if the warehouses are open in the weekend or not.
- Variable *PUDOHubCarrier:* With this variable, we can set the lead time PUDO to the hub of the carrier.
- Variable *MaxLeadTime:* With this variable, we can set the maximum lead time according to the SLA.

Statistics (C)

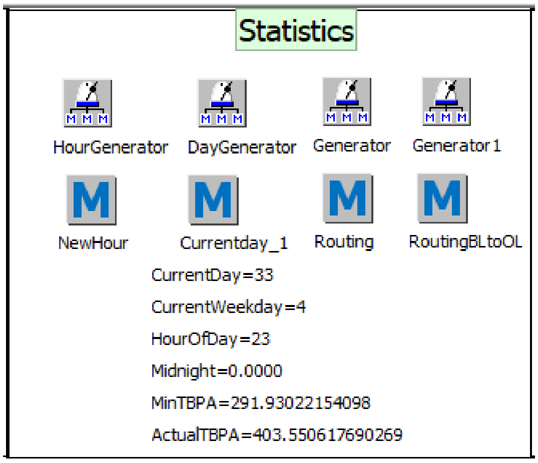

Figure 59: Statistics

This box contains the following objects:

- Generator *HourGenerator* and method *NewHour:* The generator calls every hour of simulation the method *NewHour.* This method keeps track of the hour of day and set the time between parcel arrivals for the current hour.
- Generator *DayGenerator* and method *Currentday_1:* The generator calls every day of simulation the method *Currentday_1.* This method determines the current weekday and current day of simulation. Moreover, the minimum time between parcel arrivals is determined and set as an interval in the Source object.
- Generator *Generator* and method *Routing:* The generator calls every hour of simulation the method *Routing.* This method determines the routing of parcels at the hub of the carrier, as described in Section 4.3.1.
- Generator *Generator1* and method *RoutingBLtoOL:* The generator calls every hour of simulation the method *RoutingBLtoOL.* This method determines the routing of parcels at the hub of Company X, as described in Appendix B.
- Variable *CurrentDay:* Displays the current day of simulation.
- Variable *CurrentWeekday:* Displays the current weekday of simulation (0=Sunday … 6=Saturday).
- Variable *HourOfDay:* Displays the current hour of simulation.
- Variable *Midnight:* This variable is used to check for a new day in the method *Currentday_1.*
- Variable *MinTBPA:* Displays the minimum time between parcel arrivals of the current day and is used for the thinning algorithm.
- Variable *ActualTBPA:* Displays the actual time between parcel arrivals in the current hour and is used for the thinning algorithm.

Results (D)

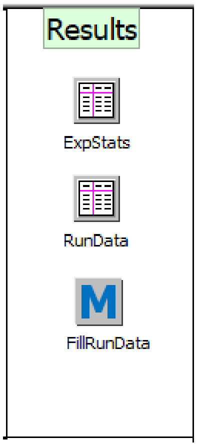

Figure 60: Results

This box contains the following objects:

- TableFile *ExpStats:* Displays the KPIs per experiment in a table.
- TableFile *RunData:* This TableFile is used for determining the number of replications and warmup period.
- Method *FillRunData:* This method fills the TableFile *RunData* to determine the number of replications and warmup period.

HubCarrier – HubCompany X – WarehousesPlace A (E)

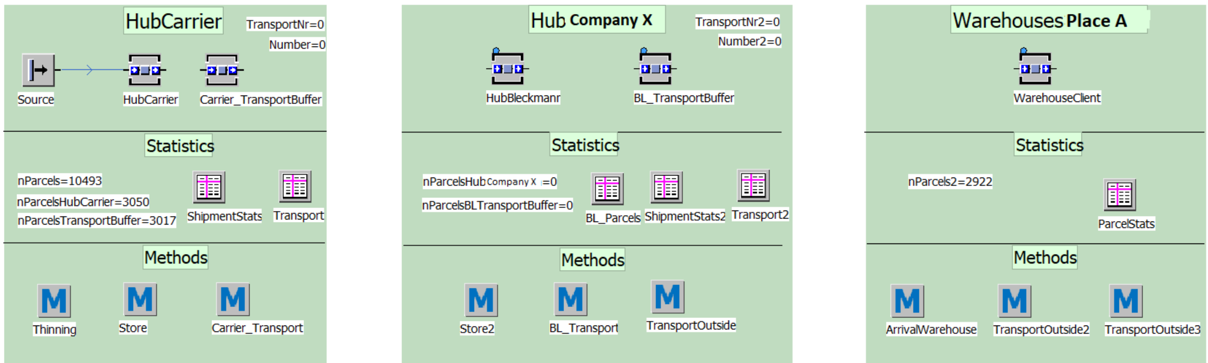

Figure 61: HubCarrier - HubCompany X - Warehouses Place A

The box HubCarrier contains the following objects:

- Object *Source:* This object ensures that parcels arrive at the hub of the carrier.
- Buffer *HubCarrier:* This buffer serves as a storage at the hub of the carrier.
- Buffer *Carrier_TransportBuffer:* Parcels are stored in this buffer if they are on transport.
- Variable *TransportNr:* Tracks the number of departed trucks at hub carrier.
- Variable *Number:* Tracks the number of arrived trucks at hub Company X.
- Variable *nParcels:* This variable shows how many parcels entering the *Source.*
- Variable *nParcelsHubCarrier:* This variable shows how many parcels entering the *HubCarrier,* after the thinning algorithm is applied.
- Variable *nParcelsTransportBuffer:* This variable shows how many parcels entering the *Carrier_TransportBuffer.*
- TableFile *ShipmentStats:* This table is used to keep track of the number of parcels per day.
- TableFile *Transport:* This table displays the number of parcels per transport.

- Method *Thinning:* This method is called by the *Source* and applies the thinning algorithm.
- Method *Store:* This method is called by the buffer *HubCarrier* and stores the arrival time of a parcel and the number of parcels entering the *HubCarrier.*
- Method *Carrier_Transport:* This method is called by the buffer *Carrier_TransportBuffer* and stores the departure time of a truck and the number of parcels entering the *Carrier_TransportBuffer.*

The box HubCompany X contains the following objects:

- Buffer *HubCompany X:* This buffer serves as a storage at the hub of Company X.
- Buffer *BL_TransportBuffer:* Parcels are stored in this buffer if they are on transport.
- Variable *TransportNr2:* Tracks the number of departed trucks at hub Company X.
- Variable *Number2:* Tracks the number of arrived trucks at the warehouses.
- Variable *nParcelsHubCompany X:* This variable shows how many parcels entering the *HubCompany X.*
- Variable *nParcelsTransportBuffer:* This variable shows how many parcels entering the *BL_Transportbuffer.*
- TableFile *BL_Parcels:* This table is used to keep track of the parcels that enter the hub of Company X. The arrival time, transport time, and current day and current weekday of each parcel are stored.
- TableFile *ShipmentStats2:* This table is used to keep track of the number of parcels per day.
- TableFile *Transport2:* This table displays the number of parcels per transport.
- Method *Store2:* This method is called by the buffer *HubCompany X* and stores the arrival time and the number of parcels entering the hub of Company X.
- Method *BL_Transport:* This method is called by the buffer *BL_TransportBuffer* and stores statistics about the arriving parcels in the TableFile *BL_Parcels.*
- Method *TransportOutside:* This method is called by the method *Routing* and schedules the arrival of a truck if the hub of Company X is closed.

The box WarehousesPlace A contains the following objects:

- Buffer *WarehouseClient:* This buffer serves as the warehouses of the clients.
- Variable *nParcels2:* This variable shows how many parcels entering the buffer *WarehouseClient*.
- TableFile *ParcelStats:* This table is used to keep track of the parcels that enter the warehouses of the clients. The arrival time, lead time, parcels above the maximum lead time, and the current day and weekday are stored.
- Method *ArrivalWarehouse:* This method is called by the buffer *WarehouseClient* and stores statistics about the arriving parcels in the TableFile *ParcelStats.*
- Method *TransportOutside2:* This method is called by the method *Routing* and schedules the arrival of a truck if the warehouses are closed.
- Method *TransportOutside3:* This method is called by the method *RoutingBLtoOL* and schedules the arrival of a truck if the warehouses are closed.

Departure-HubCarrier & Departure-HubCompany X (F)

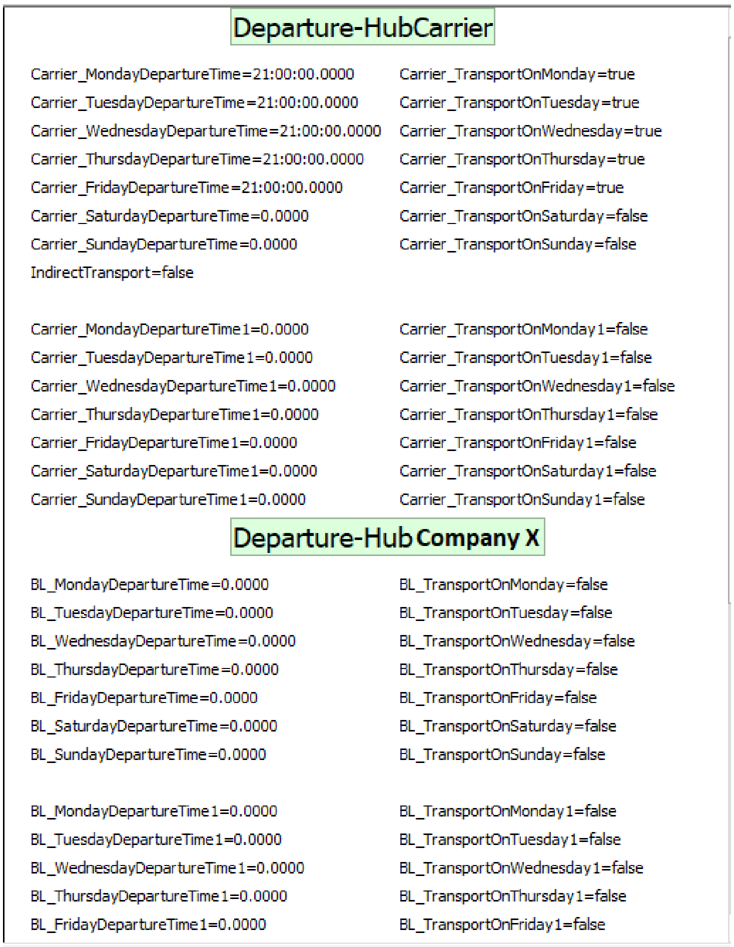

Figure 62: Departure HubCarrier & HubCompany X

This box contains the departure times and days for the hub of the carrier and the hub of Company X. These variables changes per experiment and serves no other purpose than monitoring the departure times and days while the simulation is running.

Appendix D – Warmup period and number of replications

Warmup period

To determine the warmup period, we use the Welch's graphical method as stated in Law (2015, p. 542-545). First, we make 10 replications of the simulation, each of length m = 20 days. Second, we calculate the average over each cycle in every replication. From the simulation output, we conclude that a cycle is equal to one day. Next, we take the average over the same cycle in all replications. Then the moving average is taken to smooth out high-frequency fluctuations. Figure 63 shows the moving average for w = 2. We conclude from this graph that after two days of simulation, the system is in steady state. So, the warmup period is two days.

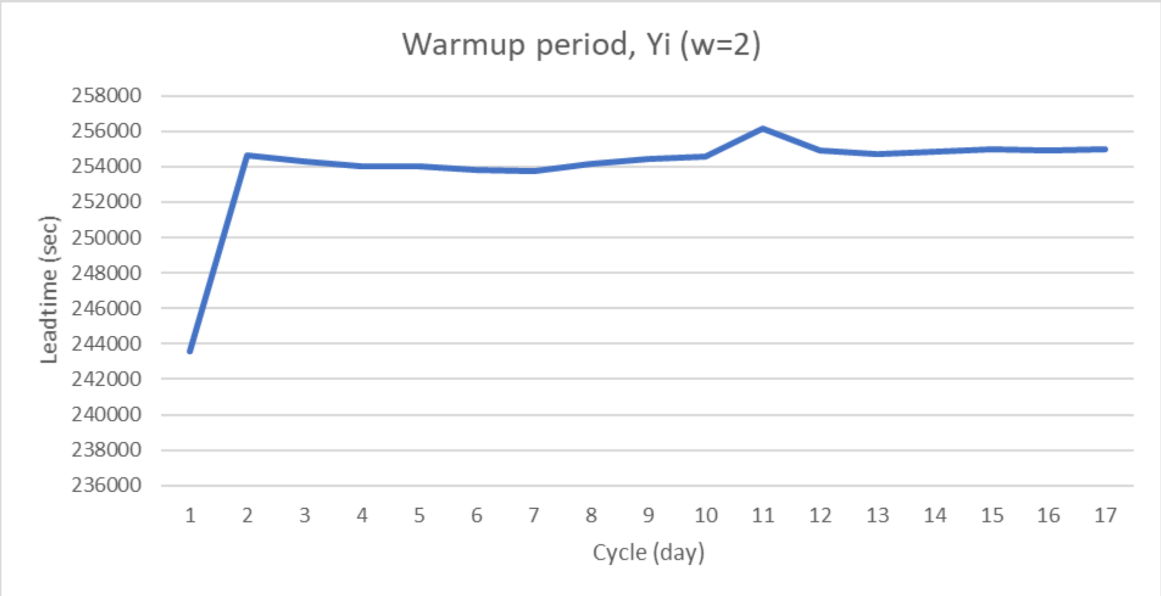

Figure 63: Graph warmup period with w=2

Number of replications

We use the approach as stated in Law (2015, p. 498-507) to determine the number of replications. First, we make n independent replications with same initial conditions, same terminating event and different seed values per replication. We perform multiple replications and measure the performance for each replication, in this case the average lead time per replication. Replications are performed until the width of the confidence interval, relative to the average, is sufficiently small. We use

Equation 4 to calculate the interval half width and to determine when the width is sufficiently small. The interval half width must be smaller than γ', the corrected target value. The corrected target value is calculated by using the formula of

Equation 5. We use a relative error (γ) of 5% and a significance level of 95%, resulting in a corrected target value of 0.047619. Table 36 shows that three replications is sufficient for our simulation.

$$\frac{t_{n-1,1-\alpha/2}\sqrt{S^2/n}}{\overline{X}} < \gamma'$$

Equation 4: Number of replications

In which,

$t_{n-1,1-\alpha/2}$ = Student's t-distribution for n-1 degrees of freedom and a probability of 1-(α/2)

S^2 = sample variance over n replications

n = number of replications

$\bar{X}$ = cumulative mean of the output data

γ' = Corrected target value

$$\gamma' = \frac{\gamma}{(1+\gamma)}$$

Equation 5: Corrected target value

n	Average lead time per run	Average lead time n replications	Variance	t-inv	CI half-width	Error	OK / NOTOK
1	330606.5						
2	327665.6	329136.1	4324402.8	12.7	18683.7	0.056766	NOTOK
3	334195.5	330822.6	10694914.4	4.3	8123.9	0.024557	OK
4	345330.0	334449.4	59746156.0	3.2	12299.5	0.036775	OK
5	340764.0	335712.3	52784533.8	2.8	9021.1	0.026871	OK

Table 36: Calculations number of replications

Appendix E – Description of experiments - one pickup per day

Carrier B	FACTOR A Departure time carrier	FACTOR B Departure day carrier	FACTOR C Departure time Company X hub: BL	FACTOR D Departure day Company X hub: BL	Nr Exp
Scenario 1	10 am, 12 pm, 2 pm, 4 pm	To choose from: Mo,Tu,Wed,Thu,Fri,Sat	7 am, 10 am, 1 pm, 4 pm	Mo to Fri	
5 x week	4x	$\binom{6}{5}$= 6x	4x	$\binom{5}{5}$= 1	=96
6 x week	4x	$\binom{6}{6}$= 1x	4x	$\binom{5}{5}$= 1	=16
Scenario 2	10 am, 12 pm, 2 pm, 4 pm	To choose from: Mo,Tu,Wed,Thu,Fri,Sat	8 am, 12 pm, 4 pm, 8 pm	Mo to Sun	
5 x week	4x	$\binom{6}{5}$=6x	4x	$\binom{7}{7}$=1	=96
6 x week	4x	$\binom{6}{6}$=1x	4x	$\binom{7}{7}$=1	=16
Scenario 3	10 am, 12 pm, 2 pm, 4 pm	To choose from: Mo,Tu,Wed,Thu,Fri,Sat	N/A	N/A	
5 x week	4x	$\binom{6}{5}$=6			=24
6 x week	4x	$\binom{6}{6}$=1			=4
Scenario 4	10 am, 12 pm, 2 pm, 4 pm	To choose from: Mo,Tu,Wed,Thu,Fri,Sat	N/A	N/A	
5 x week	4x	$\binom{6}{5}$=6			=24
6 x week	4x	$\binom{6}{6}$=1			=4

Table 37: Description of experiments Carrier B

Since carriers Carrier G and Carrier F deliver directly at the Company X hub in Place C, we consider the factor A "departure time carrier" and B "departure day carrier" as the departure time and day at the Company X hub in Place C.

Carrier G	FACTOR A Departure time carrier	FACTOR B Departure day carrier	FACTOR C Departure time Company X hub: BL	FACTOR D Departure day Company X hub: BL	Nr Exp
Scenario 1	8 am, 12 pm, 4 pm, 8 pm	Mo to Fri	7 am, 10 am, 1 pm, 4 pm	Mo to Fri	
5x week	4x	$\binom{5}{5}$=1	4x	$\binom{5}{5}$=1	=16
Scenario 2	8 am, 12 pm, 4 pm, 8 pm	Mo to Fri	8 am, 12 pm, 4 pm, 8 pm	Mo to Sun	
5x week	4x	$\binom{5}{5}$=1	4x	$\binom{7}{7}$=1	=16
Scenario 3	8 am, 12 pm, 4 pm, 8 pm	Mo to Fri	N/A	N/A	
5 x week	4x	$\binom{5}{5}$=1			=4
Scenario 4	8 am, 12 pm, 4 pm, 8 pm	Mo to Fri	N/A	N/A	
5 x week	4x	$\binom{5}{5}$=1			=4

Table 38: Description of experiments Carrier G

Carrier F	FACTOR A Departure time carrier	FACTOR B Departure day carrier	FACTOR C Departure time Company X hub: SW	FACTOR D Departure day Company X hub: SW	Nr Exp
Scenario 1	8 am, 12 pm, 4 pm, 8 pm	Mo to Fri	7 am, 10 am, 1 pm, 4 pm	Mo to Fri	
5 x week	4x	$\binom{5}{5}$=1	4x	$\binom{5}{5}$=1	=16
Scenario 2	8 am, 12 pm, 4 pm, 8 pm	Mo to Fri	8 am, 12 pm, 4 pm, 8 pm	Mo to Sun	
5 x week	4x	$\binom{5}{5}$=1	4x	$\binom{7}{7}$=1	=16
Scenario 3	8 am, 12 pm, 4 pm, 8 pm	Mo to Fri	N/A	N/A	
5 x week	4x	$\binom{5}{5}$=1			=4
Scenario 4	8 am, 12 pm, 4 pm, 8 pm	Mo to Fri	N/A	N/A	
5 x week	4x	$\binom{5}{5}$=1			=4

Table 39: Description of experiments Carrier F

Since Carrier H delivers directly at the Company X hub in Place B, we consider only Scenario 3 and 4. So, in this case, we consider the Company X hub in Place B as the hub of the carrier.

Carrier H	**FACTOR A** Departure time carrier	**FACTOR B** Departure day carrier	**FACTOR C** Departure time Company X hub: BL	**FACTOR D** Departure day Company X hub: BL	**Nr Exp**
Scenario 1	Starting point is Company X hub in Place B, because Carrier H delivers directly at this hub				
Scenario 2	Starting point is Company X hub in Place B, because Carrier H delivers directly at this hub				
Scenario 3	N/A	N/A	7 am to 5 pm	Mo to Fri	
5 x week			11x	$\binom{5}{5}$=1	=11
Scenario 4	N/A	N/A	6 am to 10 pm	Mo to Fri	
5 x week			17x	$\binom{5}{5}$=1	=17

Table 40: Description of experiments Carrier H

Carrier C	FACTOR A Departure time carrier	FACTOR B Departure day carrier	FACTOR C Departure time Company X hub: BL	FACTOR D Departure day Company X hub: BL	Nr Exp
Scenario 1	9 am, 11 am, 3 pm, 5 pm	To choose from: Mo,Tu,Wed,Thu,Fri	7 am, 10 am, 1 pm, 4 pm	Mo to Fri	
1 x week	4x	$\binom{5}{1}$= 5x	4x	$\binom{5}{5}$= 1	=80
2 x week	4x	$\binom{5}{2}$= 10x	4x	$\binom{5}{5}$= 1	=160
3 x week	4x	$\binom{5}{3}$= 10x	4x	$\binom{5}{5}$= 1	=160
4 x week	4x	$\binom{5}{4}$= 5x	4x	$\binom{5}{5}$= 1	=80
5 x week	4x	$\binom{5}{5}$= 1x	4x	$\binom{5}{5}$= 1	=16
Scenario 2	9 am, 11 am, 3 pm, 5 pm	To choose from: Mo,Tu,Wed,Thu,Fri	8 am, 12 pm, 4 pm, 8 pm	Mo to Sun	
1 x week	4x	$\binom{5}{1}$= 5x	4x	$\binom{7}{7}$=1	=80
2 x week	4x	$\binom{5}{2}$= 10x	4x	$\binom{7}{7}$=1	=160
3 x week	4x	$\binom{5}{3}$= 10x	4x	$\binom{7}{7}$=1	=160
4 x week	4x	$\binom{5}{4}$= 5x	4x	$\binom{7}{7}$=1	=80
5 x week	4x	$\binom{5}{5}$= 1x	4x	$\binom{7}{7}$=1	=16
Scenario 3	9 am, 11 am, 3 pm, 5 pm	To choose from: Mo,Tu,Wed,Thu,Fri	N/A	N/A	
1 x week	4x	$\binom{5}{1}$= 5			=20
2 x week	4x	$\binom{5}{2}$= 10			=40
3 x week	4x	$\binom{5}{3}$= 10			=40
4 x week	4x	$\binom{5}{4}$= 5			=20
5 x week	4x	$\binom{5}{5}$= 1			=4
Scenario 4	9 am, 11 am, 3 pm, 5 pm	To choose from: Mo,Tu,Wed,Thu,Fri	N/A	N/A	
1 x week	4x	$\binom{5}{1}$= 5			=20
2 x week	4x	$\binom{5}{2}$= 10			=40
3 x week	4x	$\binom{5}{3}$= 10			=40
4 x week	4x	$\binom{5}{4}$= 5			=20
5 x week	4x	$\binom{5}{5}$= 1			=4

Table 41: Description of experiments Carrier C

Carrier D	FACTOR A Departure time carrier	FACTOR B Departure day carrier	FACTOR C Departure time Company X hub: BL	FACTOR D Departure day Company X hub: BL	Nr Exp
Scenario 1	9 am, 12 pm, 3 pm, 6 pm	To choose from: Mo,Tu,Wed,Thu,Fri	7 am, 10 am, 1 pm, 4 pm	Mo to Fri	
1 x week	4x	$\binom{5}{1}$= 5x	4x	$\binom{5}{5}$= 1	=80
2 x week	4x	$\binom{5}{2}$= 10x	4x	$\binom{5}{5}$= 1	=160
3 x week	4x	$\binom{5}{3}$= 10x	4x	$\binom{5}{5}$= 1	=160
4 x week	4x	$\binom{5}{4}$= 5x	4x	$\binom{5}{5}$= 1	=80
5 x week	4x	$\binom{5}{5}$= 1x	4x	$\binom{5}{5}$= 1	=16
Scenario 2	9 am, 12 pm, 3 pm, 6 pm	To choose from: Mo,Tu,Wed,Thu,Fri	8 am, 12 pm, 4 pm, 8 pm	Mo to Sun	
1 x week	4x	$\binom{5}{1}$= 5x	4x	$\binom{7}{7}$=1	=80
2 x week	4x	$\binom{5}{2}$= 10x	4x	$\binom{7}{7}$=1	=160
3 x week	4x	$\binom{5}{3}$= 10x	4x	$\binom{7}{7}$=1	=160
4 x week	4x	$\binom{5}{4}$= 5x	4x	$\binom{7}{7}$=1	=80
5 x week	4x	$\binom{5}{5}$= 1x	4x	$\binom{7}{7}$=1	=16
Scenario 3	9 am, 12 pm, 3 pm, 6 pm	To choose from: Mo,Tu,Wed,Thu,Fri	N/A	N/A	
1 x week	4x	$\binom{5}{1}$= 5			=20
2 x week	4x	$\binom{5}{2}$= 10			=40
3 x week	4x	$\binom{5}{3}$= 10			=40
4 x week	4x	$\binom{5}{4}$= 5			=20
5 x week	4x	$\binom{5}{5}$= 1			=4
Scenario 4	9 am, 12 pm, 3 pm, 6 pm	To choose from: Mo,Tu,Wed,Thu,Fri	N/A	N/A	
1 x week	4x	$\binom{5}{1}$= 5			=20
2 x week	4x	$\binom{5}{2}$= 10			=40
3 x week	4x	$\binom{5}{3}$= 10			=40
4 x week	4x	$\binom{5}{4}$= 5			=20
5 x week	4x	$\binom{5}{5}$= 1			=4

Table 42: Description of experiments Carrier D

Carrier E	FACTOR A Departure time carrier	FACTOR B Departure day carrier	FACTOR C Departure time Company X hub: BL	FACTOR D Departure day Company X hub: BL	Nr Exp
Scenario 1	10 am, 12 pm, 2 pm, 4 pm	To choose from: Mo,Tu,Wed,Thu,Fri	7 am, 10 am, 1 pm, 4 pm	Mo to Fri	
1 x week	4x	$\binom{5}{1}$= 5x	4x	$\binom{5}{5}$= 1	=80
2 x week	4x	$\binom{5}{2}$= 10x	4x	$\binom{5}{5}$= 1	=160
3 x week	4x	$\binom{5}{3}$= 10x	4x	$\binom{5}{5}$= 1	=160
4 x week	4x	$\binom{5}{4}$= 5x	4x	$\binom{5}{5}$= 1	=80
5 x week	4x	$\binom{5}{5}$= 1x	4x	$\binom{5}{5}$= 1	=16
Scenario 2	10 am, 12 pm, 2 pm, 4 pm	To choose from: Mo,Tu,Wed,Thu,Fri	8 am, 12 pm, 4 pm, 8 pm	Mo to Sun	
1 x week	4x	$\binom{5}{1}$= 5x	4x	$\binom{7}{7}$=1	=80
2 x week	4x	$\binom{5}{2}$= 10x	4x	$\binom{7}{7}$=1	=160
3 x week	4x	$\binom{5}{3}$= 10x	4x	$\binom{7}{7}$=1	=160
4 x week	4x	$\binom{5}{4}$= 5x	4x	$\binom{7}{7}$=1	=80
5 x week	4x	$\binom{5}{5}$= 1x	4x	$\binom{7}{7}$=1	=16
Scenario 3	10 am, 12 pm, 2 pm, 4 pm	To choose from: Mo,Tu,Wed,Thu,Fri	N/A	N/A	
1 x week	4x	$\binom{5}{1}$= 5			=20
2 x week	4x	$\binom{5}{2}$= 10			=40
3 x week	4x	$\binom{5}{3}$= 10			=40
4 x week	4x	$\binom{5}{4}$= 5			=20
5 x week	4x	$\binom{5}{5}$= 1			=4
Scenario 4	10 am, 12 pm, 2 pm, 4 pm	To choose from: Mo,Tu,Wed,Thu,Fri	N/A	N/A	
1 x week	4x	$\binom{5}{1}$= 5			=20
2 x week	4x	$\binom{5}{2}$= 10			=40
3 x week	4x	$\binom{5}{3}$= 10			=40
4 x week	4x	$\binom{5}{4}$= 5			=20
5 x week	4x	$\binom{5}{5}$= 1			=4

Table 43: Description of experiments Carrier E

Appendix F – Description of experiments - two pickups per day

Carrier A	**FACTOR A** Departure time carrier	**FACTOR B** Departure day carrier	**FACTOR C** Departure time Company X hub: BL	**FACTOR D** Departure day Company X hub: BL	**Nr Exp**
Scenario 1	7 am and 3 pm 11 am and 7 pm	To choose from: Mo,Tu,Wed,Thu,Fri,Sat	7 am and 1 pm 10 am and 4 pm	Mo to Fri	
5 x week	2 x	$\binom{6}{5}$= 6x	2 x	$\binom{5}{5}$= 1	=24
6 x week	2 x	$\binom{6}{6}$= 1x	2 x	$\binom{5}{5}$= 1	=4
Scenario 2	7 am and 3 pm 11 am and 7 pm	To choose from: Mo,Tu,Wed,Thu,Fri,Sat	8 am and 4 pm 12 pm and 8 pm	Mo to Sun	
5 x week	2x	$\binom{6}{5}$=6x	2x	$\binom{7}{7}$= 1	=24
6 x week	2x	$\binom{6}{6}$=1x	2x	$\binom{7}{7}$=1	=4
Scenario 3	7 am and 3 pm 11 am and 7 pm	To choose from: Mo,Tu,Wed,Thu,Fri,Sat	N/A	N/A	
5 x week	2x	$\binom{6}{5}$=6			=12
6 x week	2x	$\binom{6}{6}$=1			=2
Scenario 4	7 am and 3 pm 11 am and 7 pm	To choose from: Mo,Tu,Wed,Thu,Fri,Sat	N/A	N/A	
5 x week	2x	$\binom{6}{5}$=6			=12
6 x week	2x	$\binom{6}{6}$=1			=2

Table 44: Description of experiments Carrier A two pickups per day

Carrier B	**FACTOR A** Departure time carrier	**FACTOR B** Departure day carrier	**FACTOR C** Departure time Company X hub: BL	**FACTOR D** Departure day Company X hub: BL	**Nr Exp**
Scenario 1	10 am and 2 pm 12 pm and 4 pm	To choose from: Mo,Tu,Wed,Thu,Fri,Sat	7 am and 1 pm 10 am and 4 pm	Mo to Fri	
5 x week	2x	$\binom{6}{5}$= 6x	2x	$\binom{5}{5}$= 1	=24
6 x week	2x	$\binom{6}{6}$= 1x	2x	$\binom{5}{5}$= 1	=4
Scenario 2	10 am and 2 pm 12 pm and 4 pm	To choose from: Mo,Tu,Wed,Thu,Fri,Sat	8 am and 4 pm 12 pm and 8 pm	Mo to Sat	
5 x week	2x	$\binom{6}{5}$=6x	2x	$\binom{7}{7}$=1	=24
6 x week	2x	$\binom{6}{6}$=1x	2x	$\binom{7}{7}$=1	=4
Scenario 3	10 am and 2 pm 12 pm and 4 pm	To choose from: Mo,Tu,Wed,Thu,Fri,Sat	N/A	N/A	
5 x week	2x	$\binom{6}{5}$=6			=12
6 x week	2x	$\binom{6}{6}$=1			=2
Scenario 4	10 am and 2 pm 12 pm and 4 pm	To choose from: Mo,Tu,Wed,Thu,Fri,Sat	N/A	N/A	
5 x week	2x	$\binom{6}{5}$=6			=12
6 x week	2x	$\binom{6}{6}$=1			=2

Table 45: Description of experiments Carrier B two pickups per day

Carrier G	FACTOR A Departure time carrier	FACTOR B Departure day carrier	FACTOR C Departure time Company X hub: SW	FACTOR D Departure day Company X hub: SW	Nr Exp
Scenario 1	8 am and 4 pm 9 am and 5 pm 10 am and 6 pm 11 am and 7 pm 12 pm and 8 pm	Mo to Fri	7 am and 1 pm 8 am and 2 pm 9 am and 3 pm 10 am and 4 pm 11 am and 5 pm	Mo to Fri	
5 x week	5 x	$\binom{5}{5}$=1	5x	$\binom{5}{5}$=1	=25
Scenario 2	8 am and 4 pm 9 am and 5 pm 10 am and 6 pm 11 am and 7 pm 12 pm and 8 pm	Mo to Fri	8 am and 4 pm 9 am and 5 pm 10 am and 6 pm 11 am and 7 pm 12 pm and 8 pm	Mo to Sun	
5 x week	5 x	$\binom{5}{5}$=1	5x	$\binom{7}{7}$=1	=25
Scenario 3	8 am and 4 pm 9 am and 5 pm 10 am and 6 pm 11 am and 7 pm 12 pm and 8 pm	Mo to Fri	N/A	N/A	
5 x week	5 x	$\binom{5}{5}$=1			=5
Scenario 4	8 am and 4 pm 9 am and 5 pm 10 am and 6 pm 11 am and 7 pm 12 pm and 8 pm	Mo to Fri	N/A	N/A	
5 x week	5 x	$\binom{5}{5}$=1			=5

Table 46: Description of experiments Carrier G two pickups per day

Carrier F	FACTOR A Departure time carrier	FACTOR B Departure day carrier	FACTOR C Departure time Company X hub: SW	FACTOR D Departure day Company X hub: SW	Nr Exp
Scenario 1	8 am and 4 pm 9 am and 5 pm 10 am and 6 pm 11 am and 7 pm 12 pm and 8 pm	Mo to Fri	7 am and 1 pm 8 am and 2 pm 9 am and 3 pm 10 am and 4 pm 11 am and 5 pm	Mo to Fri	
5 x week	5 x	$\binom{5}{5}$=1	5x	$\binom{5}{5}$=1	=25
Scenario 2	8 am and 4 pm 9 am and 5 pm 10 am and 6 pm 11 am and 7 pm 12 pm and 8 pm	Mo to Fri	8 am and 4 pm 9 am and 5 pm 10 am and 6 pm 11 am and 7 pm 12 pm and 8 pm	Mo to Sun	
5 x week	5 x	$\binom{5}{5}$=1	5x	$\binom{7}{7}$=1	=25
Scenario 3	8 am and 4 pm 9 am and 5 pm 10 am and 6 pm 11 am and 7 pm 12 pm and 8 pm	Mo to Fri	N/A	N/A	
5 x week	5 x	$\binom{5}{5}$=1			=5
Scenario 4	8 am and 4 pm 9 am and 5 pm 10 am and 6 pm 11 am and 7 pm 12 pm and 8 pm	Mo to Fri	N/A	N/A	
5 x week	5 x	$\binom{5}{5}$=1			=5

Table 47: Description of experiments Carrier F two pickups per day

Carrier H	FACTOR A Departure time carrier	FACTOR B Departure day carrier	FACTOR C Departure time Company X hub: SW	FACTOR D Departure day Company X hub: SW	Nr Exp
Scenario 1	Starting point is Company X hub in Place B, because Carrier H delivers directly at this hub				
Scenario 2	Starting point is Company X hub in Place B, because Carrier H delivers directly at this hub				
Scenario 3	N/A	N/A	7 am and 12 pm 8 am and 1 pm 9 am and 2 pm 10 am and 3 pm 11 am and 4 pm 12 am and 5 pm	Mo to Fri	
5 x week			6x	$\binom{5}{5}$=1	=6
Scenario 4	N/A	N/A	8 am and 4 pm 10 am and 6 pm 12 pm and 8 pm 2 pm and 10 pm	Mo to Fri	
5 x week			4x	$\binom{5}{5}$=1	=4

Table 48: Description of experiments Carrier H two pickups per day

Appendix G – Departure days and times trucks

Carrier A – one pickup per day	Departure hub Carrier A	Departure Place B
Scenario 1 – 5x/week	Ma to Fri, 7:00 am	Mo to Fri, 1:00 pm
Scenario 1 – 6x/week	Ma to Sat, 7:00 am	Mo to Fri, 10:00 am
Scenario 2 – 5x/week	Tu to Sat, 7:00 am	Mo to Sun, 4:00 pm
Scenario 2 – 6x/week	Ma to Sat, 7:00 am	Mo to Sun, 4:00 pm
Scenario 3 – 5x/week	Ma to Fri, 7:00 am	-
Scenario 3 – 6x/week	Ma to Sat, 11:00 am	-
Scenario 4 – 5x/week	Ma to Thu, Sat, 7:00 am	-
Scenario 4 – 6x/week	Ma to Sat, 7:00 am	-
Carrier A – two pickups per day	**Departure hub Carrier A**	**Departure Place B**
Scenario 1 – 10x/week	Mo to Fri, 7:00 am/3:00 pm	Mo to Fri, 10:00 am/4:00 pm
Scenario 1 – 12x/week	Mo to Sat, 7:00 am/3:00 pm	Mo to Fri, 10:00 am/4:00 pm
Scenario 2 – 10x/week	Tue to Sat, 7:00 am/3:00 pm	Mo to Sun, 12:00 pm/8:00 pm
Scenario 2 – 12x/week	Mo to Sat, 7:00 am/3:00 pm	Mo to Sun, 8:00 am/4:00 pm
Scenario 3 – 10x/week	Mo to Fri, 7:00 am/3:00 pm	-
Scenario 3 – 12x/week	Mo to Sat, 7:00 am/3:00 pm	-
Scenario 4 – 10x/week	Mo to Fri, 7:00 am/3:00 pm	-
Scenario 4 – 12x/week	Mo to Sat, 7:00 am/3:00 pm	-

Table 49: Departure days and times Carrier A

Carrier B – one pickup per day	Departure hub Carrier B	Departure Place B
Scenario 1 – 5x/week	Ma to Fri, 10:00 am	Mo to Fri, 1:00 pm
Scenario 1 – 6x/week	Ma to Sat, 10:00 am	Mo to Fri, 1:00 pm
Scenario 2 – 5x/week	Mo, Wed to Sat, 12:00 pm	Mo to Sun, 4:00 pm
Scenario 2 – 6x/week	Ma to Sat, 12:00 pm	Mo to Sun, 4:00 pm
Scenario 3 – 5x/week	Ma to Fri, 10:00 am	-
Scenario 3 – 6x/week	Ma to Sat, 10:00 am	-
Scenario 4 – 5x/week	Ma to Wed, Fri, Sat, 4:00 pm	-
Scenario 4 – 6x/week	Ma to Sat, 4:00 pm	-
Carrier B – two pickups per day	**Departure hub Carrier B**	**Departure Place B**
Scenario 1 – 10x/week	Mo to Fri, 12:00 pm/4:00 pm	Mo to Fri, 7:00 am/1:00 pm
Scenario 1 – 12x/week	Mo to Sat, 12:00 pm/4:00 pm	Mo to Fri, 10:00 am/4:00 pm
Scenario 2 – 10x/week	Mo to Fri, 10:00 am/2:00 pm	Mo to Sun, 12:00 pm/8:00 pm
Scenario 2 – 12x/week	Mo to Sat, 10:00 am/2:00 pm	Mo to Sun, 12:00 pm/8:00 pm
Scenario 3 – 10x/week	Mo, Tu, Thu to Sat, 12:00 pm/4:00 pm	-
Scenario 3 – 12x/week	Mo to Sat, 12:00 pm/4:00 pm	-
Scenario 4 – 10x/week	Mo, Tu, Thu to Sat, 10:00 am/2:00 pm	-
Scenario 4 – 12x/week	Mo to Sat, 10:00 am/2:00 pm	-

Table 50: Departure days and times Carrier B

Carrier C	Departure hub Carrier C	Departure Place B
Scenario 1 – 1x/week	Mo, 9:00 am	Mo to Fri, 10:00 am
Scenario 1 – 2x/week	Mo and Wed, 9:00 am	Mo to Fri, 10:00 am
Scenario 1 – 3x/week	Mo, Wed, Thu, 9:00 am	Mo to Fri, 10:00 am
Scenario 1 – 4x/week	Mo to Thu, 9:00 am	Mo to Fri, 10:00 am
Scenario 1 – 5x/week	Mo to Fri, 9:00 am	Mo to Fri, 10:00 am
Scenario 2 – 1x/week	Thu, 9:00 am	Mo to Sun, 4:00 pm
Scenario 2 – 2x/week	Mo and Wed, 9:00 am	Mo to Sun, 4:00 pm
Scenario 2 – 3x/week	Mo, Wed, Thu, 9:00 am	Mo to Sun, 4:00 pm
Scenario 2 – 4x/week	Mo, Tue, Thu, Fri, 9:00 am	Mo to Sun, 4:00 pm
Scenario 2 – 5x/week	Mo to Fri, 9:00 am	Mo to Sun, 4:00 pm
Scenario 3 – 1x/week	Mo, 11:00 am	-
Scenario 3 – 2x/week	Mo and Wed, 11:00 am	-
Scenario 3 – 3x/week	Mo, Wed, Thu, 11:00 am	-
Scenario 3 – 4x/week	Mo to Thu, 11:00 am	-
Scenario 3 – 5x/week	Mo to Fri, 11:00 am	-
Scenario 4 – 1x/week	Thu, 11:00 am	-
Scenario 4 – 2x/week	Mo and Wed, 11:00 am	-
Scenario 4 – 3x/week	Mo, Wed, Thu, 11:00 am	-
Scenario 4 – 4x/week	Mo, Tue, Wed, Fri, 11:00 am	-
Scenario 4 – 5x/week	Mo to Fri, 11:00 am	-

Table 51: Departure days and times Carrier C

Carrier D	Departure hub Carrier D	Departure Place B
Scenario 1 – 1x/week	Tue, 9:00 am	Mo to Fri, 1:00 pm
Scenario 1 – 2x/week	Tue and Thu, 9:00 am	Mo to Fri, 1:00 pm
Scenario 1 – 3x/week	Mo, Tue, Thu, 9:00 am	Mo to Fri, 1:00 pm
Scenario 1 – 4x/week	Mo to Thu, 9:00 am	Mo to Fri, 1:00 pm
Scenario 1 – 5x/week	Mo to Fri, 9:00 am	Mo to Fri, 1:00 pm
Scenario 2 – 1x/week	Tue, 9:00 am	Mo to Sun, 4:00 pm
Scenario 2 – 2x/week	Tue and Thu, 9:00 am	Mo to Sun, 4:00 pm
Scenario 2 – 3x/week	Mo, Tue, Thu, 9:00 am	Mo to Sun, 4:00 pm
Scenario 2 – 4x/week	Mo to Thu, 9:00 am	Mo to Sun, 4:00 pm
Scenario 2 – 5x/week	Mo to Fri, 9:00 am	Mo to Sun, 4:00 pm
Scenario 3 – 1x/week	Tue, 9:00 am	-
Scenario 3 – 2x/week	Tue and Thu, 9:00 am	-
Scenario 3 – 3x/week	Mo, Tue, Thu, 9:00 am	-
Scenario 3 – 4x/week	Mo to Thu, 9:00 am	-
Scenario 3 – 5x/week	Mo to Fri, 9:00 am	-
Scenario 4 – 1x/week	Tue, 9:00 am	-
Scenario 4 – 2x/week	Tue and Thu, 9:00 am	-
Scenario 4 – 3x/week	Mo, Tue, Thu, 9:00 am	-
Scenario 4 – 4x/week	Mo to Thu, 9:00 am	-
Scenario 4 – 5x/week	Mo to Fri, 9:00 am	-

Table 52: Departure days and times Carrier D

Carrier E	Departure hub Carrier E	Departure Place B
Scenario 1 – 1x/week	Wed, 10:00 am	Mo to Fri, 1:00 pm
Scenario 1 – 2x/week	Wed and Fri, 10:00 am	Mo to Fri, 1:00 pm
Scenario 1 – 3x/week	Tue, Thu, Fri, 10:00 am	Mo to Fri, 1:00 pm
Scenario 1 – 4x/week	Mo, Tue, Wed, Fri, 10:00 am	Mo to Fri, 1:00 pm
Scenario 1 – 5x/week	Mo to Fri, 10:00 am	Mo to Fri, 1:00 pm
Scenario 2 – 1x/week	Wed, 12:00 pm	Mo to Sun, 4:00 pm
Scenario 2 – 2x/week	Wed and Fri, 12:00 pm	Mo to Sun, 4:00 pm
Scenario 2 – 3x/week	Tue, Thu, Fri, 12:00 pm	Mo to Sun, 4:00 pm
Scenario 2 – 4x/week	Mo, Tue, Wed, Fri, 12:00 pm	Mo to Sun, 4:00 pm
Scenario 2 – 5x/week	Mo to Fri, 12:00 pm	Mo to Sun, 4:00 pm
Scenario 3 – 1x/week	Wed, 10:00 am	-
Scenario 3 – 2x/week	Wed and Fri, 10:00 am	-
Scenario 3 – 3x/week	Tue, Thu, Fri, 10:00 am	-
Scenario 3 – 4x/week	Mo, Tue, Wed, Fri, 10:00 am	-
Scenario 3 – 5x/week	Mo to Fri, 10:00 am	-
Scenario 4 – 1x/week	Wed, 12:00 pm	-
Scenario 4 – 2x/week	Wed and Fri, 12:00 pm	-
Scenario 4 – 3x/week	Tue, Thu, Fri, 12:00 pm	-
Scenario 4 – 4x/week	Mo, Tue, Wed, Fri, 12:00 pm	-
Scenario 4 – 5x/week	Mo to Fri, 12:00 pm	-

Table 53: Departure days and times Carrier E

Carrier F – one pickup per day	Departure Place C	Departure Place B
Scenario 1 – 5x/week	Mo to Fri, 12:00 pm	Mo to Fri, 10:00 am
Scenario 2 – 5x/week	Mo to Fri, 4:00 pm	Mo to Sun, 8:00 am
Scenario 3 – 5x/week	Mo to Fri, 12:00 pm	-
Scenario 4 – 5x/week	Mo to Fri, 4:00 pm	-
Carrier F – two pickups per day	**Departure Place C**	**Departure Place B**
Scenario 1 – 10x/week	Mo to Fri, 8:00/4:00 pm	Mo to Fri, 9:00 am/3:00 pm
Scenario 2 – 10x/week	Mo to Fri, 12:00 pm/8:00 pm	Mo to Fri, 8:00 am/1:00 pm
Scenario 3 – 10x/week	Mo to Fri, 8:00 am/4:00 pm	-
Scenario 4 – 10x/week	Mo to Fri, 12:00 pm/8:00 pm	-

Table 54: Departure days and times Carrier F

Carrier G – one pickup per day	Departure Place C	Departure Place B
Scenario 1 – 5x/week	Mo to Fri, 12:00 pm	Mo to Fri, 10:00 am
Scenario 2 – 5x/week	Mo to Fri, 8:00 pm	Mo to Sun, 8:00 am
Scenario 3 – 5x/week	Mo to Fri, 8:00 am	-
Scenario 4 – 5x/week	Mo to Fri, 8:00 am	-
Carrier G– two pickups per day	**Departure Place C**	**Departure Place B**
Scenario 1 – 10x/week	Mo to Fri, 8:00 am/4:00 pm	Mo to Fri, 9:00 am/3:00 pm
Scenario 2 – 10x/week	Mo to Fri, 9:00 am/5:00 pm	Mo to Sun, 8:00 am/1:00 pm
Scenario 3 – 10x/week	Mo to Fri, 8:00 am/4:00 pm	-
Scenario 4 – 10x/week	Mo to Fri, 9:00 am/5:00 pm	-

Table 55: Departure days and times Carrier G

Carrier H – one pickup per day	Departure Place B
Scenario 3 – 5x/week	Mo to Fri, 8:00 am
Scenario 4 – 5x/week	Mo to Fri, 4:00 pm
Carrier H – two pickups per day	**Departure Place B**
Scenario 3 – 10x/week	Mo to Fri, 7:00 am/12:00 pm
Scenario 4 – 10x/week	Mo to Fri, 8:00 am/4:00 pm

Table 56: Departure days and times Carrier H