MASTER

Development of a design model for integrated passenger and freight transportation systems

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Development of a Design Model for Integrated Passenger and Freight Transportation Systems

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in Operations Management and Logistics**

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Abstract

This master thesis describes the appropriateness of an integrated passenger- and freight transportation system. For the chosen research area Millingen aan de Rijn, several techniques are applied to outline the current situation regarding passenger and freight flows. In addition, a simulation model based on coloured Petri Nets (CPN) is designed for matching supply and demand. Two scenarios (line buses and taxis) are examined for feasibility of integration. Calculations provide evidence that with current volumes and arrival times, both scenarios are operationally, economically, environmentally, and socially appropriate.

Executive summary

This report is the result of a master thesis conducted for the Dinalog R&D project *'Cargo Hitching'*. The Cargo Hitching project aims to design and test integrated people and freight synchromodal transportation networks and the related coordination (4C), planning and scheduling policies to enable efficient and reliable delivery of both persons and small- to medium-sized freight volumes[1]. The aim of this thesis is an efficient supply and at the same time maintaining accessibility towards the villages in the rural area in the Netherlands. To narrow the scope of the overall project to a feasible thesis project, the main research question of this research is defined as:

Is there a scenario in which it is appropriate (operationally, economically, environmentally, and socially) to integrate passengers and freight towards the villages of rural areas which results in a more efficient supply and at the same time maintaining accessibility?

Previous literature acknowledges the potential benefits of integrating passengers and freight transportations flows. However, little research has been done concerning the modelling of this concept. Millingen aan de Rijn is chosen for this study to be the geographical research area. This village in the rural area of Nijmegen is chosen due to the geographical location at the border with Germany and the Rhine river, and because it is categorized as 'underserved urban municipality' by the *Centraal Bureau van de Statistiek* (CBS).

The current situation regarding independent freight transport and public transport is analyzed. To identify traffic flows, traffic monitoring has taken place at the main entrance road of Millingen aan de Rijn. Interviews with local businesses have been conducted to gain insight in the freight transport demand and to establish a general freight profile of Millingen aan de Rijn. Interviews with Parcel Delivery Service Providers have been conducted to gain insight in current movements, volumes, frequencies and other transport related aspects. To determine the volumes destined for Millingen aan de Rijn, not only traffic monitoring and interviews are conducted, also research has taken place into statistical data from Thuiswinkel Markt Monitor. Furthermore, public transport towards the rural area of Nijmegen consists of line buses and taxis. For both transport modes, utilizations have been measured during traffic monitoring days.

Results from the current situation show that freight- as well as public transport towards the rural area of Nijmegen can be optimized. Parcel Delivery Service Providers confirms that transport vans are far from FTL for last mile delivery. Different techniques indicated that a daily demand of 320 parcels are requested for the total rural area in which Ooij, Erlecom, Leuth, Kekerdom, and Millingen aan de Rijn are delivered. Furthermore, both

[1] http://www.cargohitching.wordpress.com/

public transport modes have utilization peaks of outflow in the morning and inflow in the late afternoon. However, overall the utilization rate is relatively low.

For the integration of passenger- and freight transport flows, a simulation model based on coloured Petri Nets (CPN) is designed for matching supply and demand. Parcel delivery service providers can arrive at the Logistic Service Center (LSC) in Nijmegen according a uniform distribution or a more realistic distribution. Line buses and taxis are included as hitching modes. Line buses arrive at the consolidation bus station according to their fixed time schedule and taxis arrive at the LSC according to the time planning based on probabilities. To compare calculation results, output parameters are: *(i)* number of undelivered parcels (one day delivery), *(ii)* inventory levels at the LSC, *(iii)* utilization levels for public transport, and *(iv)* average waiting times of parcels at the LSC.

In addition to the simulation model, a sensitivity analysis is performed on the results and potential benefits are indicated. Thereafter, a small study is conducted to assess whether this integration of passengers and freight transportation is conform the Dutch legislation and regulations.

The findings of this research indicate that:

- Current daily demand of 320 parcels can be delivered by both line buses and taxis towards the rural area of Nijmegen.
- Public transport is currently far from optimal. Two scenarios are appropriate to integrate passengers and freight flows. Both line buses and taxis independently have ample capacity to accommodate upcoming e-commerce. Independently, both transport modes have capacity up to 750 parcels a day.
- Daily, €243.33 is extracted from the traditional system and is the margin in which the integrated system should work.
- Approximately 400 kilometers are daily eliminated which not only reduce congestion, it also reduces CO_2 emissions.
- The integrated passenger- and freight transport system keeps public transport viable to the rural area of Nijmegen. This is essential for specific populations groups. Furthermore, it avoids further isolation of rural areas.

Finally, a number of limitations and recommendations need to be considered. Limitations are:

- The number of participated businesses in the freight profile analysis is relatively low.
- Lack of prior research studies on the topic.
- No big data was obtained. The amount of data from traffic monitoring is limited.
- Self-reported data (e.g. interviews) can rarely be independently verified.

Future work should concentrate on:

- Further elaboration on the financial aspects and consequences on integrating passenger and freight flows.
- Data generation in other rural areas in the Netherlands. More data can lead to more academic knowledge.
- The implementation of a pilot project in Millingen aan de Rijn. Gaining practical knowledge will further extend academic knowledge and persuade other stakeholders to participate as well.

Acknowledgement

This thesis is the result of 9 months of hard work on my master thesis project in order to fulfill my master degree in Operations Management and Logistics at Eindhoven University of Technology. This thesis project was carried out from February 2014 to November 2014 at Binnenstadservice BV and is part of the Dinalog *Cargo Hitching* project. I realize that this thesis was only possible with the help and guidance of others. I would like to take this opportunity to thank some people who surrounded me and who motivated me during my master and during my master thesis project.

First of all, I would like to thank my supervisor from the university. Dr. D. Krushynskyi was my first supervisor during my master thesis project. He offered important feedback, took time for meetings, and gave quick answers to all kinds of questions. I would also like to thank my second supervisor from the university, Prof. dr. T. van Woensel. Despite his hectic schedule, the meetings were very efficient and helpful. At Binnenstadservice, I want to thank my supervisor Mrs. Hendriks. Her practical experience together with her extensive network and high level of commitment helped me with the project.

Secondly, I would like to thank my friends, family, and my girlfriend who supported me during my master thesis project. They gave me the confidence I needed and they took the time to give me useful feedback. I am very lucky with the support and love of them.

Finally, I would like to thank my fellow students for the wonderful time at the University. I really enjoyed the time together; it has been an unforgettable period in my life.

Tijs Jansen
Eindhoven, November 2014

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Chapter 1

Introduction

A well-known phenomenon in the Netherlands is carpooling. When people have to go to the same direction and it will also fit in one car, why not ride together? After all, it is far from efficient to drive the same route with more vehicles than needed.

Another scenario; freight and public transport also drive the same route to the rural areas of the Netherlands. It is expected that freight transport drives far from 'Full Truck-load'(FTL) and public transport copes with a declining amount of passengers. Why not ride together? After all, it is far from efficient to drive the same route with more vehicles than needed.

The research conducted in this project is part of the *Cargo Hitching* project and executed at the company Binnenstadservice BV. A short introduction of Binnenstadservice BV is given below, followed by the structure of this report.

1.1 Binnenstadservice BV

Binnenstadservice is a receiving- and shipping cross dock warehouse on behalf of the joint retailers and other organizations that are located in the (inner) city. Figure 1.1 illustrates the positions of Binnenstadservice within the supply chain (highlighted in green). Binnenstadservice acts on behalf of, and is authorized by, the end receiver and senders. For authorization, Binnenstadservice make a contract with each end receiver and/or sender. Therefore Binnenstadservice is an endpoint of deliveries and starting point of shipment.

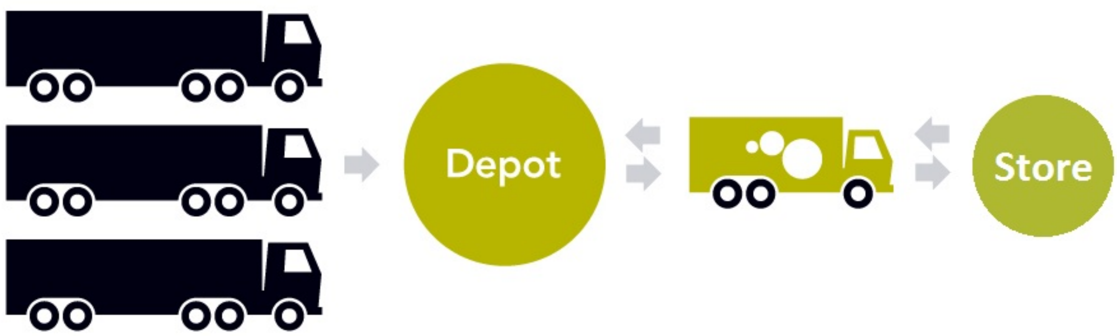


Figure 1.1: Schematic representation of Binnenstadservice within the supply chain

Suppliers deliver goods to the central depot of Binnenstadservice (located outside the city). Subsequently, Binnenstadservice consolidates the goods and delivers them to the stores with environmentally friendly vehicles.

1.2 Structure of report

This report continues with the research design which outlines the aim of the research project and the research questions. Secondly, a summary of the literature review is given. Thirdly, the geographical research area Millingen aan de Rijn is introduced with its characteristics, business entities and population. After that, the current situation is outlined regarding the independent transportation of both freight and passengers towards the rural area of Nijmegen. The simulation model with the sensitivity analysis is performed in Chapter 6. In addition, computational results are given and potential benefits are calculated. Subsequently, steps to practical implementation are given in Chapter 7. Finally, Chapter 8 concludes this report, and limitation and recommendations for future research will be given in Chapter 9.

Chapter 2

Research Design

2.1 Aim of the research project

Limited literature exists on the integration of passenger and freight transportation systems. On the one hand, the population in rural areas appears to be shrinking, and on the other hand critical environmental issues are becoming more important. Further research into integrating passengers and freight transportation flows towards rural areas is therefore worthwhile. This can make socially desirable transport options economically viable in rural areas. Therefore, the problem is formulated as follows:

An inefficient supply and at the same time difficulties in maintaining the accessibility towards the villages in the rural area of the Netherlands.

This research is a part of a larger scholarly project named *Cargo Hitching*. The Cargo Hitching project aims to design and test integrated people and freight synchromodal transportation networks and the related coordination (4C), planning and scheduling policies to enable efficient and reliable delivery of both persons and small- to medium-sized freight volumes [1]. Therefore, this research will contribute to the theoretical part by means of a design model for matching supply and demand as well as the practical significance of data collection in the research area in preparation for a pilot. The aim of this research project is as follows:

Design a framework for an efficient supply and at the same time maintaining accessibility towards the villages in the rural area in the Netherlands

[1] http://www.cargohitching.wordpress.com/

2.2 Research questions

The research question is formulated as follows:

Is there a scenario in which it is appropriate (operationally, economically, environmentally, and socially) to integrate passengers and freight towards the villages of rural areas which results in a more efficient supply and at the same time maintaining accessibility?

The answer to above mentioned research question can be obtained by means of answering the following sub questions:

1. *What is the current situation regarding passenger transport and freight transport towards the research area (Figure 2.1)?*
   (a) What are the characteristics of the research area? .... **Chapter 4**
   (b) What are the current (freight) traffic movements? .... **Chapter 5.2 & 5.3.1**
   (c) How many parcel delivery service movements are there currently? .... **Chapter 5.3.2**
   (d) What is the trend in e-commerce? .... **Chapter 5.3.3**
   (e) What are the current volumes of small freight transport? ... **Chapter 5.3.3**
   (f) What are the current utilizations of public transport? .... **Chapter 5.4**
2. *Which scenarios are conceivable with an integrated passenger and freight transportation system?* .... **Chapter 6.1**
3. *How should a simulation model for integration of passengers and freight be designed?* .... **Chapter 6.2**
4. *What are potential benefits when integration of passengers and freight transportation systems take place?* .... **Chapter 6.5**
5. *How should the practical implementation be designed?* .... **Chapter 7**

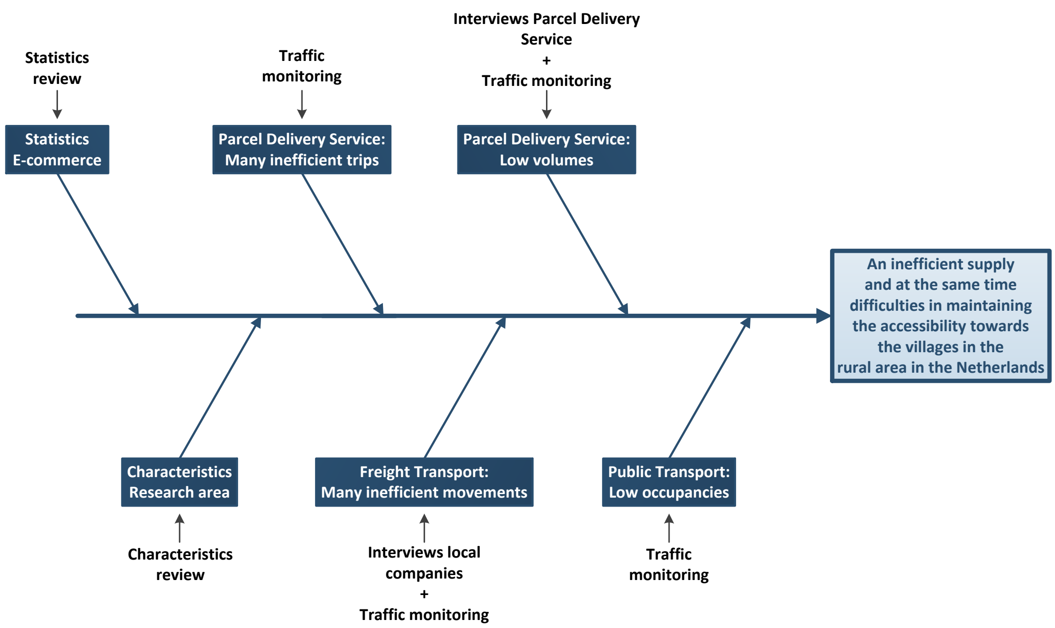


Figure 2.1: Current situation map of the problem

Chapter 3

Summary Literature Review

Different ride sharing transportation systems have emerged during the last decades. Most important ride sharing exists among people, where people share a ride with other people. However, another ride sharing is possible between people and freight.
This chapter gives a summary of the integration of passengers and freight transportation systems. First of all, benefits and problems that emerge from this integration are outlined. Thereafter, differences and commonalities highlighted from previous literature are described.

3.1 Benefits and problems

Demand for ride sharing service between people has increased in recent years (Saranow, 2006). According to Levofsky and Greenberg (2001), ridesharing takes advantage of the underused infrastructure and provides opportunities for a flexible and affordable service. Furthermore, ridesharing ensures a decrease not only in congestion, it also reduces CO_2 emissions. Finally, ridesharing systems encourage car-free living due to elimination of required car ownership which is interrelated with different cost factors such as operation cost (oil prices increased up to 60% since 2009 [1], insurance cost, parking cost and with vehicle theft and vandalism (Levofsky and Greenberg, 2001).

Although it seems that ridesharing has the ability to increase car occupancy rates, decrease environmental degradation, and encourage car-free living, several drawbacks can be mentioned against this phenomenon.

Firstly, Morency (2007) mentioned that one of the most important problems regarding ridesharing are the ill-assorted ride-matching tools which are developed by public and private organizations, which means that these ride-matching tools do not give the optimal matches that it should produce.

Furthermore, bad experiences can create a form of fear to share a ride with a stranger (Agatz et al., 2012) and it also seems obvious to improve congested urban areas by implementing ridesharing systems due to the high probability of potential sharing-matches. However, due to the ill-assorted tools and inevitable advanced communication systems, in practice the chance of finding a correct sharing-match is much smaller (Agatz et al., 2012).

[1] http://www.nasdaq.com/markets/crude-oil.aspx?timeframe=9y

Combining people with freight has a completely different approach and leads to other benefits and problems. Research into the integration of passenger and freight transport systems is quite new (Ghilas et al., 2013), only a few practical examples are introduced.

As mentioned with ridesharing, currently, the total capacity of public urban transport is also under used (Frost, 2008; Levofsky and Greenberg, 2001). This indirectly states that improvements can be made in terms of efficiency. Furthermore, critical environmental issues like CO_2 emission, congestion, and air pollution are becoming more important not only at integrating people with people, also for the integration of people and freight (Trentini and Mahléné, 2010; Ghilas et al., 2013). Reasonable time and cost savings can be expected and consequently a decrease in the above mentioned environmental issues.

From the perspective of freight transportation, it is possible that the delivery time of freight to rural areas will be shortened if people and freight integration with public transport is applied. This is due to the fact that delivery with public transport can take place every time step (e.g. every hour), while delivery service for instance will only deliver once per day. Ghilas et al. (2013) stated that especially during off-peak hours, the capacity utilization of fixed scheduled line (FSL) vehicles in public transport is low.

Although integrating passengers and freight seems to be an attractive business opportunity, few drawbacks of this integration are listed below.

Binsbergen and Visser (2001) observed that a theoretical approach cannot provide sufficient information about the feasibility of the integration of people and freight.
Furthermore, practical knowledge is needed to test if this innovation will actually lead to a greater transport efficiency (Trentini and Mahléné, 2010). This is particularly important due to the fact that little research has taken place in practice.

Macario stated, *"The demands falling over an urban mobility system are very diverse and require the system to continuously adjust to the urban changes"*. In addition to this, a total trip time of a passenger request is usually more crucial, whereas for packages it is more flexible (Ghilas et al., 2013).

3.2 Differences and commonalities

It can be concluded that there are both benefits and problems for different types of ridesharing systems. From another point of view, difference and commonalities can be observed between those types of ridesharing systems (Figure 3.1).

Firstly, in general, the trip times for passengers are usually more crucial compared to freight (Ghilas et al., 2013). A delay of a few hours on a (short)trip is obviously unacceptable for passengers, while for freight this is much more flexible.

Secondly, on the one hand, ride-sharing with people is widely applied by private entities. People who own a vehicle can share a ride to decrease their cost. On the other hand, integration of people with freight is mostly applied by the public section where it increases the utilization and gives opportunities to public transport companies (Ghilas et al., 2013), e.g. buses, trams, and taxis (Li et al., 2014).

	Integration of People with People	Integration of People with Freight
Triptimes and preferences	Desired triptimes and preferences are crucial for both.	Different desired trip times. People is crucial → Freight is more flexible, no personal preferences.
Environmental issues	Decrease Airpollution, congestion etc. Increase utilization rates	Decrease Airpollution, congestion etc. Increase utilization rates
Private entities vs Public sector	The drivers which provide the rides are mostly independent private entities.	Mostly focus on public sector: buses, trams, planes etc.
Adaptation of vehicles	Same transport type - no special vehicle is needed	Transformation of transport mode may be needed
Demand distribution	Peak demand in Peak-hours	Freight demand almost equally during day
Cost sharing	Important aspect is Cost sharing	Important aspect is Cost sharing
Single trips	Focus on single, non-recurring trips.	Focus on single, non-recurring trips.
Marketing	Advertisement focus on people (privats)	Advertisement focus on companies - packet service providers etc.

Table 3.1: Summary of differences and commonalities between ridesharing systems

From a practical point of view, mostly no transformation is needed for privately owned cars to share rides with people, vehicles for the transportation of people and freight do need transformation compared to the traditional compartmentalized systems (separate passenger transportation and freight transportation)(French Environment and Energy Management Agency, 2012).

Furthermore, due to the demand distribution, ride-sharing vehicles are mostly under-utilized outside the peak hours. This is in contrast with freight, which can be equally distributed over the day. Resulting in an increased utilization of public transport by distributing freight during the off-peak hours.

Finally, to make ridesharing a success and to gain popularity, the only target group are the people (private), both drivers and passengers. For the integration of passengers and freight, more target groups should be observed. To make it work, not only individuals are a target group, also the packet service providers and other freight transport companies are stakeholders which should be taken into account.

Although there are differences between the types of ridesharing, commonalities can be mentioned as well.

Firstly, one objective that both types of ridesharing have, is a decrease in air pollution, CO_2 emissions, traffic congestion, mobility problems in urban areas and other societal and environmental issues (Agatz et al., 2010; Levofsky and Greenberg, 2001; Trentini and Mahléné, 2012; Trentini et al., 2012).

Secondly, when participating one of the ride sharing systems, it should be beneficial for all participants to participate from the perspective of cost reduction (Agatz et al., 2012).

Finally, as Agatz et al. (2012) outlines, both ride sharing systems focus on single, non-recurring trips. In principle, the driver (private or public transport) transports the passenger for the origin to the destination. If the passenger would return to the origin, the system will deal with this as a new request.

3.3 Conclusion of the literature review

From a ridesharing point of view, relevant literature acknowledges the potential benefits of integrating passenger and freight transportation systems. Furthermore, differences and commonalities are mentioned between different ride sharing systems. However, most of the relevant literature is based on theory and innovative future ideas towards a sustainable and environmental friendly transport, and little research has been done concerning the modelling of it. Another gap is the loss of practical knowledge on integrating passengers and freight. Only two examples can be mentioned (On-route and Multibus) of which one is only a concept.

To conclude, two gaps in the literature exist; concerning the modelling of integrated passenger and freight transportation systems and the practical knowledge. During this master thesis, knowledge about this relatively new way of transport will be added to the literature by means of modelling and a pilot project.

Chapter 4

Geographical research area

For the collection of data to verify whether it is accessible and appropriate to integrate passengers and freight transport towards rural areas in the Netherlands, Millingen aan de Rijn has been chosen as the research area for this project. Millingen aan de Rijn is located in the east of the Netherlands at the border with Germany and near the Rhine river. Figure 4.1 shows the geographical location of Millingen aan de Rijn in the Netherlands.

Figure 4.1: Map of the Netherlands

4.1 Characteristics of Millingen aan de Rijn

With 5876 inhabitants [1], Millingen aan de Rijn is a small village in the rural area nearby the large city of Nijmegen and is the center of nature reserve De Gelderse Poort (Figure 4.2). At a distance of approximately 20 kilometers of Nijmegen, Millingen aan de Rijn is the last small village before the German border. It is accessible via the N840 which is also the access road for several small villages like Ooij, Erlecom, Leuth and Kekerdom and which eventually runs into Klever Straße (Germany).

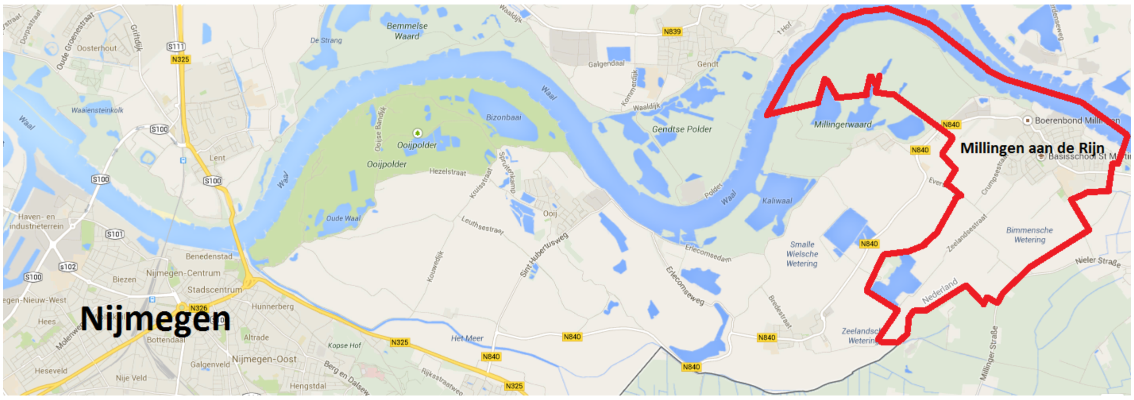


Figure 4.2: Geographical location of Millingen aan de Rijn

Furthermore, the total area of Millingen aan de Rijn is 10.27 km^2 of which 8.66 km^2 land and 1.61 km^2 inland water, and the population density per km^2 land is 684 which results in an *urbanization grade* of 4 (1=very urbanized municipalities, 5=non urbanized municipalities, data: January 1, 2013). By way of comparison, the total area of Nijmegen is 57.60 km^2 and has a population density per km^2 land of 3,103 with an urbanization grade of 2.

4.2 Business entities

Besides the fact that Millingen aan de Rijn is characterized by its rural setting, it also has a small city center with shopping facilities, catering facilities, sport clubs and other business activities. According to a self-conducted study in Millingen aan de Rijn, different business activities in different sectors are exploited. During an on-site study, in total 72 businesses (organizations, emergency services and sport clubs included) are identified and are categorized in different sectors as can be seen in Figure 4.3. See Chapter 5.3.1 for more details about the business entities in Millingen aan de Rijn.

[1] January 1, 2014 - http://statline.cbs.nl/StatWeb/publication/?DM=SLNL&PA=03759ned&D1=0,3,6,9,12&D2=129-132&D3=119,454,546&D4=25-26&HDR=T&STB=G2,G3,G1&VW=T

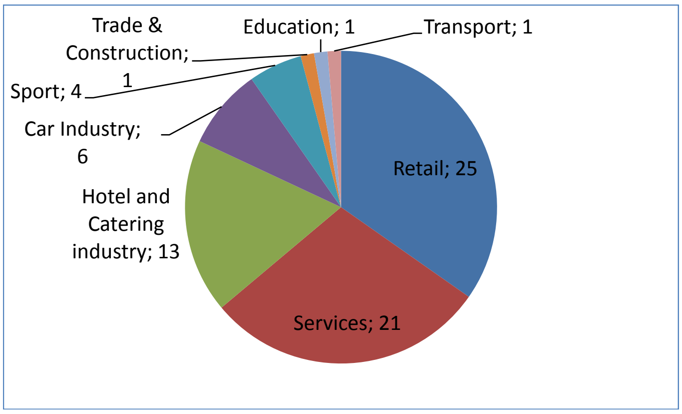


Figure 4.3: Businesses in Millingen aan de Rijn categorized by sector

4.3 Population

According to the *Centraal Bureau van de Statistiek* (CBS), the population of Millingen aan de Rijn is distributed by age as shown in Figure 4.4. This figure also shows the population size of 5876 on January 1, 2014, which is a slight decrease compared to the 5924 inhabitants of Millingen aan de Rijn on January 1, 2013. Not only the size of the population has remained approximately the same, also the distribution in the different age-categories is roughly equal.

Despite the fact that on the one hand over the past decades rural areas in Europe are depopulating and on the other hand urbanization takes place (Westhoek et al., 2006), Figure 4.4 shows that the population of Millingen aan de Rijn is in fact nearly stable over the past 10 years.

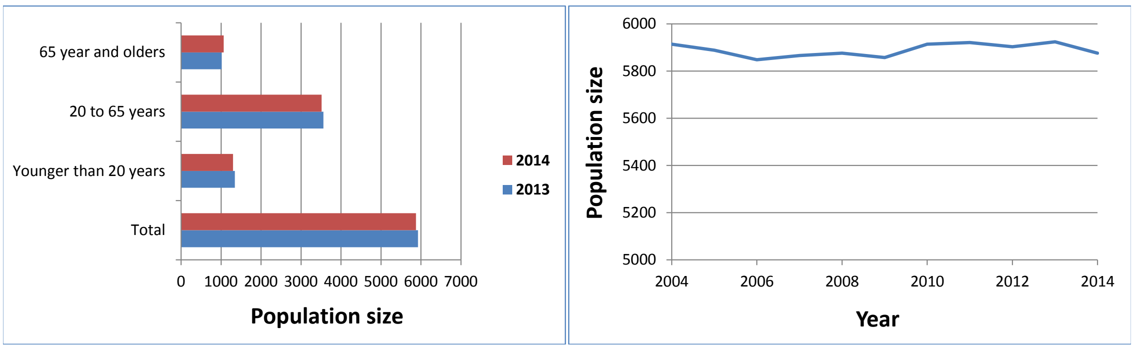


Figure 4.4: Population distribution of Millingen aan de Rijn

4.4 Conclusion of the research area

Despite Millingen aan de Rijn is not depopulated over the last 10 years, it is an attractive research area for the integration of passengers and freight towards rural areas. This is due to the geographical location at the border with Germany and the Rhine river, and because Millingen aan de Rijn is categorized as 'underserved urban municipality' by the CBS.

Chapter 5

Current situation

Currently, the transport sector in the Netherlands can be divided into two main parallel systems. On the one hand, freight transport, which consists of transportation of goods by different transport modes. On the other hand, public transport which consists of passengers transported by buses, taxis, and other public transport modes. This research specifically focuses on the distribution of small freight volume (parcels, small freight volume, and small volume is used interchangeably) for Business to Business (B2B) as well as Business to Consumer (B2C) and the distribution of passengers by fixed line buses and taxis to the rural areas in the Netherlands.

This chapter outlines the current situation regarding the independent transportation of both freight and passengers towards the rural area of Nijmegen.

In the first section, the traffic monitoring approach is explained which provides general insights in traffic movements from and towards Millingen aan de Rijn. Second section, the situation regarding freight transport is analyzed in which more qualitative and quantitative information about freight transport movements is gathered by means of interviews which were conducted with business entities within Millingen aan de Rijn, as well as interviews conducted with Parcel Delivery Service Providers (PDSPs). Furthermore, quantitative data about volumes are extracted and computed from information from the CBS as well as interviews and traffic monitoring data. Third, the situation regarding public transport is analyzed by means of desk research into current routes and trip planning as well as a field study to determine and confirm the arrival times of buses and taxis with their corresponding utilization rates.

5.1 Traffic monitoring approach

In the last few years, several Intelligent Transportation Systems (ITS) are developed for improving traffic management such as in-situ technologies, which can be categorized into *intrusive*- and *non-intrusive methods*, and *Floating Car Data (FCD)*. With intrusive methods data is collected with sensors in- or on the road, while non-intrusive methods apply remote observations. With FCD, traffic data is collected with locating vehicles via mobile phones or GPS on the entire road network (Leduc, 2008).

For the assessment of the current situation in Millingen aan de Rijn, an intrusive method for collecting data does not seem to be the most appropriate technique due to high cost and relatively little detailed information since intrusive methods focus on quantitative data rather than qualitative data. Therefore, a traditional non-intrusive technique of manual counting has been applied.

5.2 General results of traffic monitoring

Traffic monitoring has taken place at a parking area located near the main road towards Millingen aan de Rijn as can be seen in Figure 5.1. Traffic data was collected during two days of monitoring (Tuesday May 6, 2014 and Friday May 16, 2014), in which each monitoring day consisted of 12 consecutive hours of obtaining data (06.00h - 18.00h). To provide a detailed level of analysis and a more accurate result, the traffic monitoring was recorded in 15 minutes intervals (Leduc, 2008).

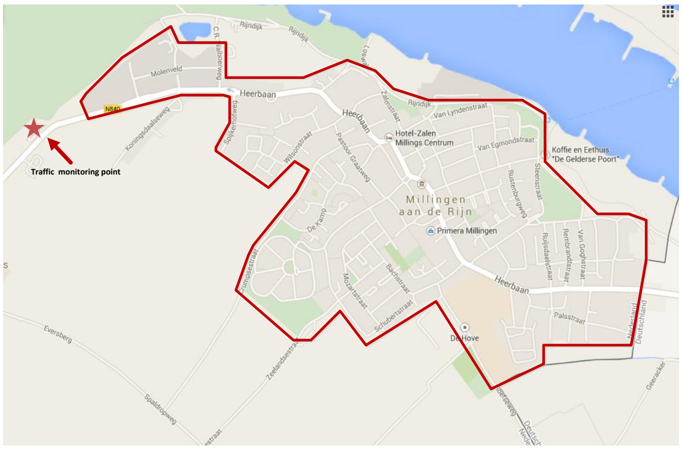


Figure 5.1: Millingen aan de Rijn traffic monitoring point

5.2.1 Tally sheets recording

Various traffic data is collected by means of different tally sheets:

1. Quantity per vehicle classification per time unit;
2. Public transport utilization rate per vehicle classification;
3. Quality data for freight transport.

The first tally sheet includes data about numbers of vehicles per classification per time unit. Within three main categories, 13 different vehicle classification are defined, namely:

- Coach buses, small buses (max 9 pers.), remaining buses (touring cars etc.);
- Trailers (max: 18m), trucks (max: 16m), pickup vans, delivery vans, transporters, remaining trucks;
- Taxis, passenger cars, motorcycles, remaining cars.

As mentioned before, 15 minutes intervals were used. Furthermore, a distinction was made between inflow- and outflow traffic. The tally sheet format 'Quantity per vehicle classification per time unit' is included in Appendix A.1.

The second tally sheet includes data about utilization rates of line buses as well as taxis along with associated times and whether it is inflow- or outflow traffic. The format of this tally sheet is included in Appendix A.2.

Finally, the third tally sheet records specific freight transport data (company names, vehicle types, and inflow or outflow). It also shows for which duration vehicles were in Millingen aan de Rijn. An example of this tally sheet is included in Appendix A.3.

5.2.2 Results of traffic intensities Millingen aan de Rijn

Figure 5.2 shows the intensity-time diagram of the total traffic flow during both monitoring days. This traffic intensity includes all traffic flows with the exception of public transport (line buses and taxis) per time unit of 15 minute periods. Clearly, a trend can be observed between 06.00h and 09.00h, outflow traffic at both monitoring days is considerably higher compared to inflow traffic (which is almost negligible). Subsequently, between 16.00h and 18.00h this is the other way around, then there is significantly more inflow traffic than outflow traffic. These results offer valuable evidence that Millingen aan de Rijn can be characterized as a rural area where commuting towards Nijmegen takes place.

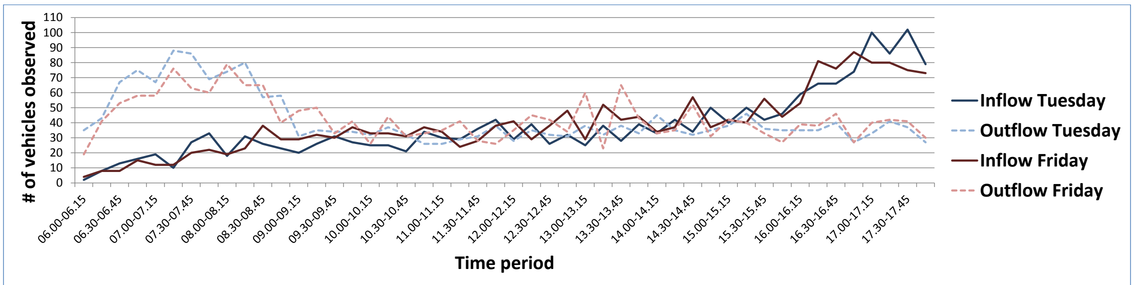


Figure 5.2: Intensity-time diagram of total traffic (excl. public transport)

However, to identify the underlying causes of this trend and to discover to what extent this trend is caused by freight transport, a more detailed look at the above mentioned data is needed. Considering the different traffic categories, a distinction can be made between three general categories:

- Public transport: Line buses and taxis (discussed in Chapter 5.4);
- Private transport: Cars and motorbikes;
- Freight transport: Trucks, vans and transporters.

As shown in Figure 5.3, a slight peak can be observed in the morning and in the late afternoon. This is due to the fact that in these peak hours, an extra bus line is used. Public transport is discussed in more detail in Chapter 5.4. When the intensity-time diagram of private transport (Figure 5.4) is compared to the intensity-time diagram of freight transport (Figure 5.5), it is clear that the increased outflow in the morning as well as the increased inflow in the afternoon can be related to private transport. The freight transport however, shows little fluctuation. The trend is approximately stable.

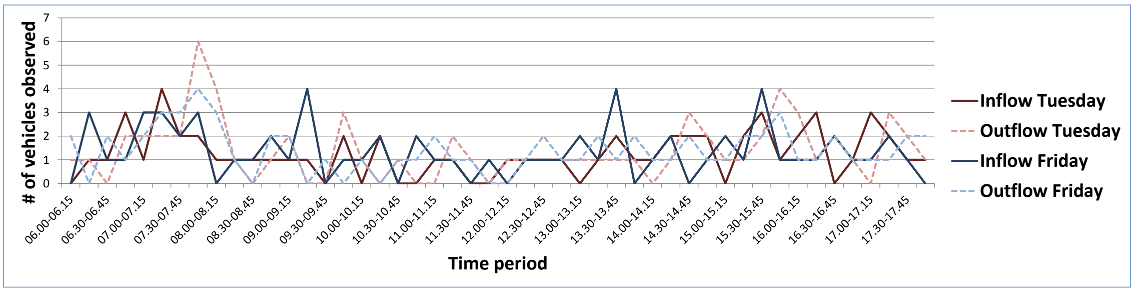


Figure 5.3: Intensity-time diagram of public transport

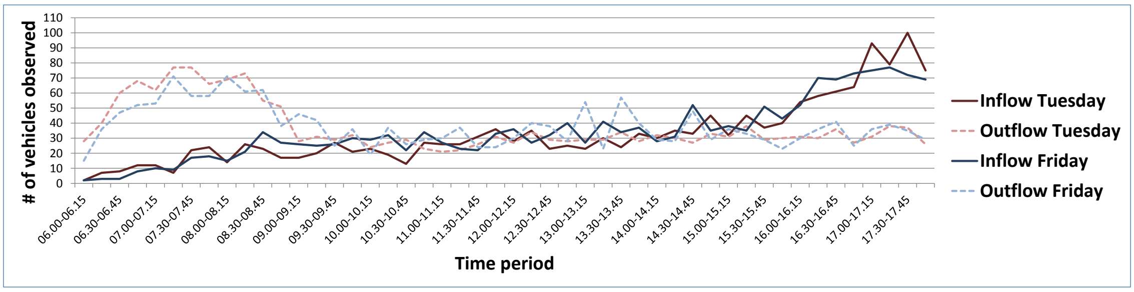


Figure 5.4: Intensity-time diagram of private traffic

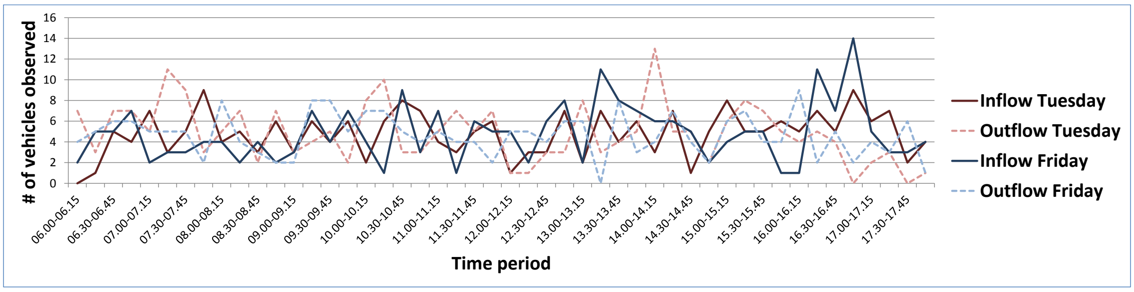


Figure 5.5: Intensity-time diagram of freight traffic

While Millingen aan de Rijn can be characterized as a rural area, no specific conclusions can be drawn from the intensity-time diagrams about types of freight movements with their corresponding volumes, delivery patterns and other freight related aspects. Furthermore, not only movements are of high importance, in-depth research should lead to more information about specific utilization rates of public transport.

In the following subchapters, these freight- and public transport systems will be discussed in more detail for the research area Millingen aan de Rijn.

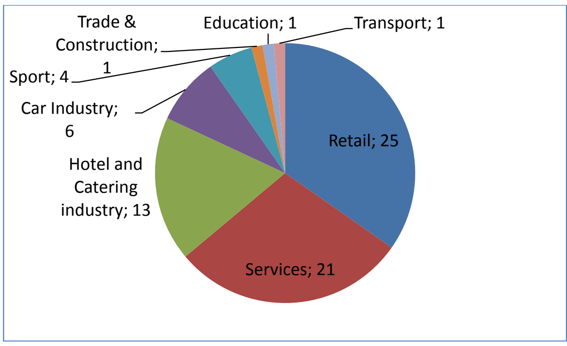
5.3 Freight transport

Due to the geographical boundaries, there is a possibility that (freight) traffic considers Millingen aan de Rijn to be a dead end where freight transport both ways potentially drive the same route. It is essential to gain more detailed information about frequencies and volumes that carriers drive to Millingen aan de Rijn.

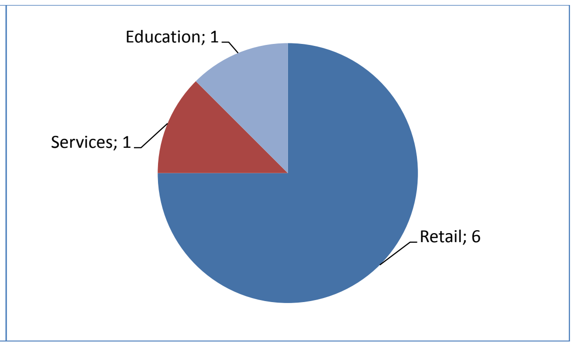
In order to gain above mentioned information on frequencies and volumes, freight transport of small volumes is examined from different B2B and B2C perspectives. Interviews have been conducted with businesses in Millingen aan de Rijn to establish a general freight profile including small volume. Interviews with PDSPs have been conducted to gain information on small volume movements. Furthermore, different techniques are applied to provide information on current small freight volumes towards the rural area of Nijmegen. Finally, future trends in small volumes are examined.

5.3.1 Freight profile of businesses

Interviews have been conducted among several businesses located in Millingen aan de Rijn to gain insight in the freight transport demand within these businesses and to establish a general freight profile of Millingen aan de Rijn. Key questions in these interviews focused on characteristics of the company, suppliers, carriers, type of supplies, volumes, type of vehicle used, and other transport related aspects. As mentioned in Chapter 4.1, a total of 72 businesses (Figure 5.6a) have been identified in Millingen aan de Rijn of which 25 have received a request for an interview. This resulted in 8 interviews (Figure 5.6b), thus a response rate of 32% and a total participation rate of 11%. The interviews were directed by means of survey questions which can be found in Appendix B.1.



(a) Identified businesses



(b) Participating businesses

Figure 5.6: Identified and participating businesses in Millingen aan de Rijn

Six interviews have been conducted with businesses in the retail sector: Bike shop, *Bike Totaal Jos van Hees*; Fashion store, *Iets 4 jou*; gift shop & cigarettes, *Primera*; Supermarket, *Albert Heijn vd Hatert*; Pharmacy store, *Kruidvat*; General shop, *Marskramer*. One within the education sector: Primary School, *Martinusschool*, and another one within the service sector: Library, *de Bibliotheek Millingen*.

Number of deliveries per week

On average there were 10 deliveries per week in Millingen aan de Rijn (Figure 5.7a). However, Albert Heijn has far more deliveries per week compared to the other respondents. When Albert Heijn is excluded (due to the fact that this study focuses on small volumes), the average drops down to 5.5 deliveries per week.

Type of suppliers

Business entities use different types of suppliers. The results highlight that the vast majority of suppliers consist of wholesalers (71%). The remaining part are manufacturers (10%) and other types of suppliers (19%, e.g. own organization). Another result to emerge from the data is that all respondents have indicated not to a retailer as a supplier.

Type of vehicle used

Each respondent was asked by what kind of vehicle the suppliers deliver goods. The results are shown in Figure 5.7b. As can be seen, the suppliers that are identified, significantly more often make use of a PDSP with transport vans compared to other vehicle types. Suppliers with trailers and trucks more often supply the large stores such as Albert Heijn, Kruidvat, and Marskramer. Furthermore, the results show that neither cars nor bikes are used for transport.

Usual goods receiving times

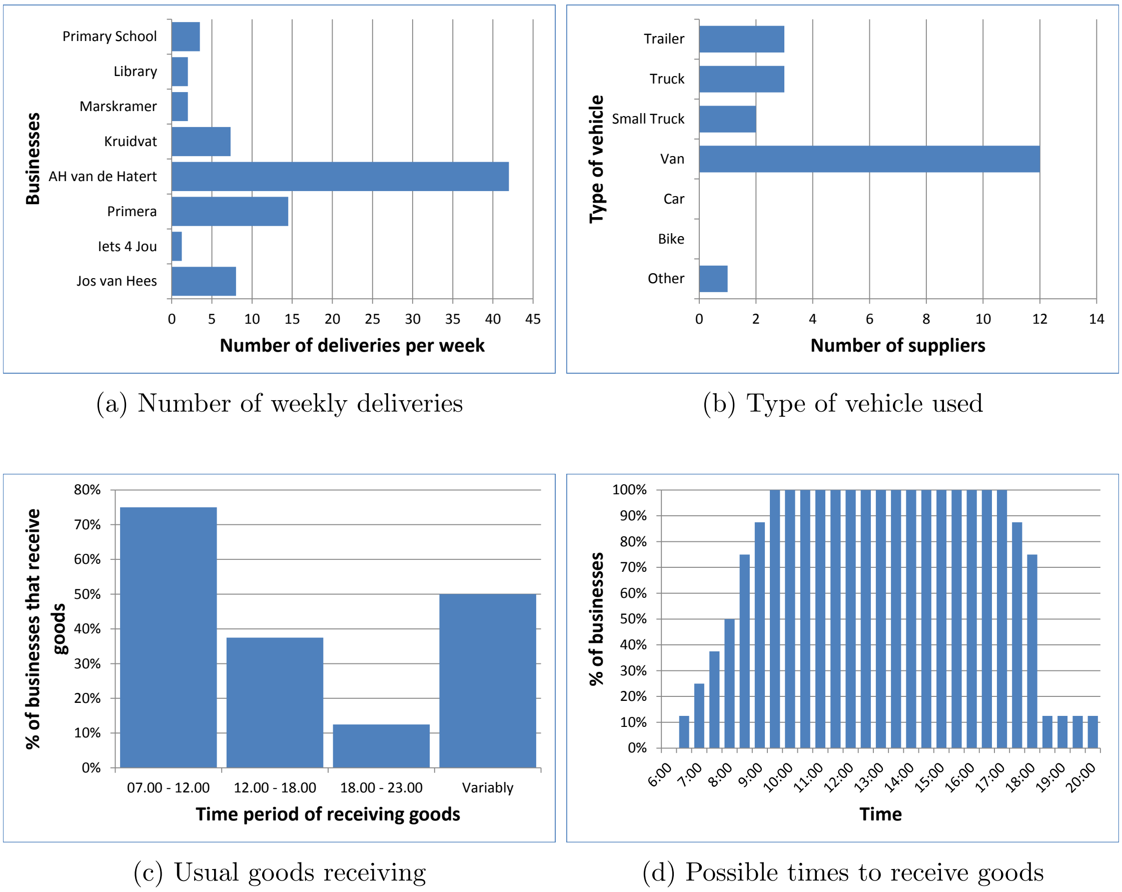
Other important aspects about the freight transport towards Millingen aan de Rijn are the usual receiving times of the respondents. Figure 5.7c shows that goods are usually received in the morning, between 07.00h and 12.00h. However, also 50% of the respondents indicates that they receive goods at random times throughout the day. Finally, due to the fact that Albert Heijn is open until 20.00h, it is the only respondent that actually receives goods in the evening.

Possible goods receiving times

Besides the fact that it is important to know what the usual goods receiving time is, it is even more important to know when the businesses have the possibility to receive goods. Figure 5.7d clearly shows that during the morning, the number of businesses that actually can receive goods is increasing by the hour, which is caused by the opening times of the receiving businesses. All respondents have indicated that they have the possibility to receive goods in the period between 10.00h and 17.00h. The number of businesses that can receive goods after 17.00h is decreasing, caused by the closing times of the businesses involved.

Inventory storage

With regards to inventory storage, all businesses indicated that they have at least some storage capacity at their own location. Interestingly, all respondents have both an indoor sales area (except the primary school), as well as access to an indoor warehouse. This indicates that goods can be stored in the backroom, so there is no need to deliver just-in-time.



(a) Number of weekly deliveries

(b) Type of vehicle used

(c) Usual goods receiving

(d) Possible times to receive goods

Figure 5.7: Interview results from businesses in Millingen aan de Rijn

Given that these findings are based on a limited number of questionnaires, the interviews results should consequently be treated with considerable caution. Furthermore, due to the limited number of completed questionnaires, extrapolating data was not applied as it would create an unrealistic perception of the freight demand towards Millingen aan de Rijn.

The interviews with businesses in Millingen aan de Rijn focused mainly on Business to Business (B2B). The next section outlines the Parcel Delivery Service movements which contain both B2B deliveries as well as Business to Consumer (B2C) deliveries.

5.3.2 Parcel delivery service movements

The current freight transport is studied with a focus on the small freight volume deliveries. Due to the certainty of deliveries of small volumes by PDSPs to both B2B and B2C, this study examines their movements and associated volumes. In most European countries, the national universal postal service providers have traditionally been the major operators of parcel home delivery services (Borsengerger et al., 2014). In the Netherlands, the national postal service is PostNL. Other well-known parcel delivery services active in the Netherlands are DPD, DHL, UPS, TNT, GLS and Selectvracht.

Supply Chain

Figure 5.8 shows a simplified representation of the supply chain of a general single Parcel Delivery Service Provider. In this chain, the PDSP picks up (mostly bundled) parcels at warehouses, distribution centers and other logistics pick up points, mostly consisting of e-commerce companies. Consequently the parcels are delivered at a Central Distribution Center (CDC) and from this point, goods are received, reallocated (based on the locations of the Regional Distribution Centers (RDC)) and transported to RDCs. Finally, 'the last mile' logistics is either done by PDSP itself or subcontractors who possess their own vehicle but drive in behalf of only one PDSP.

Figure 5.8: Supply chain single Parcel Delivery Service Provider

Considering that Millingen aan de Rijn is in the delivery area of multiple PDSPs/subcontractors, and for each PDSP/subcontractor aforementioned supply chain is applicable, this results in the last mile parcel delivery traffic as shown in Figure 5.9.

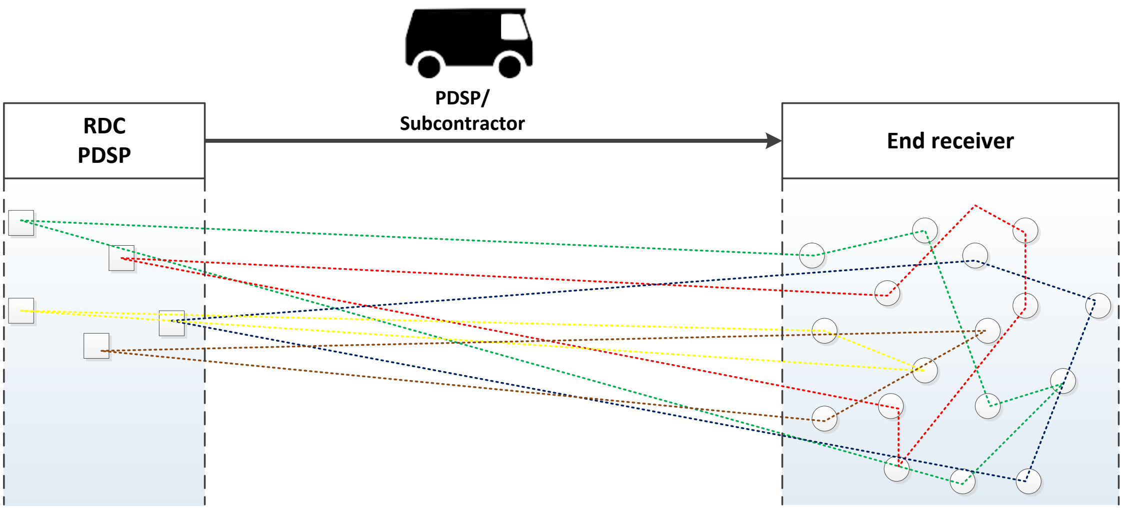


Figure 5.9: Illustration of last mile network with multiple PDSP's

As mentioned in Chapter 4.1, Millingen aan de Rijn is a village at the border of Germany and the Rhine river, so PDSPs are likely to drive the same route back towards Nijmegen.

Interview results

To gain more insight in small volume movements and deliveries for both B2B and B2C to Millingen aan de Rijn, a questionnaire was created for Parcel Delivery Service Providers (Appendix B.2). Relevant questions about type of vehicle used, type of deliveries, number of deliveries, time of deliveries, and volumes are covered. From the total of 7 PDSPs only one PDSP completed and returned the questionnaire and two Parcel Delivery Service Providers gave limited information about their parcel delivery data. Therefore, extreme caution must be taken with regards to the results of these interviews.

DHL Express is the only Parcel Delivery Service Provider which completed and returned the questionnaire. First of all, DHL Express merely delivers to- as well as picks up parcels at customers (B2C) 6 days a week. The depot for Millingen aan de Rijn is located in Apeldoorn, and from this point the route passes through Arnhem Presikhaaf, Huissen, Bemmel, Gend, and Lent, and then arrives in Millingen aan de Rijn. The route continues through Groesbeek, Berg en Dal, and finally Beek-Ubbergen. In total, a driver's working day in which delivery in Millingen aan de Rijn is included, takes 8 to 9 hours with an approximated distance of 250 kilometers. Although delivery and pick up is done in the same trip, DHL Express visits Millingen aan de Rijn 1 or 2 times per day. Subsequently, the total number of delivery stops is 45, of which 2 or 3 stops are in Millingen aan de Rijn with an average duration per stop of 1 minute. Usually, DHL Express is in Millingen aan de Rijn for an approximated time of 15 minutes, from 14.00h to 14.15h.

Due to time reasons, PostNL and UPS did not have the possibility to fill in the questionnaire. However, they did provide information in a short conversation. Both PostNL and UPS mentioned that they deliver in Millingen aan de Rijn 6 days per week, once every day. On average UPS has 15 to 30 stops in Millingen aan de Rijn within a time frame of 1 hour. Unfortunately, PostNL did not provide information on this topic. Finally, due to express shipments, UPS' route starting place varies daily. Express shipments need to be delivered before 12.00h, and therefore these specific stops will be scheduled at the beginning of the route.

Where DHL Express has indicated it takes 6 minutes on average per stop to deliver in Millingen aan de Rijn (2-3 stops in 15 minutes), UPS has indicated it takes on average 2.7 minutes per stop (22.5 stops in 60 minutes). A possible cause of this discrepancy between the time per stop can be the fact that in general, an increase in stop density, results in a decrease in the average time per stop.

Traffic monitoring data - movement results

As mentioned in Chapter 5, also qualitative data is collected during the traffic monitoring. Specifically, company names were registered as well as whether it was inflow or outflow traffic. Extracting the Parcel Delivery Service Providers resulted in 2 charts as shown in Figure 5.10 and Figure 5.11. The first and second traffic monitoring day, respectively 9 and 10 parcel delivery movements were identified. There however were fluctuations within the presence of Parcel Delivery Service Providers. While PostNL was delivering to Millingen aan de Rijn on both days several times with different vehicles, DHL was absent on day 1 and had 2 deliveries on day 2. In spite of the possibility of daily delivery by PDSPs(resulted from interview results), it is observed during traffic monitoring that this is not always the case.

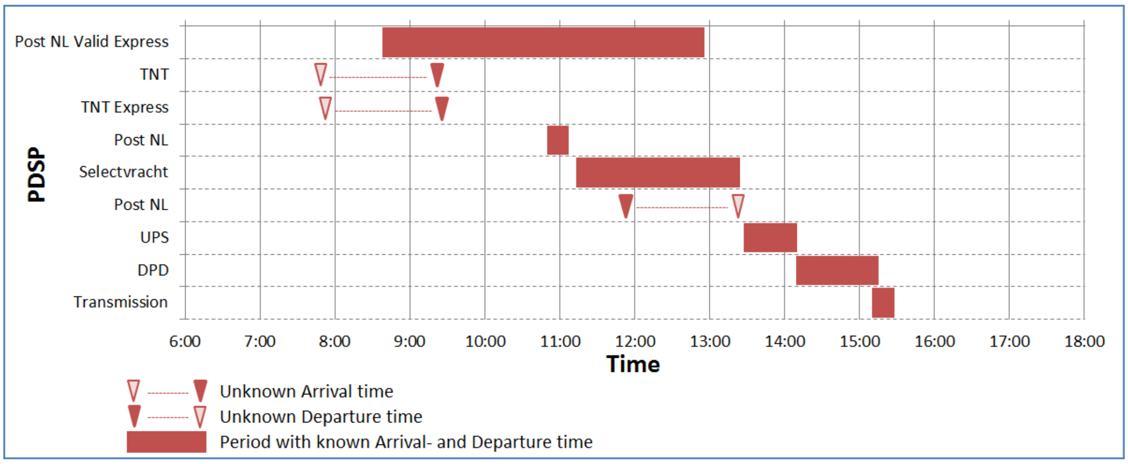


Figure 5.10: Observed PDSP's on Tuesday May 6, 2014

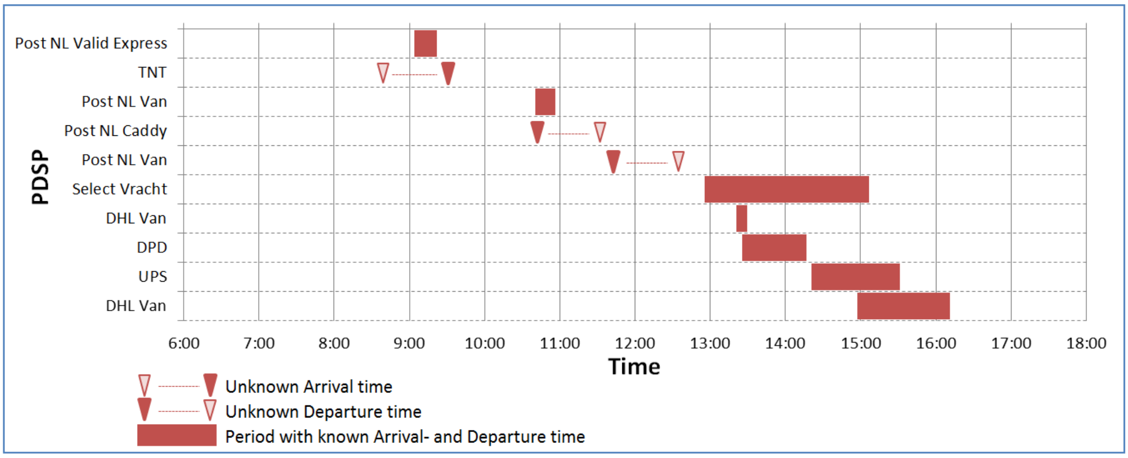


Figure 5.11: Observed PDSP's on Friday May 16, 2014

A remarkable result that emerges from the data, is the missing arrival- or departure time for some deliveries. The underlying cause of these missing data might be attributed to the fact that the PDSP arrived in Millingen aan de Rijn before 06.00h, or departed after 18.00h. Although the results from the questionnaires show that Millingen aan de Rijn is considered a dead-end village near the German border, results from the traffic monitoring data do not confirm that Parcel Delivery Service Providers do drive the same route back to Nijmegen. Instead, they could drive through Germany to continue their route to for instance Groesbeek, a village 15 kilometers south of Millingen aan de Rijn.

Besides the fact that it is important to identify the B2B and B2C small volume movements towards Millingen aan de Rijn for the sake of time management, the actual volumes associated with these movements are also relevant for the sake of capacity management.

5.3.3 Small freight volumes

To determine the small freight volumes for Millingen aan de Rijn, various techniques were applied. To start, national statistics were requested from Thuiswinkel Markt Monitor (B2C). Secondly, interviews were conducted with businesses in Millingen aan de Rijn. Thereafter, interviews were held with PDSPs and finally traffic monitoring data was applied to determine the small freight volumes.

Thuiswinkel Markt Monitor - Statistical results

According to Thuiswinkel Markt Monitor 2014, almost 100 million online purchases have taken place in the Netherlands in 2013 which is an increase of 11% compared to 2012. With almost 11 million people in the Netherlands that have made an online purchase in 2013, this results in on average 9.0 online orders per purchaser. Compared to an average of 8.3 online orders per purchaser in 2012, this represents an increase of 9 percent. In the first quarter of 2014 there were more than 25 million online orders made by more than 10 million purchasers.

From a financial perspective, the average amount spend per purchasing order in 2013 was €109.00, which is a minor decrease of 2% compared to 2011. According to the Thuiswinkel Markt Monitor, this is due to the fact that online purchasers place small orders more often, which decreases the average amount spend per order. Contrary to expectations for 2014, the first quarter of 2014 has shown a major increase in average spending per order of €140.32.

No detailed data about online purchases was available for Millingen aan de Rijn. However, based on the statistics from Thuiswinkel Markt Monitor, it can be assumed that in 2013 generally 65.5% of the total population of the Netherlands made an online purchase. Furthermore, in the first quarter of 2014, on average 2.47 orders per purchaser were made (1.9 product orders, 77%; 0.57 service orders, 23%). Converted for Millingen aan de Rijn with 5876 inhabitants, this results in 562.8 orders per week and therefore 93 orders per day (based on a 6 day delivery week).

Businesses in Millingen aan de Rijn - Interview results

Based in the interview results on volumes per type of delivery, an estimation can be made of the total volume transported towards Millingen aan de Rijn for the interviewed businesses (B2B). The following five types of deliveries can be distinguished:

1. Parcels/crates, 0.1 m^3 per unit;
2. Roll containers, 1 m^3 per unit;
3. Pallets, 1.6 m^3 per unit;
4. Fashion racks, 0.5 m^3 per unit;
5. Unpackaged (e.g. bikes), 1 m^3 per unit.

As Table 5.1 shows, a weekly total volume of 443 m^3 is transported. However, these interview results will be considered to a lesser extent for the desired passenger and freight integration system due to the fact that 86 % of the total volume is for Albert Heijn, most volume cannot be considered as small volume, and data is derived from only 11% of the total businesses in Millingen aan de Rijn.

Type	Average m³	Amount per week	Total m³ per week	Amount per day	Total m³ per day
Parcels/Crates	0.1	150	15.0	25	2.5
Rolcontainers	1	390	390.0	65	65.0
Pallets	1.6	14	23.0	2	3.8
Fashion racks	0.5	0	0.0	0	0.0
unpackaged (bikes)	1	15	15.0	3	2.5
Total			**443.0**		**73.8**

Table 5.1: Delivery volume of participated businesses in Millingen aan de Rijn

Parcel Delivery Service Providers - Interview results

To validate the number of small volumes which flow towards Millingen aan de Rijn for both B2B as well as B2C, data was collected by interviews with Parcel Delivery Service Providers. Subsequently this data can be used together with traffic monitoring data as input for a mathematical model for volume calculations.

Interview results from DHL Express show that the daily route starts with an average truckload (type of vehicle: van) of 40%, of which 4% is destined for Millingen aan de Rijn. During 2 to 3 stops, DHL Express delivers a mere 2 to 3 parcels per day in Millingen aan de Rijn.

Contrary to DHL Express who delivers only B2C, PostNL delivers B2C as well as B2B. For PostNL this resulted in daily 200 parcels for Millingen aan de Rijn (Full truckload, FTL), without indicating a time frame and number of stops in which these parcels are normally delivered. Furthermore, UPS has indicated it delivers between 40 and 60 parcels per day, with 15 to 30 stops within a time frame of 1 hour.

Concerning the parcels to be picked up from Millingen aan de Rijn, PostNL has indicated it has a maximum of 15 parcels per day. UPS mentioned a maximum of 5 pick-up parcels, which is far less than the number of parcels delivered to Millingen aan de Rijn.

From the data of DHL Express and UPS, it can be concluded that the number of parcels per stop in Millingen aan de Rijn is respectively 1 and 2.2. The figures for PostNL are unknown. This results in a total average of 1.6 parcels per stop. Moreover, DHL Express delivers on average 1 parcel per 6 minutes in Millingen aan de Rijn, while UPS delivers 1 parcel per 1.2 minutes which is attributable to a higher number of parcels per stop. This results in on average 3.6 minutes per parcel. Finally, the number of parcels daily delivered by DHL Express (2.5), PostNL (200), and UPS (50) sums up to 252.5.

Traffic monitoring data - calculation results

According to the traffic monitoring data, the presence of a PDSPs in Millingen aan de Rijn varies between 9 minutes up to 4 hours and 18 minutes. With the information gathered by the questionnaires, it can be assumed that an average of 3.6 minute per parcel is maintained as standard. To calculate the number of parcels delivered per trip, the following formula is applied:

$$\frac{T_D - T_A}{M_P} = \frac{\delta T}{M_P} = \text{Parcels delivered in trip}$$

Where:

- T_A = Arrival time
- T_D = Departure time
- M_P = Minutes per parcel

As mentioned before, data is missing regarding arrival- and/or departure times, which results in unknown elapse times. Listwise deletion of these cases will result in a substantial decrease in cases available for volume calculations. Mean substitution, in which missing values are replaced by the average of the observed values, will cause biased results. This is due to the fact that some aspects of the distribution (variances and correlation coefficients) are altered (Schafer and Graham, 2002). However, it is a relatively simplified approach and the before mentioned altered aspects of the distribution will not be taken into account in the simulations. The following formulas generate arrival times respectively departure times by means of substituted elapse times:

Missing arrival time (T_A) respectively *Missing departure time* (T_D)

$$T_A = T_D - \overline{\delta T} \qquad T_D = T_A + \overline{\delta T}$$

Taken this into consideration for all trips, this leads to a daily average of 185 parcels (Table 5.2 and Table 5.3), 222 parcels on Tuesday and 147 parcels on Friday.

Parcel delivery service provider	Arrival time	Departure time	Elapse time	# Parcels
Post NL Valid Express	8:38	12:56	4:18	72
TNT	**7:59**	9:28	**1:28**	25
TNT Express	**8:03**	9:32	**1:28**	25
Post NL	10:50	11:07	0:17	5
Selectvracht	11:13	13:24	2:11	36
Post NL	11:59	**13:27**	**1:28**	25
UPS	13:27	14:10	0:43	12
DPD	14:09	15:15	1:06	18
Transmission	15:10	15:28	0:18	5
Total			**13:19**	**222**

Table 5.2: Calculated amount of parcel deliveries on Tuesday May 6, 2014

Parcel delivery service provider	Entry time	Departure time	Elapse time	# Parcels
Post NL Valid Express	9:04	9:22	0:18	5
TNT	**8:42**	9:35	**0:52**	15
Post NL Van	10:41	10:57	0:16	4
Post NL Caddy	**10:42**	11:35	**0:52**	15
Post NL Van	11:42	**12:34**	**0:52**	15
Select Vracht	12:56	15:07	2:11	36
DHL Van	13:21	13:30	0:09	2
DPD	13:26	14:17	0:51	14
UPS	14:21	15:32	1:11	20
DHL Van	14:58	16:12	1:14	21
Total			**8:48**	**147**

Table 5.3: Calculated amount of parcel deliveries on Friday May 16, 2014

Due to a desired integrated passenger and freight transport system to the rural area of Nijmegen, it can be of importance to take into account the villages in between Nijmegen and Millingen aan de Rijn as well for the volume calculations. This concerns Ooij, Erlecom, Leuth, and Kekerdom. Although the total volume of other villages depends on several aspects such as the level of business activities and distribution of population by age, the daily demand for small volume is determined as a ratio of the number of inhabitants. This results in the following ratios:

Village	# inhabitants	Ratio
Millingen aan de Rijn	5876	1.00
Kekerdom	500	0.09
Leuth	1650	0.28
Erlecom	580	0.10
Ooij	2035	0.35
Total	**10641**	**1.81**

Table 5.4: Volume ratio villages in-between Nijmegen and Millingen aan de Rijn

Conclusion small freight volumes

With the statistical results from the Thuiswinkel Markt Monitor, interviews with Parcel Delivery Service Providers, and the volume calculation extracted from traffic monitoring data, an overall picture of small volume for Millingen aan de Rijn can be made. There is no reason to assume that one technique is more crucial for the estimation of the total volume of small freight than others. Therefore, the average is taken from the results of the different techniques. Subsequently, the total flow of small volume towards the rural area of Nijmegen can be calculated with the use of the ratios. This results in a daily average of 319.9 parcels. A summary of small volumes towards Millingen aan de Rijn, including the villages along the route, is shown in Table 5.5.

Village	# inhabitants	PDSP	Traffic Monitoring	CBS	Average
Millingen aan de Rijn	5876	252.5	184.5	93.0	176.7
Kekerdom	500	21.5	15.7	7.9	15.0
Leuth	1650	70.9	51.8	26.1	49.6
Erlecom	580	24.9	18.2	9.2	17.4
Ooij	2035	87.4	63.9	32.2	61.2
Total	**10641**	**457.2**	**334.1**	**168.4**	**319.9**

Table 5.5: Total small volume for the rural area of Nijmegen

Trends in E-commerce

With worldwide annual sales up to $ 1,251 trillion in 2013 (B2C), an increase of 18.2% compared to 2012, e-commerce is a rapidly growing market. As reported by the Emarketer's latest forecasts (eMarketer, 2014), the worldwide B2C e-commerce will increase for at least the upcoming three years. The major underlying aspects of this forecasted increase are the rapidly expanding mobile user base in emerging markets, upcoming mobile-commerce (which includes trade by use of smart phones and is supported by E-commerce), the growing trust in security, on-time delivery, and the internationalization by major brands.

Data from Thuiswinkel Markt Monitor 2013[1] shows that not only on global scale the e-commerce market is increasing, also the Dutch B2C e-commerce market has shown an increase of 8.5% of sales up to 10.6 billion in 2013. In the first quarter of 2014, 3.63 billion is spent on online purchases of which 42% on products and 58% on services (e.g, insurance, airline tickets, and flower delivery).

5.3.4 Conclusion of freight transport

In conclusion, different techniques were applied to gain more insight in the current freight transport of small volumes towards Millingen aan de Rijn. Traffic monitoring showed that inflow as well as outflow of freight transport is currently stable. Furthermore, interviews with businesses within Millingen aan de Rijn provide evidence that transport vans are currently the most used type of vehicle, that most deliveries are in the morning between 09.00h and 13.00h, and that there are on average 10 deliveries each week. These findings highlights that the main volume can be categorized as large volume, which is beyond the scope of this research. Subsequently, due to the small sample size, caution must be taken. These business interview results will not be taken into account in further calculations, since the response rate was too low to generally conclude about the small volumes destined for Millingen aan de Rijn. However, this data can be relevant for practical implementation and further elaboration of the desired integrated system.

Interview results with PDSPs together with traffic monitoring data offer powerful evidence that optimalisation within parcel delivery is possible. Currently, the majority of PDSPs have small amount of parcels for this rural area which possibly can be consolidated. Contrary to the expectation, PDSPs do not always see Millingen aan de Rijn as a dead-end village, and continue their routes through Germany to Groesbeek.

Furthermore, although no specific data was available concerning current daily small freight volumes towards the rural area of Nijmegen, with the use of different techniques, the daily amount of small volume is expected to be approximately 320 parcels.

The worldwide B2C e-commerce is and will increase for at least the upcoming three years. This will immediately influence the total small volume deliveries, which is relevant to take into consideration for a viable desired integration system.

Next chapter outlines the public transport towards the rural area of Nijmegen.

5.4 Public transport

To verify whether an integrated Passenger & Freight transportation system is viable, besides an analysis of the freight transport, a review of the current public transport of the research area is a prerequisite. A field study in Millingen aan de Rijn and in other villages in the rural area of Nijmegen revealed that most common public transport modes are line buses and taxis (no train network). Although taxis are not merely public transport, throughout this research, both line buses and taxis are considered as public transport. Therefore, the public transport is divided into two categories namely: line buses and taxis.

[1] https://www.thuiswinkel.org/data/uploads/marktonderzoeken/thuiswinkel_markt_monitor/Infographic_Thuiswinkel_Markt_Monitor_2014_1.pdf

5.4.1 Line buses

On January 1, 2001 a major change took place in the public transport sector. Before this moment, the majority of the public transport companies were owned by the authorities, since then WP2000 (Law Passenger transport) was introduced and concessions in public transport have taken place. In this case, public transport is split up by region or connection subsequently tendered to commercial passenger transport companies. These temporary and fully exclusive rights create competition within the market. This monopoly position both comes with rights and obligations. Depending on the concession the carrier either has to pay for this position or get paid by the authorities.

Concession for the bus connection between Nijmegen and Millingen aan de Rijn has been granted (09.12.2012 - 10.12.2022) to Hermes (Connexxion) who drives by the brand name *BRENG*. Currently, line 80 is the general bus line which drives every half hour throughout the day visiting Nijmegen, Beek-Ubbergen, Ooij, Erlecom, Leuth, Kekerdom, and Millingen aan de Rijn (Figure 5.12). All stops are highlighted with red pins. Current duration of a trip with line 80 from Nijmegen Central Station to Millingen City hall (central) is 36 minutes. Furthermore, line 82 accommodates the peak hours in the morning (06.00 - 08.30) and end of the afternoon (14.45 - 18.00). However, line 82 skips Ooij and Erlecom (Figure 5.13). Line 82 has significantly fewer stops compared to line 80. Therefore, a trip with line 82 from Nijmegen Central Station to Millingen City hall takes 25 minutes.

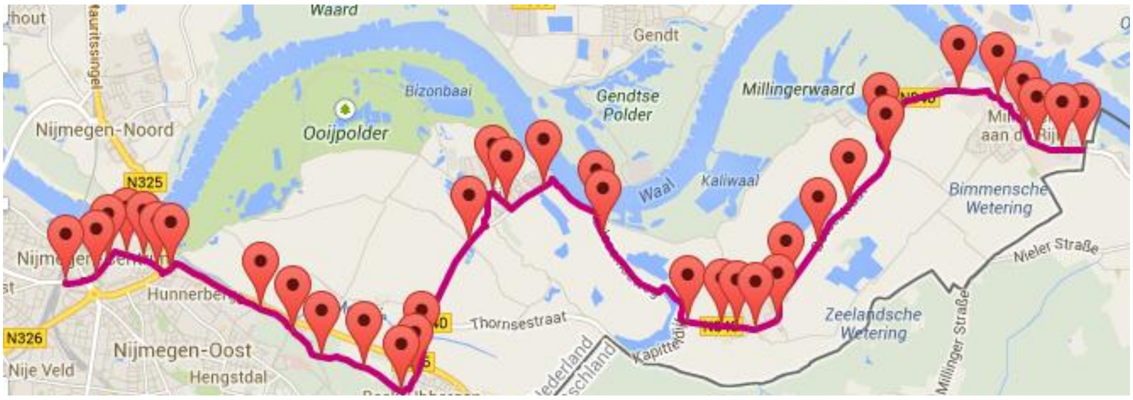


Figure 5.12: Bus route 80

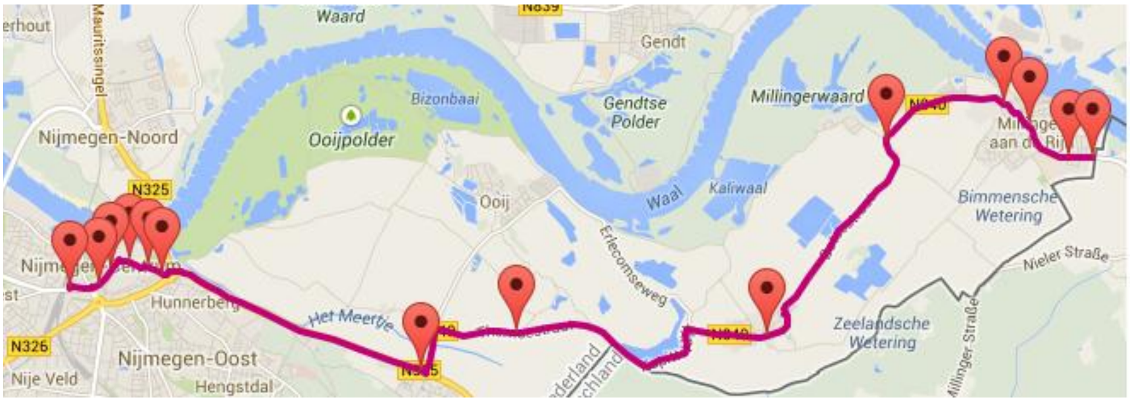


Figure 5.13: Bus route 82

In view of the desired situation to integrate passengers and freight, and therefore with the underlying idea to transport freight with public transport, data is collected in respect to the utilizations of line buses. During the traffic monitoring days at Millingen aan de Rijn, also bus utilizations were measured.

The results shown in Figure 5.14 and Figure 5.15 reveal that these bus utilizations follow the same pattern as private traffic. To the extent that in the morning, outflow utilizations are significantly higher than inflow utilizations. Subsequently between 14.00h and 17.00h the inflow utilizations are significantly higher than the outflow utilizations. Despite this trend, both figures show that the actual utilization rates are never equivalent to the maximum capacity of 28 seats (different types of buses are identified with seats varying between 28 and 36. For the sake of simplicity, the lower bound is taken into account).

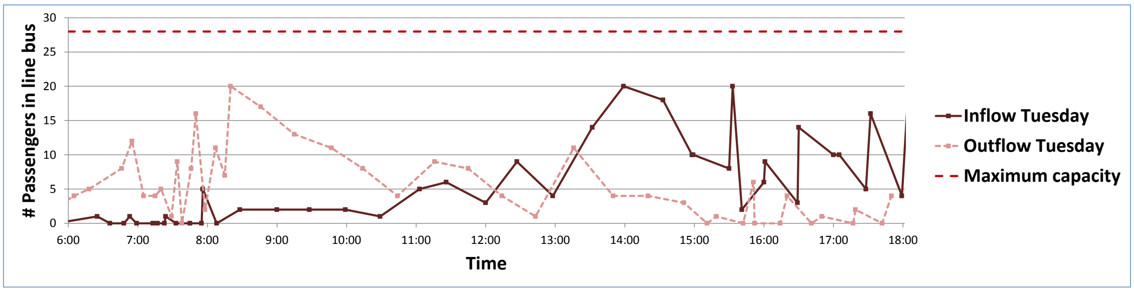


Figure 5.14: Bus utilization on May 6, 2014

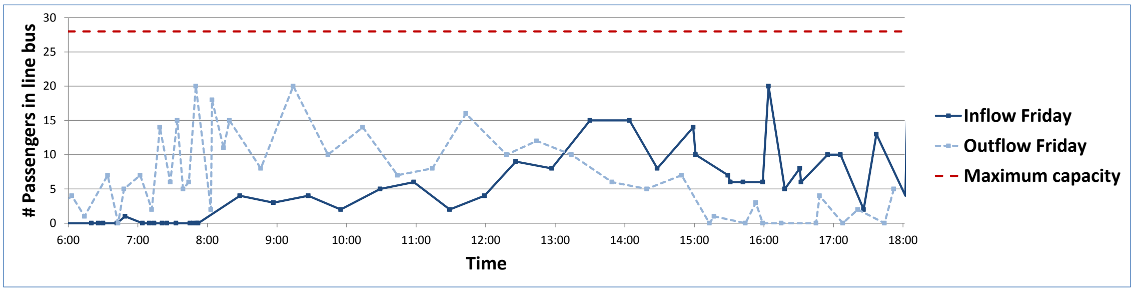


Figure 5.15: Bus utilization on May 16, 2014

However, on the one hand, it is important to know the utilization rate of line buses at the arrival in Millingen aan de Rijn, on the other hand, other important data to take into consideration is the utilization rate of line buses at the departure in Nijmegen towards Millingen aan de Rijn, more specifically at the point where parcels destined for Millingen aan de Rijn can be placed in the line bus, to confirm that empty space is available for freight. Therefore, due to the traffic density at the innercity, the best possible place where parcels can be placed in the line bus, is at the border of Nijmegen where the line bus leaves the city. Figure 5.16 shows the arrival utilizations of line buses from the innercity at Nijmegen Hunnerpark and the departure utilizations from Nijmegen Hunnerpark to Millingen aan de Rijn.

As can be seen, although the graph shows different peaks during the day, on average there is empty space available almost the entire day (for parcels towards Millingen aan de Rijn), with exception of 13.00h.

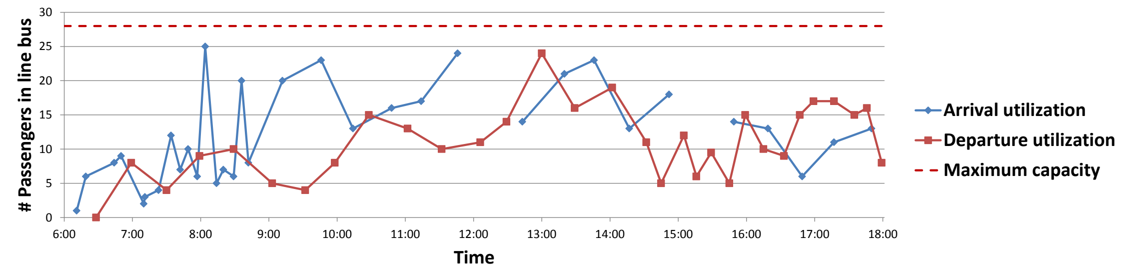


Figure 5.16: Bus utilization Nijmegen on June 27, 2014

5.4.2 Taxi services

As mentioned before, the second category of public transport are taxis. Although it is public transport, the major difference between line buses and taxis is the fact that the taxi driver knows in advance which passengers should be picked up, that it does not have a fixed route with fixed arrivals, and that trip tariffs are mostly higher compared to line buses. Nevertheless, due to the geographical location of Millingen aan de Rijn, it is expected that most taxi rides from Millingen aan de Rijn will visit, or at least drive through, Nijmegen. During the traffic monitoring days, taxi buses with a capacity between 7 and 9 persons are identified. Traffic monitoring data showed that taxi services from- and towards Millingen aan de Rijn are mainly carried out by a few companies. Approximately 80% of all trips are conducted by three taxi companies namely, Taxi Millingen (located in Millingen aan de Rijn), Leenders Passenger Transport (located in Ooij), and Munckhof (located in Nijmegen).

The results shown in Figure 5.17 and Figure 5.18 offer powerful evidence that the inflow to- as well as the outflow from Millingen aan de Rijn is far from an optimal utilization, in that on average 60.8% and 60.0% of all trips for respectively inflow and outflow have no utilization. The trend that also occurs with taxi services, is the outflow peak around 08.00h and an inflow peak between 12.30h and 15.00h, and can be assigned to school transport.

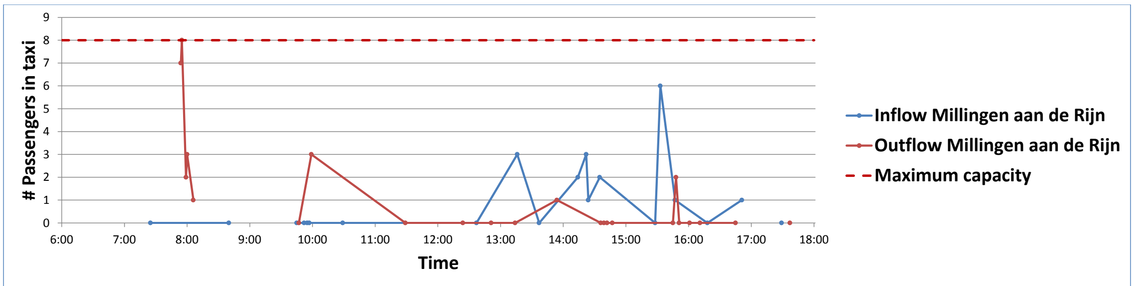


Figure 5.17: Taxi utilization on May 6, 2014

An interview approach was selected for the three above mentioned taxi companies in order to gain information about taxi trips from- and towards the rural area. The most striking result to emerge from the interviews is that taxis are eagerly looking for alternative ways to make profit. Already in the first 8 months of 2014, 44 taxi companies went bankrupt due to the cuts by government in care transport[2]. Furthermore, the municipalities become

[2]http://www.gelderlander.nl/algemeen/economie/bezuinigingen-zorg-worden-taxichauffeurs-fataal-1.

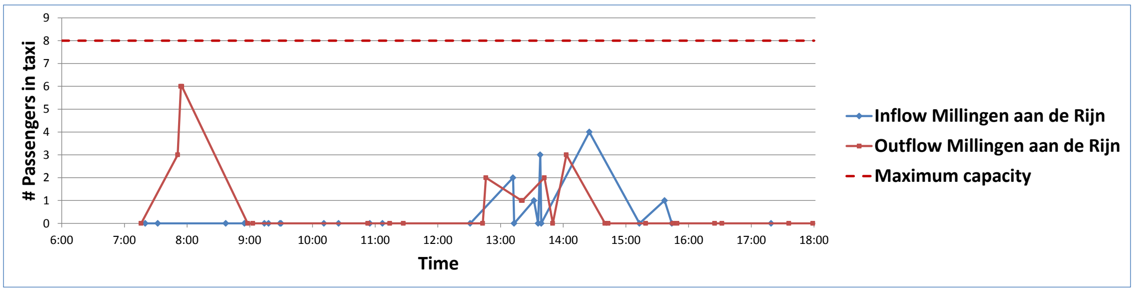


Figure 5.18: Taxi utilization on May 16, 2014

more rigorous and the WMO-indication is tightened which leads to less taxi trips. Also insurers increasingly lower trip fees which directly influence the financial outcome. This highlights the potential usefulness of an integrated passenger and freight transportation system for taxi services. Further results of these interviews can be seen in Chapter 6.2.3.

5.4.3 Conclusion of public transport

With the results from traffic monitoring data, there is strong evidence to support that these transport modes do not operate at maximum capacity. These results highlight that buses have to adhere to the fixed driving periods of 30 minutes. However, with the current utilization rates, the profitability is at stake. Similar to buses, traffic monitoring data offer powerful evidence that taxi services also have low utilization rates. Along with the budget cuts that are made to the transport of vulnerable students, disabled people and the elderly, taxi companies diligently looking for ways to keep their business profitable.

5.5 Conclusion of the current situation

To summarize, the current situation of transport towards Millingen aan de Rijn is divided into two main parallel sectors namely, Freight Transport and Public Transport.

Currently, the freight transport of small volumes towards the rural area of Nijmegen can be optimized. From interviews with local businesses, it can be concluded that their main volume cannot be categorized as small volume. However, all participating businesses do have sporadic small volume deliveries. Due to the low response rate, results from interviews with local businesses will not be taken into account for the desired situation. The results can be seen as additional information.

Traffic monitoring data along with information from interviews with Parcel Delivery Service Providers confirms the assumption that transport vans are far from FTL (Full Truck-Load) for last mile delivery. On average 10 transport trips have been observed during the traffic monitoring days, where elapse times vary between 9 minutes up to 4 hours and 18 minutes.

Different techniques are deployed to gain more information about current volumes towards Millingen aan de Rijn. Trends in B2C E-commerce shows that the worldwide e-commerce will increase for at least the upcoming three years which indicates that small volume deliveries will also increase. Thuiswinkel Markt Monitor also forecasts an increase within

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the e-commerce market and calculated that in the first quarter of 2014, on average 2.47 orders per purchaser are made. Converted for Millingen aan de Rijn, this sums up to 93 orders per day.

From interviews with Parcel Delivery Service Providers which focus on both B2B as well as on B2C, this number of small volume is much higher. According to them, daily delivery demand for Millingen aan de Rijn sums up to 252.5 parcels.

Furthermore, traffic monitoring data along with information from interviews with Parcel Delivery Service Providers not only reveal that the transport vans do not drive FTL, the calculations also show that small volume towards Millingen aan de Rijn is on average 185 parcels per day.

Therefore, to come to a conclusion regarding the small volume towards the total rural area, the average of the different techniques with ratio's for the other villages are used and this results in a daily demand of 319.9 parcels.

For public transport, the bus line and taxis are elaborated in more detail to identify current routes, driving times, and utilization rates. Generally speaking, both transport modes have utilization peaks of outflow in the morning and inflow in the late afternoon.

Overall, the utilization rate is surprisingly low, which indicates that the evidence from this study points towards the idea that improvement can be made by integrating passengers and freight towards the rural area of Nijmegen. The next chapter outlines the desired situation in which passengers and freight transport flows are integrated for the rural area of Nijmegen.

Chapter 6

Desired situation

"The main objective is to design integrated people and freight synchromodal transportation networks and related planning and scheduling policies to enable efficient and reliable delivery of each parcel and retail delivery."- Project plan Cargo Hitching (Eindhoven University of Technology, Univerisity of Groningen, University of Twente, 2012)

By integrating passenger- and small volume freight flows for rural areas in the Netherlands, it is expected that utilization and efficiency of deliveries increases and simultaneously keeping public transport viable (Eindhoven University of Technology, Univerisity of Groningen, University of Twente, 2012). Relevant literature acknowledges potential benefits of integrating passengers and freight transportation systems, however little research has been done concerning the modelling of this innovative system (Chapter 3).

Computational experiments on integrating passenger and freight transportation have been performed in 2013 by Li et al. (2014). The obtained numerical results provided valuable insights in successful ride sharing system for taxi services and small volume delivery. Furthermore, Ghilas et al. (2013) proposed an arc-based mixed MIP formulation in which they focused on transport planning. It can be concluded from this research that integrating passenger- and freight flow leads to reduced operational costs, decreased CO_2 emissions, and reduced traffic density in urban areas.

Petri Nets have been used in several applications: Manufacturing, data collection and processing, protocols and logistics. van der Aalst (1992) reported on developments in the field of logistics at the time, which have complicated the management of the logistic processes. He concluded that there is a need for an integrated framework for the modelling and analysis of logistic systems and that Petri Nets can offer this solution. Furthermore, it is shown that Petri Net modelling is a powerful technique used to study passenger flows and optimize procedures (Bouyekhf et al. (2003), Takagi et al. (2003)). Besides the fact that Petri Nets are useful in passenger transport, it has also proven its usefulness in transshipment processes of cargo handing at container terminals (Maione and Ottomanelli (2005), Silva et al. (2014)). Due to the usability and high level of visual representation of Petri Nets in transportations, this method is used for the modelling and visual representation of an integrated passenger and freight transportation system.

This chapter is organized as follows. The first section provides a brief overview of possible hitching modes in which a decision is made which hitching modes will be taken into account. Secondly, a simulation model is proposed. A brief explanation is given concerning arrivals of Parcel Delivery Service Providers, line buses, and taxi services. In addition, formulations are given for the output parameters. Thirdly, the results obtained from the simulation model are reported. Various analyses are executed to examine whether capacity problems arise, as well as potential consequences in delivery times. Section 4 outlines the performed sensitivity analysis. Subsequently, Section 5 presents the potential benefits when the integrated passenger and freight transportation system will be fully operational for the rural area of Nijmegen. Thereafter, legislation on integrating passengers and freight flows are examined. Finally, conclusions are stated in Section 7.

6.1 Conceivable hitching modes

Preliminary work on existing shared solutions was carried out in 2010 by Trentini and Mahléné (2010). To shift passengers and goods from private transport to other urban transport modes, Trentini and Mahléné (2010) identified four currently integrated solutions, namely: shared buses, shared subway, shared tramway, and shared 'car sharing services'. According to the research of Li et al. (2014), combining people and parcel flows using taxis is also a feasible hitching possibility. Furthermore, Vis (2014) supplements the list of conceivable hitching scenarios for parcels with meal services, medication delivery services. However, these hitching scenarios focus on integration of small volume flows with current freight flows rather than integration of small volume flows with passenger flows.

As mentioned in Chapter 5, line buses and taxis operate as public transport in the rural area of Nijmegen. This paper addresses how to integrate passenger and small volume freight flows with current line buses and taxis. An overview of the considered desired situation, compared to the current situation (Figure 5.9), is shown in Figure 6.1.

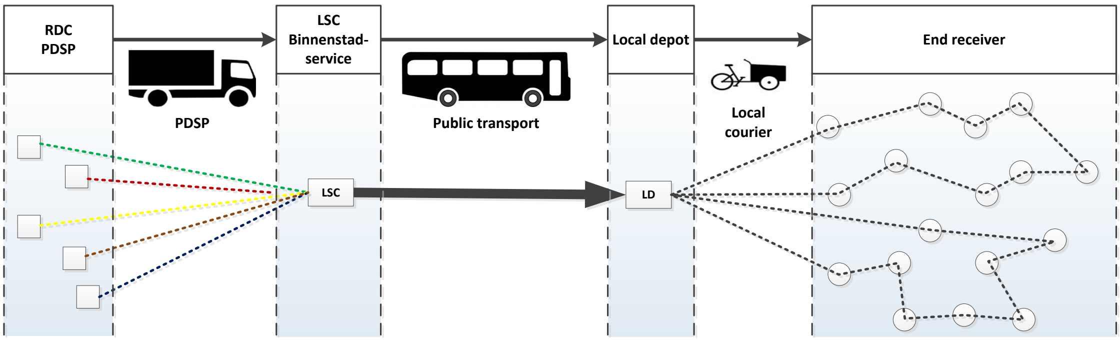

Figure 6.1: Illustration of desired last mile network with multiple PDSPs

6.2 Simulation model

This section proposes the simulation model in which small volume freight is hitched with the current bus line and taxi services towards Millingen aan de Rijn. An overall planning is generated for small volumes that arrive at the Logistic Service Center (LSC) in Nijmegen, to verify if this desired system will work properly with the current supply and demand. Additionally, small volume demand is included as variable to check to which extent the system can operate correctly,

$$Daily\ demand = D_r = 350, 400, 450, \ldots, 800\ parcels$$

For every amount of demand, 10 independent tests were carried out to validate the state of the system (where r is day 1, 2, 3, ...)

The following data are extracted from the simulation model: *(i)* undelivered parcels (one day delivery), *(ii)* inventory levels at the LSC in Nijmegen, *(iii)* utilization levels transport modes, and *(iv)* waiting times for parcels at the LSC.

First of all, descriptions and assumptions of parcel arrivals and volumes are given. Secondly, descriptions and assumptions of bus arrivals are given and thirdly, descriptions and assumptions of taxi services. Afterwards, calculation formulas are developed in order to gain above mentioned extracted outcomes.

6.2.1 Parcel delivery services

As mentioned before, within the desired transport network, Parcel Delivery Service Providers will deliver their small volumes destined for the rural area of Nijmegen to the LSC in Nijmegen. At the LSC these deliveries are consolidated and subsequently further distributed by public transport towards the rural area. Two types of arrivals at the LSC are taken into account, namely uniformly distributed arrivals and a more realistic distributed arrivals (from now on *realistic distribution*). Uniformly distributed arrivals is applied when no information of arrivals is available. In other words, the possibility of an arrival is equally distributed over the day. Realistic distributed arrivals are applied with the expert opinion of Mrs. Hendriks from Logistic Service Center *Binnenstadservice Nijmegen*. The following general parcel arrival assumptions are made:

- *Arrival interval.* Due to the fact that from traffic monitoring data the arrivals took place approximately between 09.00h and 15.00h (see Figure 5.10 and Figure 5.11). The arrival interval at the LSC is assumed to be between 09.00h and 15.00h.
- *Number of Parcel Delivery Service Providers.* Also from traffic monitoring data, the number of PDSPs on Tuesday and Friday were respectively 9 and 10. Therefore, the number of deliveries at the LSC is fixed to 10.

Uniform distribution

Arrivals of the 10 Parcel Delivery Service Providers follow a uniform distribution between 09.00h and 15.00h as can be seen in Figure 6.2. The number of packages which are delivered by a specific Parcel Delivery Service Provider follows a uniform distribution between the following bounds:

$$\text{Lower bound} = \frac{E(D_r)}{PDSP} - 5 \qquad\qquad \text{Upper bound} = \frac{E(D_r)}{PDSP} + 5$$

Where:

- $E(D_r)$ = Expected demand [Parcels/day]
- $PDSP$ = Number of Parcel Delivery Service Providers

Due to this lower- and upper bound, the daily total volume that arrive at the LSC does not have to be exactly D_r, however is close to the daily demand.

Realistic distribution

In an interview with field expert Mrs. Hendriks from Binnenstadservice the Netherlands, it is argued that rather than using an uniform distribution it might be more useful to follow a more realistic distribution as Figure 6.2 indicates.

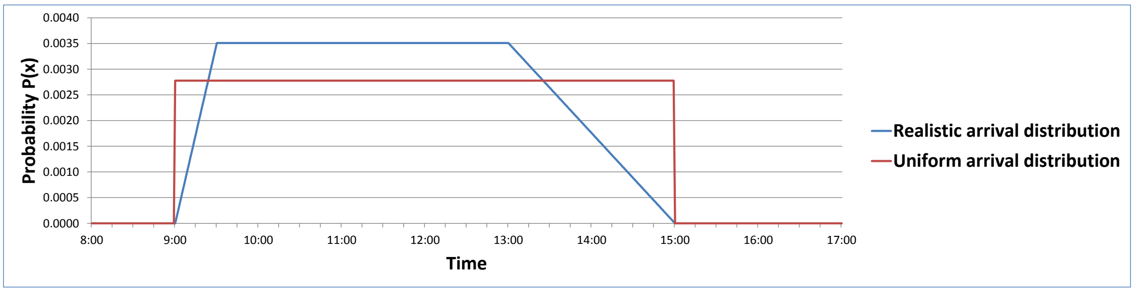

Figure 6.2: Small volume arrival distributions at the LSC

As can be seen in Figure 6.2, the peak in deliveries is between 09.30h and 13.00h which assumes that on the one hand the number of parcels that cannot be delivered will decrease, on the other hand, waiting times of parcels at the LSC can increase. Compared to the uniform distribution, in this case, the arrival times are fixed to 10 arrivals equally divided during the day. An example of a calculation of parcel arrivals with a demand of 350 parcels can be seen in Appendix D.1. Due to the fixed arrival times of PDSPs, the possibility distribution is calculated per parcel. Therefore, the difference compared to the uniform distribution is that with this more realistic distribution, at the end of the day, exactly D_r has arrived at the LSC.

6.2.2 Line buses

Current concession for bus transport towards the rural area of Nijmegen has been granted to BRENG, part of Connexxion. As mentioned before, Line 80 towards Millingen aan de Rijn operates throughout the entire day, Line 82 operates in the morning for commuters to Nijmegen and in the afternoon back to Millingen aan de Rijn. From an operational point of view, small volumes can be integrated in public transport from *Nijmegen Hunnerpark*. At the point the bus leaves the city. The main reason to choose this point, is that small volumes destined for Millingen aan de Rijn does not necessarily have to be driven into the innercity. In this way, difficulties with parking are avoided. Arrival times of fixed scheduled Lines 80 and 82 at *Nijmegen Hunnerpark* can be seen in Table 6.1.

Although traffic monitoring results offer powerful evidence that bus utilizations on average are relatively low, peak moments are observed in which small volume cannot be integrated. Therefore, integration of small volume in line buses can only take place from 06.00h to 12.15h and from 13.15h to 16.15h which can be seen in Figure 6.3.

Arrival Time *Nijmegen Hunnerpark*	Description	Parcel integration allowed	Arrival Time *Nijmegen Hunnerpark*	Description	Parcel integration allowed
5:58	Linebus 80	yes	12:59	Linebus 80	no
6:28	Linebus 80	yes	13:29	Linebus 80	yes
6:58	Linebus 80	yes	13:59	Linebus 80	yes
7:28	Linebus 80	yes	14:29	Linebus 80	yes
7:58	Linebus 80	yes	14:59	Linebus 80	yes
8:28	Linebus 80	yes	15:29	Linebus 80	yes
8:58	Linebus 80	yes	15:59	Linebus 80	yes
9:28	Linebus 80	yes	16:13	**Linebus 82**	yes
9:58	Linebus 80	yes	16:29	Linebus 80	no
10:28	Linebus 80	yes	16:59	Linebus 80	no
10:58	Linebus 80	yes	17:13	**Linebus 82**	no
11:28	Linebus 80	yes	17:29	Linebus 80	no
11:58	Linebus 80	yes	17:59	Linebus 80	no
12:29	Linebus 80	no			

Table 6.1: Arrival times line buses at *Nijmegen Hunnerpark*

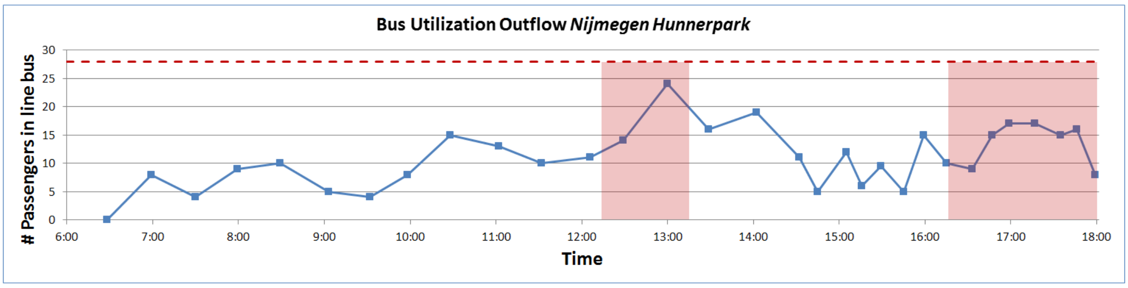

Figure 6.3: Time frame where no small volume integration is allowed

As field expert Mrs. Hendriks has highlighted during an interview, fixing the minimum number of parcels in the bus prevents the LSC to make practically empty trips. In addition, maximum capacity is assumed to be fixed to one roll container which is equivalent to 60 parcels according to optimalisation expert Mr. Sassen from UPS. Consequently, during off-peak moments, available capacity in line buses is fixed to a lower limit of 30 and an upper limit of 60.

6.2.3 Taxi services

A different approach is chosen for taxi arrivals. This is due to the irregular driving times and unknown routes. Rather than using the traffic monitoring data, interviews were conducted with *Taxi Millingen* (located in Millingen aan de Rijn) and *Leenders Personenvervoer* (located in Ooij) to gain information regarding regular taxi trips and possibilities to integrate small volumes in their planning.

Table 6.2 provides an overview of trips of Taxi Millingen and Leenders Personenvervoer with associated capacities in which small volumes can be integrated. In addition, the minimum capacity is assumed to be 0 for reason that the additional kilometers that the taxi services have to drive to pick-up small volumes at the LSC is negligible since they drive through Nijmegen anyway. For taxis it is argued that, when possible, small volume is picked up when no passengers are in the taxi. In this way, passengers encounter minimal delay. Consequently, for the simulation model, arrival times are uniformly generated.

Taxi Millingen				
# Trips	Arrival time	Capacity Sprinter	Capacity Transit	Capacity Car
2	Between 08.00h and 09.00h	240 parcels	-	-
4	Between 08.00h and 09.00h	-	180 parcels	-
2	Between 08.00h and 09.00h	-	-	20 parcels
2	Between 14.00h and 15.00h	60 parcels	-	-
4	Between 14.00h and 15.00h	-	60 parcels	-
2	Between 14.00h and 15.00h	-	-	60 parcels
4	Between 09.00h and 13.00h & 16.45h and 18.15h	120 parcels	-	-

Taxi Leenders				
# Trips	Arrival time	Capacity Sprinter	Capacity Vito	Capacity Car
4	Between 09.30h and 10.00h	240 parcels	-	-
1	Between 09.15h and 09.30h	-	40 parcels	-
1	between 08.45h and 09.15h	-	-	0 parcels

Table 6.2: Overview taxi arrivals at LSC with associated available capacities

6.2.4 Formulations

To gain results for the parameters mentioned, the following notations are introduced. Parallel to which are used up to now, new notations are added.

t	=	an index of period, t = 1, 2, ..., k so t =1 represents minute 1
i	=	an index of PDSP, i = 1, 2, 3, ..., n, so 10 represents total number of PDSPs
j	=	an index of Public transport, j = 1, 2, 3, ..., m so j = 1 represents the first available bus/taxi
$E(D_r)$	=	expected demand of small volume towards rural area at day r
D_r	=	actual demand of small volume towards rural area at day r
U_{it}	=	amount of small volume arrived from PDSP i at time t
B_{jt}	=	amount of small volume (utilization) transported by Public transport j at time t
I_t	=	Inventory position at the LSC at time t
LL	=	Lower Level, fixed at 30 for line buses, fixed at 0 for taxis
UL	=	Upper Level, fixed at 60 for line buses, variable for taxis

Table 6.3: Table of Notations

Notice that utilization levels of public transport at time t depends on the inventory position at time t, the utilization level is given by

$$B_{jt} = \begin{cases} I_t, & \text{if } LL \leq I_t \geq UL \\ 0, & \text{if } I_t < LL \\ UL, & \text{if } I_t > UL \end{cases}$$

The amount of small volume that arrive at the LSC and at the same day is delivered to the rural area can be represented as

$$D_r = \sum_{i=1}^{n} \sum_{t=1}^{k} U_{it}$$

Small volume that arrived at the LSC however could not be delivered to the rural area within the same day, are the leftovers at the LSC and can be expressed as

$$\sum_{i=1}^{n} \sum_{t=1}^{k} U_{it} - \sum_{j=1}^{m} \sum_{t=1}^{k} B_{jt}$$

The index of period measured for 1 day is from 09.00h to 18.30h. In other words, $t = 1, 2, ..., k$ where $k = 571$ (minutes). The total number of PDSPs that arrive at the LSC is fixed to 10 ($n = 10$). Furthermore, the available trips of public transport j varies between line buses and taxis. 21 trips are available with line buses ($j = 21$) and taxis have 26 trips available for integration of small volume($j = 26$).

The inventory position at the LSC at time t is the inventory position at time $t-1$ plus a potential small volume arrival of a PDSP minus a potential arrival of Public transport to delivery B amount of small volume to the rural area.

$$I_t = I_{t-1} + \sum_{i=1}^{n} U_{it} - \sum_{j=1}^{m} B_{jt}$$

Finally, the average waiting time of small volume at the LSC can be measured. Waiting time can be negatively influenced when arrivals of PDSPs and public transport are not aligned. Hence, the average waiting time is

$$\frac{1}{D_r} \cdot \sum_{t=1}^{k} I_t$$

6.3 Computational results

This section presents results from the simulation model. The software applications used to model coloured Petri Nets and to perform the analyses were CPN Tools 4.0.0 2013 and Microsoft Excel 2010®. Planning integration with Petri Nets has been done using CPN Tools 4.0.0. Appendix C Figure C.1 and Figure C.2 illustrates the planning integration model for line buses and taxis. Microsoft Excel 2010® was used to generate results from the planning concerning undelivered parcels, inventory positions at the LSC, transport utilizations, and waiting times. First of all, results of small volume integration with line buses are shown, followed by the results of small volume integration with taxis. For the sake of brevity, results are shown for a daily demand of 350 (current demand), 550, and 800 parcels.

6.3.1 Small volume integration with line buses (uniform distribution)

Figure 6.4 shows undelivered small volume for a planning horizon of 1 working day. Therefore, this volume remains at the LSC. According to the figure, the first test that failed to deliver all small volume within the planning horizon happened at a demand of 550 parcels. As can be seen, the higher the demand, not only more tests fail to deliver all parcels, also amount of undelivered small volume increases. It is worthwhile to note that an exponential growth can be observed when the average of all tests is taken. A numerical approach proves that the maximum daily capacity of the system is 780 parcels (#bus trips $\cdot$ capacity per bus $= 13 \cdot 60$).

Parcels that are not delivered within one day, do have the possibility to be delivered next day. Three line buses are available in the morning (07:58h, 08:28h, and 08:58h), after that, bus lines are not available for additional deliveries. Moreover, if after 08:58h inventory is positive, these parcels are no longer delivered.

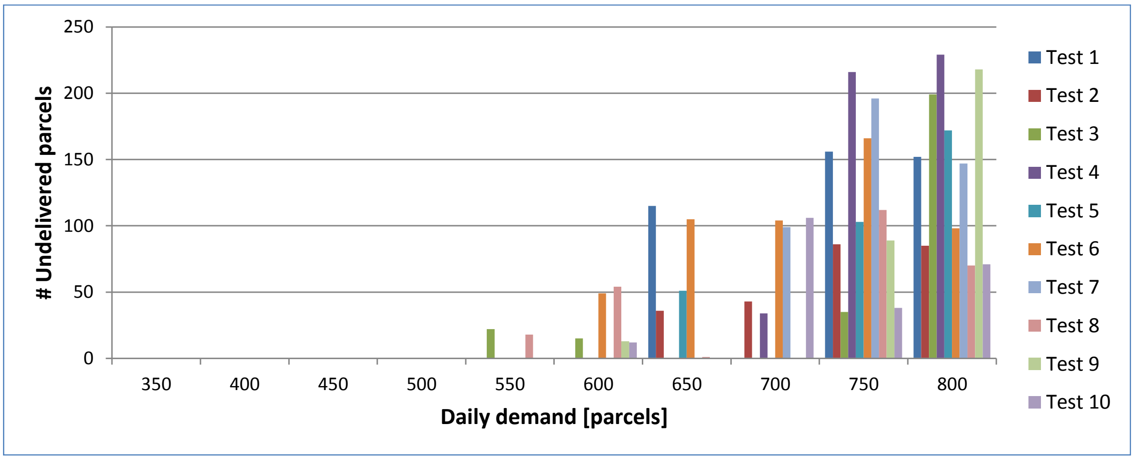

Figure 6.4: Undelivered parcels remaining at LSC after one working day

The LSC in Nijmegen serves as a consolidation center where supply and demand of small volumes are matched. Due to inevitable mismatches, inventory builds up which fluctuates during the day. Figure 6.5 presents the inventory positions at the LSC (time unit of one minute). As shown, inventory is built up to a certain level and decreases when a line bus arrives at the bus station. Furthermore, it can be clearly seen that due to capacity restrictions for the line bus, inventory is built up between 12.00h and 13.30h.

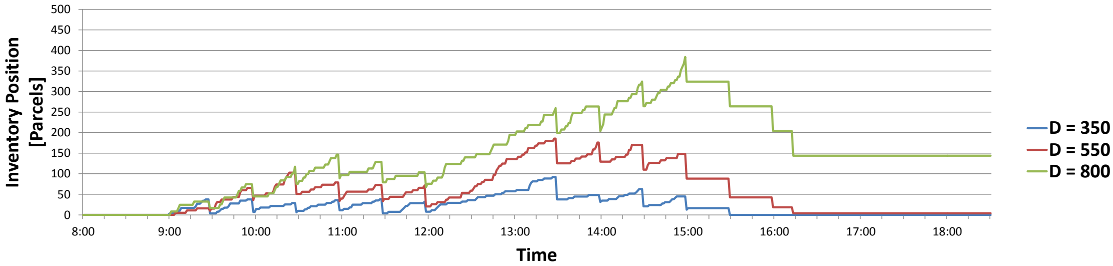

Figure 6.5: Inventory positions at the LSC

In addition to the inventory positions, Figure 6.6 shows the utilizations of the bus line for small volumes. As the demand increases, the utilizations also increase to the maximum capacity of 60 parcels per trip. Moreover, with a daily demand of 800 parcels, the system will (depending on arrivals) make use of all capacity and still unable to deliver all parcels within the planning horizon.

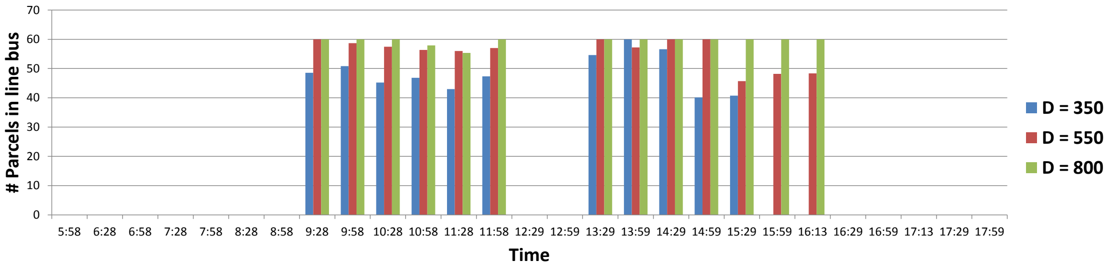

Figure 6.6: Small volume utilization in public transport

Finally, waiting times of small volumes at the LSC are extracted from the simulation. Figure 6.7 provides insights for an exponential growth trend as the demand increases. With the current daily demand of approximately 350 parcels, the average waiting time for a parcel at the LSC is 35 minutes. Although Figure 6.7 shows an exponential growth, some simulation tests reveal crucial information that waiting times already goes to infinity for a daily demand of 750 parcels and 800 parcels due to undelivered parcels after additional delivery. The tests which shown that demand could not be met, are not taken into account in Figure 6.7.

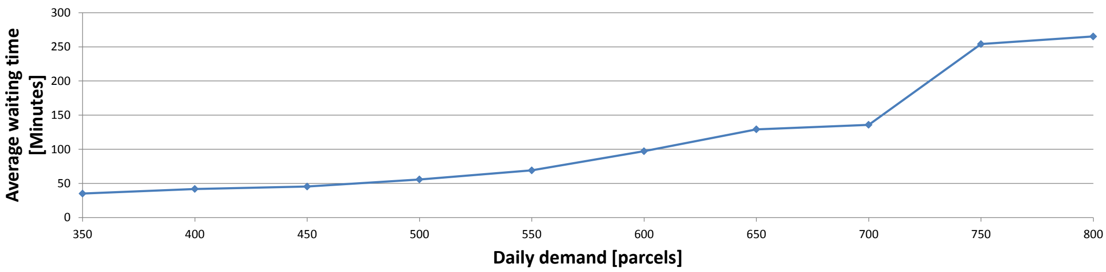

Figure 6.7: Waiting time parcels at the LSC(including next day delivery)

6.3.2 Small volume integration with line buses (realistic distribution)

It is expected that with the realistic distribution, the system will improve compared to an uniform distribution. Moreover, probabilities of arrivals between 09.30h and 13.00 are increased which assumes that more time is left to deliver small volume within the planning horizon. Figure 6.8 offers powerful evidence for this assumption as a decrease in undelivered small volume can be observed. In fact, where the uniform distribution system starts to break down from a daily demand of 550 parcels, the realistic arrival distribution system work properly and major breakdowns start at a daily demand of 750 parcels. Besides the number of breakdowns, also the amount of undelivered parcels are tremendously decreased.

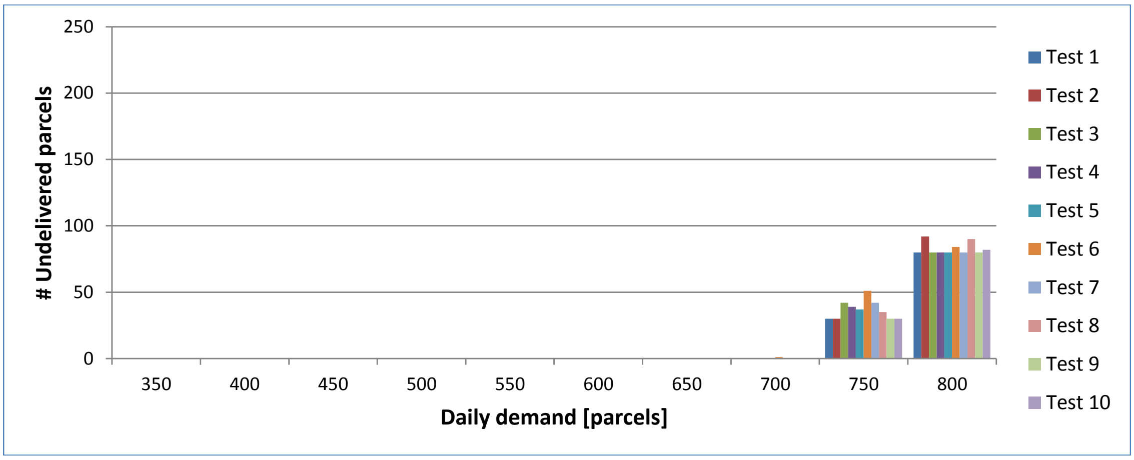

Figure 6.8: Undelivered parcels remaining at LSC after one working day

Figure 6.9 presents inventory positions with a realistic distribution. As can be seen, results from the simulations are more stable compared to the uniform distribution. This is caused by the fixed arrival times for Parcel Delivery Service Providers. A notable result is that the type of arrival distribution does not influence the level of inventory. Both distributions have a peak of approximately 375 parcels at a certain moment in time. Although no significant difference was observed between the level of inventory, the timing of this peak is shifted forward due to earlier small volume arrivals by the realistic distribution.

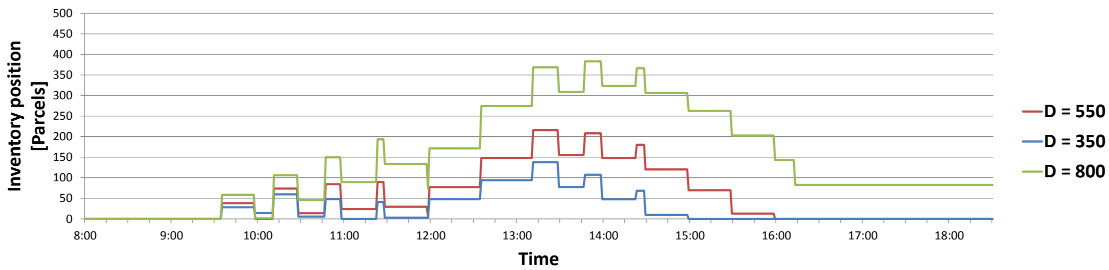

Figure 6.9: Inventory positions at the LSC

Figure 6.10 shows the utilization of the bus line for small volumes with the realistic distribution. The figure shows that with low demand, capacity at the end of the day is unused. Also with a daily demand of 550 parcels, compared to the uniform distribution, the realistic distribution uses less of the capacity at the end of the day. This leaves a reasonable capacity for being able to deal with future growth in e-commerce.

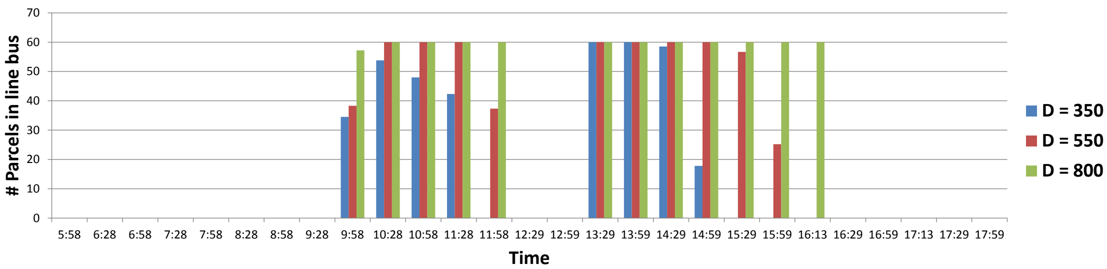

Figure 6.10: Small volume utilization in public transport

Figure 6.11 illustrates the waiting time per parcel for different demands with a realistic distribution. Also for this distribution, waiting times grows exponentially as demand increases, however, less rapidly compared to the uniform distribution. Furthermore, the undelivered parcels at the end of the working day are all delivered the next day. Hence, no small volume is stuck in the system.

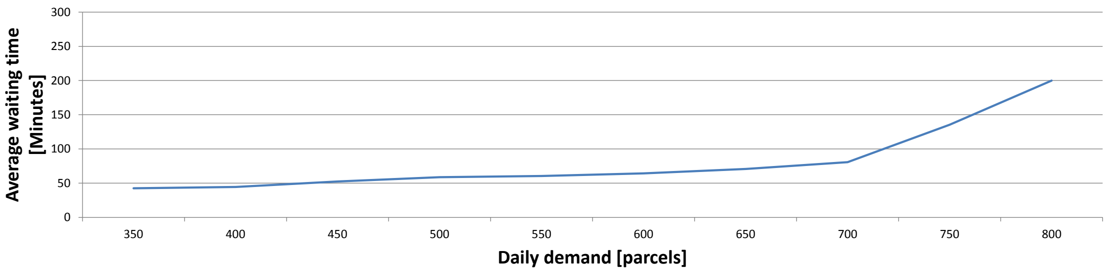

Figure 6.11: Waiting time parcels at the LSC(including next day delivery)

6.3.3 Small volume integration with taxis (uniform distribution)

Results for integration of small volume with current taxi trips are expected to be different from the results for integration of small volume with current line buses. Taxis are more flexible and do have available capacity in trips with arrival times that cannot be achieved by line buses (in the late afternoon). Also, the available capacity is more flexible and varies between 0 up to 240 parcels per trip. To note, the last taxi trip take place around a quarter past 5 and has available capacity for 120 parcels (twice the available capacity compared to line buses). Therefore, it is assumed that integration of small volumes with current taxi trips will lead to less undelivered parcels and a better working system for high demand compared to line buses.

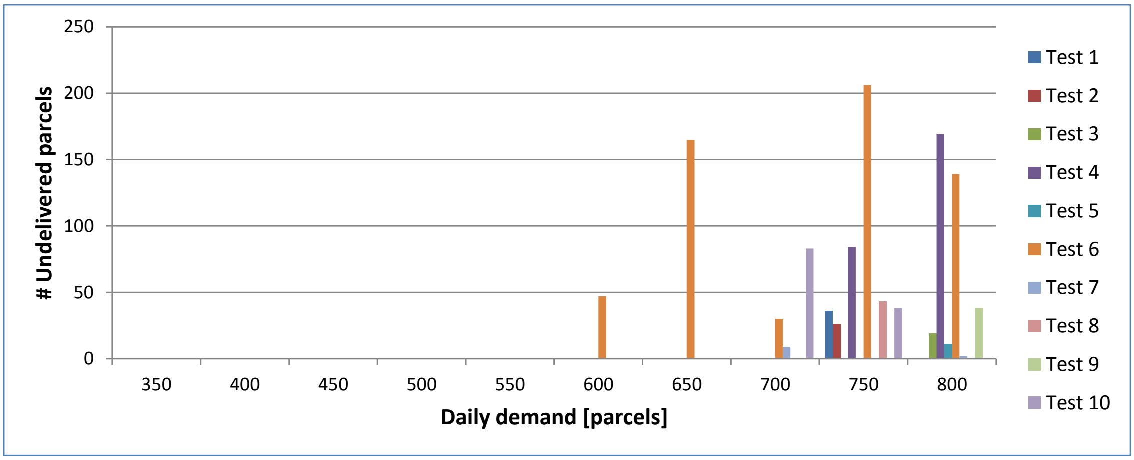

Figure 6.12: Undelivered parcels remaining at LSC after one working day

Figure 6.12 shows the undelivered parcels under different demand. Results show that in Test 6 with a daily demand of 600 parcels, delivery of all parcels starts to fail. However, more tests show failures to deliver all parcels from a daily demand of 700 or higher. The most remarkable results to emerge from the data is that although there are taxis with available capacity up to 240 parcels, the timing is far from ideal, because these taxis are available between 08.00h and 10.00h. This is when the taxis have empty return trips due to dropped off schoolchildren. Parcels arrive between 09.00h and 15.00h and therefore, this is a mismatch between supply and demand which cannot be changed. Regardless, it is noteworthy that despite this mismatch, this system seems to operate more efficiently (concerning undelivered parcels) with high demand compared to integration of small volume with line buses (Figure 6.4).

As Figure 6.13 confirms, due to the large available capacity between 08.00h and 10.00h, inventory positions at the LSC are declining and in most cases are even 0. From this point forward, inventory increases to a maximum of 310 parcels at 14.00h. Subsequently, between 14.00h and 15.00h several taxis are available again followed by a break until 17.00h. Thereafter, one or two taxi trips make it possible to deliver between 120 and 240 parcels in a trip. Due to the break between 14.00h and 15.00h, the average waiting time will increase which will be discussed further on in this section.

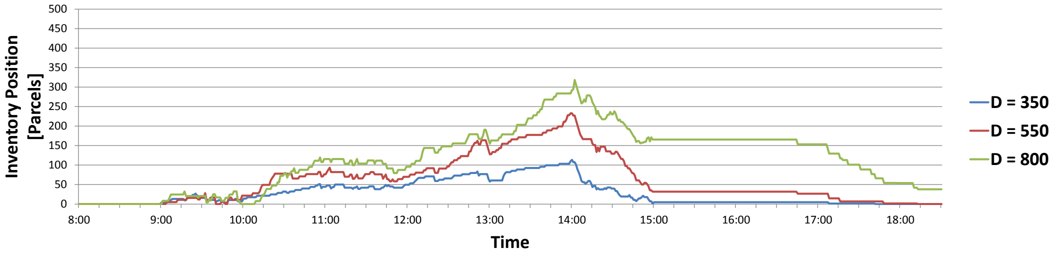

Figure 6.13: Inventory positions at the LSC

As aforementioned, mismatching takes place due to the fact that available capacity in the morning cannot be utilized, while in the afternoon, parcels get stuck in the system due to capacity problems. This mismatch is illustrated in Figure 6.14. First nine taxi trips do have capacity, however, no parcels are at the LSC to deliver to the rural area.

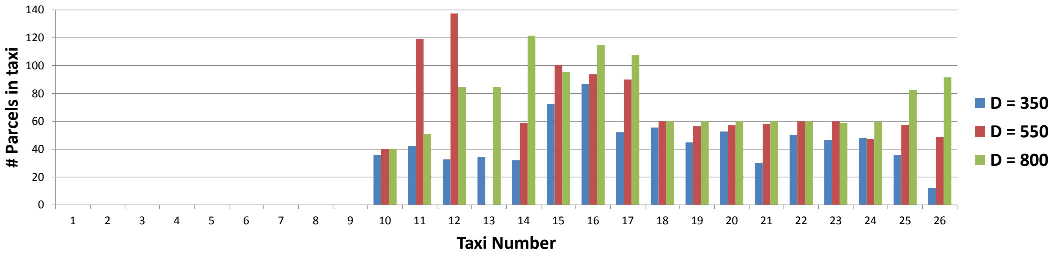

Figure 6.14: Small volume utilization in public transport

As can be seen in Figure 6.15, for the current situation of 350 parcels, waiting time at the LSC for available transport capacity is 50 minutes. This is comparable to the waiting times when integrated with the bus line. More striking is the further development when demand is increased. Despite the break between 14.00h and 15.00h, waiting times only slightly increase to a maximum of 120 minutes. This is mainly due to the small amount of undelivered parcels, which prevents that parcels have to wait to next day and which causes long waiting times.

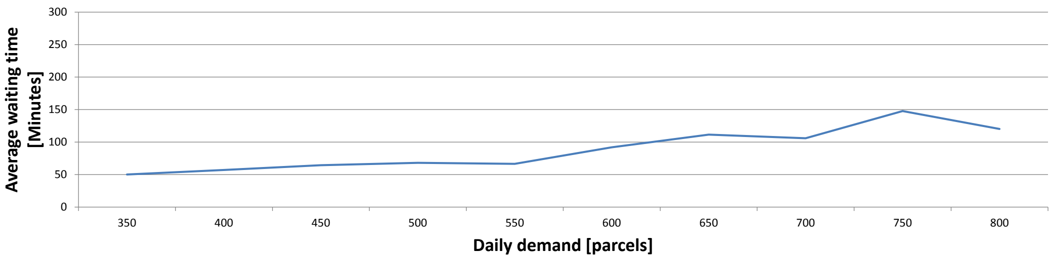

Figure 6.15: Waiting time parcels at the LSC(including next day delivery)

To conclude, according to the results of the integration of small volumes with taxis under an uniform distribution, the current daily demand of 350 parcels easily be delivered to the rural area by taxi. Even if the daily demand will increase to 600 parcels, the system will work properly. However, as mentioned before, it is assumed that the system will work even better with the realistic distribution. These results can be seen in the following section.

6.3.4 Small volume integration with taxis (realistic distribution)

For integration of small volume with line buses, it seems that a realistic arrival distribution gives better results. This section will discuss if this also applies to integration of small volume with taxis.

Figure 6.16 shows the undelivered parcels for a realistic distribution of parcel arrivals and with an integration with taxis. As can be observed, although the first undelivered parcels are identified for a daily demand of 650 parcels, the majority of tests show that inventory is build up from a daily demand of 750 parcels. Therefore, compared to the uniform distributed arrivals, it shows equivalent results regarding the starting point of failure. However, the number of undelivered parcels in the last situation is significantly lower. This provides a more efficient system compared to the uniform distributed parcel arrivals. Furthermore, compared to the integration of small volumes with line buses, these results are less stable due to the results of test 4 and test 6.

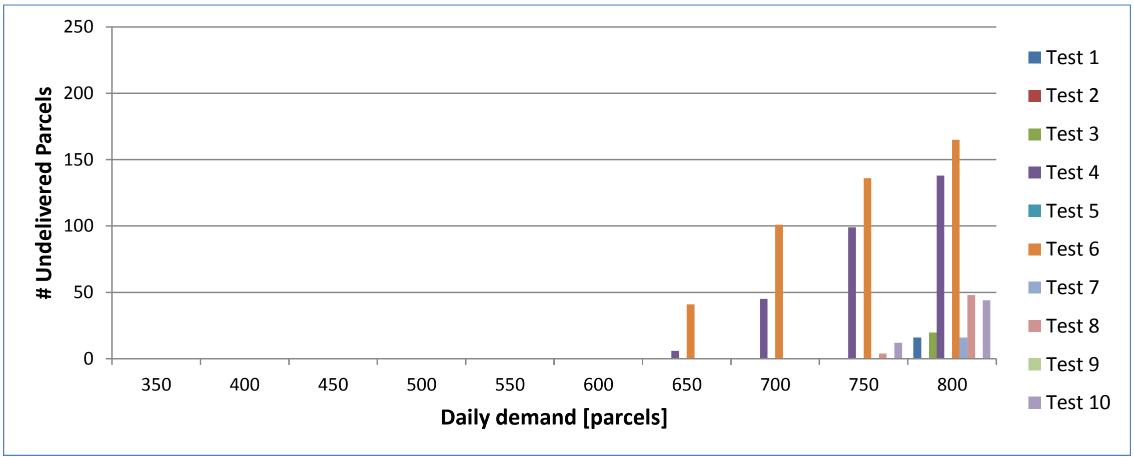

Figure 6.16: Undelivered parcels remaining at LSC after one working day

Figure 6.17 shows the inventory positions at the LSC. Interestingly, where the inventory increases to a maximum of approximately 475 parcels at 14.00h for this distribution, maximum inventory for the uniform distribution was 310 parcels at 14.00h. This finding highlights that the realistic distribution does not always give better results for all parameters. Underlying cause can be found in the arrival process in combination with the available capacity. Although parcels arrive earlier on the day with the realistic arrival distribution, at the same time, mismatch takes place as a result of non-available capacity. Moreover, this leads to increased inventory due to unnecessary early arrivals of small volume.

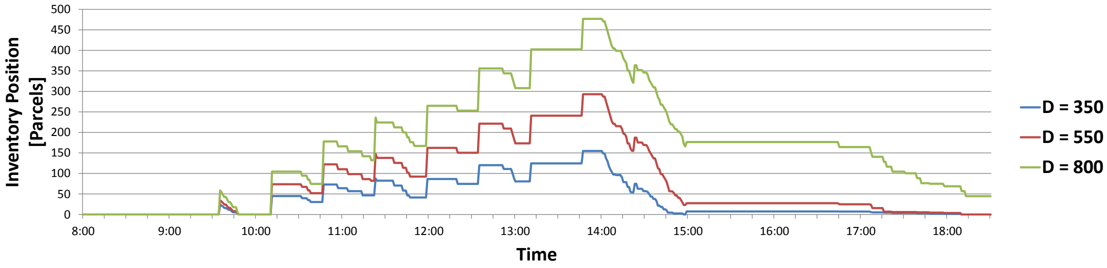

Figure 6.17: Inventory positions at the LSC

As Figure 6.18 shows, also with a realistic arrival distribution, available capacity in the morning cannot be utilized due to the time frame of small volume arrivals. Results provided from the simulation model show that taxi services can handle the daily demand properly up to 750 parcels, from this point forward, also last trips at the end of the afternoon are fully utilized.

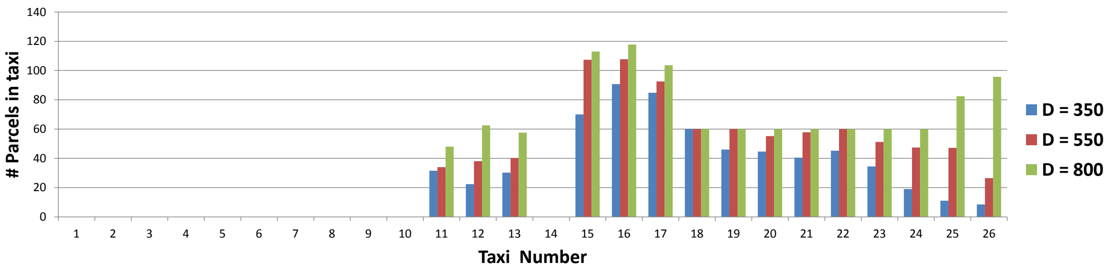

Figure 6.18: Small volume utilization in public transport

Finally, Figure 6.19 shows the waiting time per parcel including next day delivery. An exponential growth can be observed which more quickly increases compared to uniform distributed arrivals. This demonstrates that early arrival of parcels is only useful if simultaneously capacity is available. Moreover, although all undelivered parcels are delivered next day, mismatch results in increased waiting times of up to 180 minutes per parcel, compared to 125 minutes when parcels arrive according to an uniform distribution.

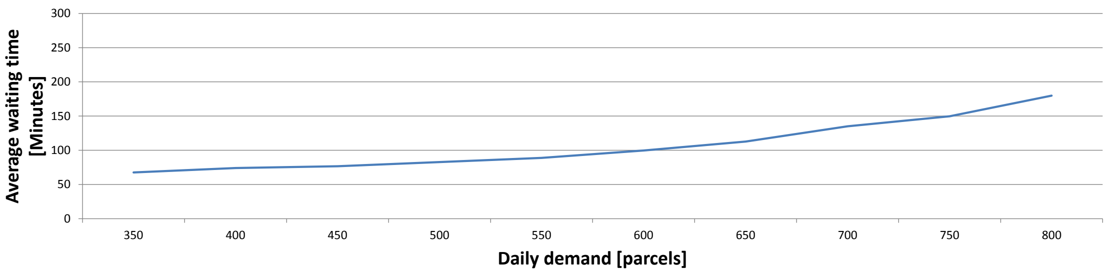

Figure 6.19: Waiting time parcels at the LSC(including next day delivery)

6.4 Sensitivity analysis

Results of the simulation model shows that for the desired situation, under given conditions, line buses as well as taxis are both potential modes for integration of passengers and small freight volumes. However, the success of the system is subject to a variety of influences of this current situation (e.g. adjustments in bus arrivals, PDSP arrivals, volumes, and capacities). Moreover, a sensitivity analysis should provide insights on whether the system is sensitive or relatively stable when assumptions are adjusted.

Several assumptions are made for the simulation model. However, it is rather time-consuming to change all variables for both transport modes. For the sake of simplicity, it is chosen to focus on bus line capacity with the realistic distribution due to their current fixed capacity of 60 parcels per trip. This is the weakest assumption. To determine whether changes in capacity have effect on the system as a whole, capacity is adjusted to 50, 55, 65, and 70 parcels per trip for the current daily demand of 350 parcels, as well as for the daily demand of 800 parcels.

At first, as can be expected, the system improves when capacities are increased. However, results offer compelling evidence that an increased available public transport capacity has significantly more effect when small volume demand is high. In case of a daily demand of 350 parcels and a capacity of 50 parcels per trip, all tests show that the system can deliver all parcels within the 1 day time horizon. For a daily demand of 800 parcels and a capacity of 50 parcels per trip, the undelivered parcels sum up to 200 (Appendix E.1).

Secondly, due to the large amounts of undelivered parcels within one day for a high demand, inventory is built up even further to maximum level of 440 parcels at the LSC when capacity is reduced to 50. Furthermore, the discrepancy between a bus line capacity of 50 or 60 parcels per trip results in a compelling difference of 120 parcels at the end of the day. For a low daily demand, this discrepancy has been reduced to zero because all the parcels are delivered within the planning horizon (See Appendix E.2 Figure E.2 and Figure E.3).

The third result from the sensitivity analysis is the adjusted bus line utilizations. Although capacities are increased, for low demand, this extra capacity is only fully utilized for two bus trips after the afternoon break (inventory is built up at LSC). For other bus trips, this extra capacity is redundant. This is in contrast to utilizations for high demand. Practically all bus trips are fully utilized, therefore additional capacity is fulfilled as well which have remarkable results for the efficiency of the system. Improved matching results in less undelivered parcels, and lower inventory at LSC (see Appendix E.3).

Finally, on the one hand, adjustments in bus line capacities have only a slight influence on waiting times at the LSC. On the other hand, an adjustment in daily demand to 800 parcels has a major influence on the waiting times. Moreover, for a daily demand of 350 parcels, the waiting times for parcels at the LSC are 50 minutes and 40 minutes with respectively a bus line capacity of 50 parcels and 70 parcels, hence a difference of 10 minutes. With a high daily demand of 800 parcels , waiting times vary between 350 minutes and 78 minutes with respectively a bus line capacity of 50 parcels and 70 parcels. In other words, an increased bus line capacity of 20 parcels per trip, reduces the average waiting time for parcels at the LSC with 272 minutes (See Appendix E.4).

6.5 Potential benefits

To conclude if an integrated passenger and freight transportation system is viable for the rural area of Nijmegen, potential benefits on different aspects have to be identified. Moreover, potential economic, environmental, and social benefits are identified.

6.5.1 Economic benefits

In the ideal situation, which is calculated in Section 6.3, all trips driven by Parcel Delivery Service Providers in the traditional system are completely eliminated. Moreover, all parcels for the rural area of Nijmegen are delivered by public transport due to ample capacity. Currently, Parcel Delivery Service Providers have permanent employees as well as subcontractors that deliver parcels to consumers. Subcontractors are independent contractors which are deployed by parcel delivery services, and have their own vehicles, and are responsible for their own business.

Figures concerning delivery tariffs of subcontractors paid by Parcel Delivery Service Providers are not disclosed due to the negotiation positions of Parcel Delivery Service Providers. According to the negotiation result of subcontractors and PostNL Parcels (Amsterdam, June 28, 2013), for a route with 145 to 155 planned stops per day (six days per week) the tariff is based on a weekly turnover of €1000.00. If this is considered to be the average, converted to the current daily demand of 350 parcels with an average of 1.6 parcels per stop (Chapter 5.3.3), 219 stops have to be made to deliver current demand. If 219 stops are eliminated from the traditional system, the economic saving gives an indication of the margin to do the last mile delivery with an integrated passenger and freight transportation system. This results in the following margin:

$$\frac{1000\ [\text{€}/\text{Week}]}{(\frac{145+155}{2})\ [\text{Stops}/\text{Day}] \cdot 6\ [\text{Days}/\text{Week}]} \cdot 219[\text{Stops}/\text{Day}] = 243.33\ [\text{€}/\text{Day}]$$

It is worthwhile to note that the majority of Parcel Delivery Service Providers have indicated that they work with region related tariffs. The tariff per stop will therefore be higher due to delivery in a rural area which are characterized by lower stop -density and larger distances between villages.

This potential daily margin of €243.33 should be sufficient for the following activities:

LSC. Is responsible for docking, consolidating, loading and keeping short time inventory.

Public transport. Although the marginal cost for the bus company and the taxi service is nearly €0,- (due to utilization of idle capacity), line buses as well as taxis do have to gain profit by delivering parcels to the rural area.

Last mile delivery. From a central point in villages, distribution have to take place to ensure home delivery. Other potential opportunities are fixed parcel lockers, one pick up point (e.g. community center or library).

To conclude, potential daily margin will be €243.33. Due to the marginal cost of €0,- for public transport, it seem to be economically possible to deliver parcels by integration, however further research with more detailed data is required to determine exactly the financial benefits of an integrated passenger and freight transportation system.

6.5.2 Environmental benefits

From an environmental point of view, the integration of passengers and freight will eliminate approximately 400 driven kilometers a day. In the traditional system, on average, 10 Parcel Delivery Service Providers drive daily to the rural area of Nijmegen. A single trip to Millingen aan de Rijn is 20 kilometers. Due to complete elimination of the Parcel Delivery Service Providers this sums up to 400 kilometers a day(10 trips $\cdot$ 40km). However, from interviews with Parcel Delivery Service Providers (Chapter 5), it has been found that some trips will go to Groesbeek via Germany. Even if all 10 trips will drive via Germany, 300 kilometers a day can additionally be eliminated. Furthermore, for home delivery, additional opportunities can be home delivery by bike courier instead of delivery van. Fixed parcel lockers to serve customers also eliminates delivery vans, hence are more environmentally friendly compared to the traditional system.

These eliminated kilometers, and simultaneously created opportunities to eliminate environmentally unfriendly delivery vans, will reduce not only congestion (less relevant for rural areas), it also reduces CO_2 emissions.

6.5.3 Social benefits

An integrated passenger and freight transportation system takes advantage of the underused infrastructure and provides opportunities for a flexible and affordable service Levofsky and Greenberg (2001). Furthermore, due to this integration, accessibility of the villages can be maintained. This is essential for certain rural population groups (e.g. young, old, or poor).

This opportunity is also confirmed by taxi services who mentioned that nowadays, trip fees for care transport are under pressure. Therefore, taxi services are seeking for other opportunities to survive in this business.

To summarize, combining people and freight can keep public transportation and freight transportation at socially acceptable levels in an economically viable way (Eindhoven University of Technology, Univerisity of Groningen, University of Twente, 2012), and it avoids further isolation of rural areas.

6.6 Legislation on integrating passengers and freight flows

For the integration of passenger and freight transportation to be implemented, it should comply with the Dutch legislations and regulations. Where for freight transport 'Wet Wegvervoer Goederen 2009' (WWG 2009) is applicable (WWG, 2014), for passenger transport, the current applicable law is 'Wet Personenvervoer 2000' (WP 2000)(WP, 2014). Due to integration of these flows, it is questionable to which extent it is permitted by law to:

- Transport freight as public transport for passengers, due to unfair competition with Parcel Delivery Service Providers, required licenses for bus- and taxi drivers and vehicle requirements;
- Simultaneously transport passengers and freight (e.g. safety, priority).

Although currently no legislation is applicable which specifically states the regulations regarding an integrated passenger and freight transport system, 'Wet Personenvervoer 2000' states that taxis are allowed to have non taxi-related business under given conditions. Taxi companies have the right to reclaim their 'BPM' (Taxation of passenger cars and motorcycles) if the car is for at least 90 % used for taxi related transport. Moreover, non taxi-related transport is not subject to the 90% regulation. According to the covenant AII.b between the Tax and Customs Administration and Royal Dutch Transport, this remaining 10 % can be used for freight transport: the collection and delivery of parcels, courier. For line buses, this covenant is not applicable.

In other words, it does not seem completely impossible and prohibited by law. However, further work needs to be performed to establish to what extent integration of passengers and freight flows is permitted by law and what regulations are applicable.

6.7 Conclusion of the desired situation

Integration of passengers and freight transportation systems creates business opportunities, it is expected that utilization, reliability and efficiency of deliveries increases and simultaneously keeps public transport viable (Eindhoven University of Technology, Univerisity of Groningen, University of Twente, 2012). Cargo Hitching takes advantage of the relatively low utilization of current public transport by integrating parcels in public transport towards the rural areas of the Netherlands. Moreover, Cargo Hitching uses available capacity in current trips which are performed anyway. In other words, contrary to general belief, the Cargo Hitching principle does not support that already stationary transport is deployed.

During the overall project, several studies have been published on Cargo Hitching. However, no studies did research practical implementation within a potential rural area in the Netherlands. Due to absence of train and tram, this study focused on Cargo Hitching with current bus line and taxi services. Furthermore, an uniform arrival of parcels as well as a realistic distribution function for arrivals at the LSC are calculated. A simulation model is introduced in which matching supply and demand of parcels and respectively public transport takes place in Nijmegen. With both supply and demand as variables, output is generated concerning undelivered parcels, inventory positions at the LSC, parcel utilization in line buses, and waiting times of parcels at the LSC.

Results have shown that with a current daily demand of 350 parcels, both line buses as well as taxis, overall have ample capacity to meet this demand on time. Both scenarios resulted in zero undelivered parcels, relatively low inventory as well as relatively low waiting time for parcels at the LSC. In addition, waiting times at the LSC do not directly lead to delayed delivery due to the fact that line buses only have one drop per village. It has only 4 drop-off points before Millingen aan de Rijn instead of 210 drops in the traditional system. In general, the realistic parcel arrival distribution function indicates improved results compared to an uniform distribution. This integration system is capable to process 750 parcels a day before structural failures are identified. Moreover, both line buses and taxis independently have enough capacity to accommodate upcoming e-commerce. Combining these two transport modes on the one hand can be an excellent combination due to the mix of constant supply by fixed line buses and the high-capacity and flexible planning of taxi services, on the other hand a combination can process even more parcels.

The sensitivity analysis has shown that with current daily demand of 350 parcels, an adjustment in available capacity in line buses does not critically influence the performance of the system as a whole, contrary to the adjustments in available capacity when daily demand is 800 parcels. A minor increase of maximum capacity from 50 to 70 parcels per trip directly results in major decrease in undelivered parcels, inventory, and average waiting times decrease with a remarkable 272 minutes per parcel.

Potential benefits resulting from the integrated passenger and freight transportation system compared to the traditional system are indicated on economic, environmental, and social grounds. In this study, daily €243.33 is extracted from the traditional system and is the margin in which the integrated system should work. Due to the marginal cost of nearly €0,- for public transport, it is expected that there is high potential that it is financially viable to integrate passenger and freight flows to the rural area of Nijmegen. Furthermore, approximately 400 kilometers of individual transport are eliminated, which not only reduce congestion, it also reduces CO_2 emissions. Finally, combining people and freight can keep public transport viable which is essential for specific population groups.

To conclude, this study provides powerful evidence that it can be useful to integrate passenger and freight transportation flows to the rural area of Nijmegen. It is shown that this system with current supply and demand, and even to a larger extend, is viable and worthwhile at different levels.

Chapter 7

Practical implementation

Now it is shown that there are two scenarios in which it is appropriate to integrate passengers and freight flows towards the rural area of Nijmegen, subsequent steps should have to be made in order to put it into practice.

7.1 Legislations and regulations

As mentioned in Chapter 6.6, more in-depth research has to be done regarding legislation and regulations of the integrated transport system. Practical implementation should always take place within the boundaries of legislations and regulations. If an integrated transport system currently is not possible due to regulations, two options are conceivable. First option is to adjust the current desired system, in such that it complies with the current legal regulations. Second option is to request an amendment. Although this procedure is extremely time-consuming and no guarantee of success, no other options are left if an adjustment of the integrated transport systems does not seem to work.

7.2 Last mile logistics

The integrated passenger and freight transportation system mainly focusses on public transport from Nijmegen towards the rural area. However, the supply chain as illustrated in Figure 6.1 also considers the way small volume arrives at the end receiver. Two main delivery scenarios are conceivable, namely:

- Fixed drop off point: Local library, community center, parcel boxes etc.;
- Home delivery: Local courier service, bike courier, school students etc.

Due to the scope of this study, further work into conceivable scenarios of end delivery should be carried out.

7.3 Pilot

The aforementioned steps suggest several courses of action in order to implement a pilot. When potential implications are overcome, the system is practically designed and a pilot can be run.
This section briefly provides a pointwise potential method that could be applied to run a pilot in the rural area of Nijmegen.

Funding application. Financial help for the start-up phase is desired. There is a probability that the MUG municipality (Millingen aan de Rijn, Ubbergen, and Groesbeek) has a subsidy fund for projects which focus on viability, accessibility and innovation within the community.

Pilot target area. For the sake of simplicity, not all villages in the rural area of Nijmegen should be included in the pilot. Millingen aan de Rijn do have the highest potential as the start-up village for the pilot. This is due to the fact that Millingen aan de Rijn is the research area of this study and therefore, the most accurate information about the current and desired situation is available. If the pilot is a success, other villages within the rural area of Nijmegen can be included in the integrated transportation system.

Pilot target group. As aforementioned, Millingen aan de Rijn is a potential start-up village due to the focus of this study. Next step is the selection of the target group(s). In particular between B2B and B2C. Due to the participation in this study of businesses with the corresponding positive response regarding an integrated passenger and freight transportation system, it could be beneficial to use this group as the pilot target group. With this pilot target group, it can be shown that small volume can be integrated in passenger transport and this can be an introduction when targeting the B2C group.

Pilot target transport mode. This study focused on the integration of small volume with line buses and taxis. Currently, preference for a specific transport mode during the pilot is the taxi. For line buses, disadvantages are the regulations from the CLA for bus drivers which are very strict; Connexxion is large company where decision making for adjustments in the process is difficult and time consuming. This makes it difficult to make temporary adjustments for the pilot, and timing of matching small volume and line buses at the bus station is more difficult compared to matching small volume and taxis at the LSC. An advantage of line bus usage in the pilot is when a person (e.g. student) takes the parcels with him/her and drive with the bus to Millingen aan de Rijn. Arrived in Millingen aan de Rijn, he/she delivers the parcels at the end receiver. In this way, no adjustments have to be made, and no regulations regarding the bus driver have to be taken into account. For taxis, a disadvantage is that taxi drivers have to deliver the parcels to the end receiver themselves, or another method should be applied. An advantage with taxis is that it can pick up parcels at the LSC and no further logistic handling is needed for integration with public transport.

Chapter 8

Conclusion

This paper seeks to address whether an efficient supply and at the same time maintaining accessibility towards the villages in the rural area in the Netherlands is appropriate. After an extensive analysis of the current situation, a simulation model was proposed. With the simulation model, two conceivable scenarios were analyzed, and additional a practical implementation has been provided.

In this chapter, answers to the sub-questions are given, and in addition the main conclusions are given, including an answer on the research question.

What is the current situation regarding passenger transport and freight transport towards the research area?

Millingen aan de Rijn can be characterized as a rural village due to the geographical location in relation to Nijmegen. Furthermore, Millingen aan de Rijn is located at the border with Germany and is categorized as 'underserved urban municipality' by the CBS.

Analysis of the current freight traffic movements shows that different type of freight movements take place. Not only B2B freight, also small volumes for B2B as well as B2C takes place. This analysis mainly focuses on small volumes by Parcel Delivery Service Providers. Traffic monitoring indicates on average 10 small volume delivery trips per day which potentially can be eliminated when integration of small volume flows with passenger flows is executed. In addition, different techniques suggest that more than 175 parcels destined for Millingen aan de Rijn are delivered daily. Converted for the rural area which also includes Ooij, Erlecom, Leuth, and Kekerdom, this sums up to a current daily demand of 320 parcels. Despite that forecasts show that the global e-commerce market is and will increase for the upcoming years, this ratio of number of PDSP movements and volume of parcels suggest that this transport is currently far from optimal.

Current public transport towards the rural area of Nijmegen consists of line buses and taxis. Utilizations of line buses are measured, and a commuting pattern can be observed. In off peak hours, utilizations are relatively low which suggests that space is available for integration of small volume. The same applies to taxis, were utilizations of trips towards the rural area are low or in the majority even zero. In addition, due to budget cuts and relatively low utilizations in public transport, companies seek for new opportunities to make their business more profitable. These findings create opportunities to integrate passengers and freight transportation flows towards the rural area of Nijmegen.

Which scenarios are conceivable with an integrated passenger and freight transportation system?

From the literature, several shared solutions are identified, namely: Shared buses, shared subway, shared tramway, shared trains, shared taxis, and car sharing service. However, for an integration of passengers and freight transportation system, the concept is to use current passenger flows towards Millingen aan de Rijn, and integrate small volume with it. To conclude, scenarios which are conceivable with an integrated passenger and freight transportation system are the current bus line and taxi service.

How should a simulation model for integration of passengers and freight be designed?

Design of a matching and supply simulation model should take several important aspects into account. Firstly, from demand point of view, PDSP's with volumes destined for the rural area which arrive at a certain moment in time at the Logistic Service Center (LSC) in Nijmegen. It shows that these arrivals take place according a more realistic distribution. Secondly, from supply point of view, arrivals at a certain moment in time of line buses or taxis with their corresponding available capacities should be taken into account. When matching aforementioned aspects, indicative parameters are: *(i)* number of undelivered parcels, *(ii)* inventory levels at the LSC, *(iii)* utilization levels for public transport, and *(iv)* average waiting times of parcels at the LSC. The Petri Net modelling technique together with Microsoft Excel 2010® are used for visualization and simulation.

What are potential benefits when integration of passengers and freight transportation systems take place?

Evidence from this study suggests that potential benefits on different aspects are possible. From economical point of view, daily potential margin of €243.33 which can be eliminated from the traditional system, should be sufficient for last mile delivery of small volume towards the rural area. Environmental benefits are expected due to possible daily elimination of 400 kilometers driven by PDSP's. These eliminated kilometers will reduce both congestion and CO_2 emissions. Furthermore, combining people and freight flows can keep public transport and freight transportation economically profitable which has positive influence on the accessibility and social viability of the rural area.

Results from the simulation model show that from operational point of view, at the right time, ample capacity is available for both public transport modes. Furthermore, there is even ample capacity within the integrated passenger and freight transportation system to cope with the expected increase of small volumes in the upcoming years.

How should the practical implementation be designed?

The practical implementation consists of a pilot in Millingen aan de Rijn. However, before being able to run a pilot, information concerning legislation and regulations should be further investigated as well as last mile logistics within the villages should be further developed. With Millingen aan de Rijn as pilot target area, companies as pilot target group, and taxis as pilot target transport mode, the feasibility of integrated passenger- and freight transport can be demonstrated.

By answering the aforementioned sub questions, an answer on the research question can be given.

Is there a scenario in which it is appropriate (operationally, economically, environmentally, and socially) to integrate passengers and freight towards the villages of rural areas which results in a more efficient supply and at the same time maintaining accessibility?

This study provides encouragement for a new way of transport. It can be concluded that, from a matching supply and demand point of view, line buses and taxis are two scenarios in which it is appropriate to integrate passenger and freight flows to the rural area of Nijmegen. Furthermore, it is shown that this new system contributes economically, environmentally, and socially to this rural area. This switch in the transport sector gives lots of opportunities to keep public transport as well as small volume transport viable. It might even be necessary in the long run.

Chapter 9

Limitations and recommendations for future research

This chapter first outlines the limitations of this research. For every limitation, an explanation is given followed by an opportunity for further research. Subsequently, recommendations for future research are made.

9.1 Limitations

It is worthwhile to note the limitations of the study involved in this thesis.

Sample size businesses. The number of the units in the analysis used is too low to generate a general supply profile for Millingen aan de Rijn. No significant numbers from the data could be conducted. A possible explanation for the low response rate from businesses in Millingen aan de Rijn may be that communication through e-mail does not trigger businesses to participate in the study. Although low response rate is not ideal, it does give insights in freight profiles of the participated businesses.

Lack of available data. Based on different methods, an approximation is made when it comes to the volume of small freight towards the rural area of Nijmegen. Data has economic value and together with the fact that this integrated system influence the current PDSP market has been a tradeoff for PDSP's to restraint. Due to the lack of precise data of small volume, this limits the scope of the thesis. Furthermore, due to time-constraints, only two days of traffic monitoring has taken place. An opportunity for further research is to collect more traffic data for different weekdays and investigate if fluctuations can be observed in small volume movements which can impact on the system.

Lack of prior research studies on the topic. Despite the concept of integrating people and freight has been known for a long period of time, little research has been done concerning modelling of it. Little information is available on a systematically approach of this concept, and therefore, this study can be seen as an exploratory study with practical implementations.

Techniques used to collect the data. Several techniques are applied to generate data. Big data is not obtained and therefore data is obtained by self-conducted research which is extremely time-consuming. As a result, the amount of data from traffic monitoring is limited. Finding significant trends and measure change over time is constrained by the due date of this study. However, the present findings might help to trigger further research into integrated passenger and freight transportation flows.

Self-reported data. The self-reported data is limited by the fact that it rarely can be independently verified. Interviews results with experts in different fields are based on opinions and views. Based on interview results, assumptions are made in the simulation model. Future research and practical implementation of the system should validate whether these assumptions correspond to reality.

9.2 Recommendations

This study is the first step towards enhancing the understanding of practical feasibility of an integrated passenger and freight transportation system. The findings throughout the study with the aforementioned limitations suggest the following recommendations and opportunities for future research:

- Future work concentrating on the financial aspect is highly desirable. This should give insight into potential revenue models for different stakeholders and therefore validate if this concept is economically viable.
- The prospect of being able to integrate passengers and freight flows, serves as a stimulus for future research in other rural areas in the Netherlands. More data can lead to more academic research which will increase academic knowledge.
- Simultaneously with aforementioned recommendation to do research in other rural areas in the Netherlands, a pilot project in Millingen aan de Rijn should be set up. During this study, the first connections and contacts are made. Furthermore, detailed data of small volume are known in advance. It is therefore an excellent opportunity to close the gap between academic literature and practical knowledge by running a pilot.

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Appendix A

A.1 Tally Sheet I

	Coach Bus	9 pers ver	Rem. Bus	Trailer	Truck	Pickup Van	Delivery Van	Transporter	Rem. Tr.	Rem. Cars	Taxis	Cars	Motors
06.00-06.15 IN													
OUT													
06.15-06.30 IN													
OUT													

A.2 Tally Sheet II

Occupancy Public Transport

	Coach Buses				Taxis			
	Time	Number	Passengers	In/out	Time	Number	Passengers	In/out
1								
2								
3								
4								
5								
6								
7								
8								
9								
10								
11								
12								
13								
14								
15								
16								
17								
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32								
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36								
37								
38								
39								
40								
41								
42								
43								

A.3 Tally Sheet III

	Descriptions e.g. company names, no predefined vehicles, noteworthy cases	
06.00-06.30		
06.30-07.00		
07.00-07.30		
07.30-08.00		
08.00-08.30		
08.30-09.00		
09.00-09.30		
09.30-10.00		
10.00-10.30		
10.30-11.00		

Appendix B

B.1 Questions for businesses in Millingen aan de Rijn

Characteristics company

1. From which year is your company located at the current location? __________
2. What is the organizational structure of your company.
   - ☐ Franchise
   - ☐ Store
   - ☐ Self employed
   - ☐ Other
3. How many full time employees does your company have (this site)? _______
4. How many part time employees does your company have (this site)? _______
5. What are the opening hours of your company on a regular weekday?
   - ☐ From ___________ am to _____________ pm
6. Between which time can your company take deliveries?
   - ☐ From ___________ am to _____________ pm
7. How often and on which days of the week are your products usually delivered?
   - ☐ Monday ____________________ Deliveries
   - ☐ Tuesday ____________________ Deliveries
   - ☐ Wednesday ____________________ Deliveries
   - ☐ Thursday ____________________ Deliveries
   - ☐ Friday ____________________ Deliveries
   - ☐ Saturday ____________________ Deliveries
   - ☐ Sunday ____________________ Deliveries
   - ☐ Variable ____________________ Deliveries
8. At what time of the day are products usually delivered?
   - ☐ In the morning 7-12 ____________________ Suppliers
   - ☐ In the afternoon 12-18 ____________________ Suppliers
   - ☐ In the evening 18-23 ____________________ Suppliers
   - ☐ Variable ____________________ Suppliers
9. Where do you stock inventory?
   - ☐ Inside the building, in the sales area
   - ☐ Inside the building, in a warehouse
   - ☐ Elsewhere, outside the store
   - ☐ No storage facilities.

Suppliers

10. How many suppliers do you have? ____________Suppliers

11. What type of suppliers do you have?

   - ☐ Retailer ____________________ Suppliers
   - ☐ Wholesaler ____________________ Suppliers
   - ☐ Producer ____________________ Suppliers
   - ☐ Other ____________________ Suppliers

12. Who delivers the goods in general?

   - ☐ Supplier (With own transport)
   - ☐ Network carrier (TNT,DPD, DHL, GLS, UPS)
   - ☐ Cooperating region specialists (Transmission)
   - ☐ Specialized carriers (Centraal Boekhuis, TNT Fashion)
   - ☐ Pick up our self.

13. Can you name your suppliers?

   - ☐ Supplier 1: ______________________ Delivers: ________________________
   - ☐ Supplier 2: ______________________ Delivers: ________________________
   - ☐ Supplier 3: ______________________ Delivers: ________________________
   - ☐ Supplier 4: ______________________ Delivers: ________________________
   - ☐ Supplier 5: ______________________ Delivers: ________________________

14. How many of each type of goods do you get delivered on average per week? And how many do you send? (type of delivery + volume)

   - ☐ Parcels/crates Number received: ______________Number send: ____________
   - ☐ Rolcontainers Number received: ______________Number send: ____________
   - ☐ Pallets Number received: ______________Number send: ____________
   - ☐ Fashion racks Number received: ______________Number send: ____________
   - ☐ Unpacked Number received: ______________Number send: ____________

15. What is the minimum, average and maximum delivery time of the suppliers?

   - ☐ Minimum delivery time _______________
   - ☐ Average delivery time _______________
   - ☐ Maximum delivery time _______________

16. With which type of vehicle do you get delivered?

- ☐ Trailer __________%
- ☐ Truck __________%
- ☐ Small truck __________%
- ☐ Van __________%
- ☐ Car __________%
- ☐ Bike __________%
- ☐ Other... __________%

17. Which part of the delivered goods eventually are send retour?

- ☐ Average percentage ______________________

18. Who picks up the retour goods?

- ☐ Supplier (With own transport)
- ☐ Network carrier (TNT,DPD, DHL, GLS, UPS)
- ☐ Cooperating region specialists (Transmission)
- ☐ Specialized carriers (Centraal Boekhuis, TNT Fashion)
- ☐ Deliver our self.

19. What is your first thought of an integrated Passenger & Freight transport system?

- ☐ Would you make use of this type of delivery?
  ____
  ____
  - Under what condition you do and/or do not?
    ____
    ____
    ____

B.2 Questions for Parcel Delivery Service Providers

Questionnaire Parcel Delivery Service **Duration: ~5 min**

All questions below are related to trips in which also Millingen aan de Rijn is delivered with parcels. Thank you very much for your participation in my research.

1. Name Company: ____________________________ Name: ____________________

2. With which type of vehicle do you deliver parcels to Millingen aan de Rijn?

   ☐ Trailer

   ☐ Truck

   ☐ Small truck

   ☐ Van

   ☐ Car

   ☐ Other namely: ____

3. To which industries do you deliver parcels in Millingen aan de Rijn?

   ☐ Department stores and Supermarkets

   ☐ Daily retail

   ☐ Other retail

   ☐ Fashion

   ☐ Equipment / furniture

   ☐ Horeca / entertainment

   ☐ Services

   ☐ Inhabitants

   ☐ Other namely: ____

4. Which type of deliveries does your company do to Millingen aan de Rijn?

   ☐ Parcels/crates __________%

   ☐ Rolcontainers __________%

   ☐ Pallets __________%

   ☐ Fashion racks __________%

   ☐ Unpackaged __________%

   Total: **100%**

5. How often do you deliver parcels per day / week / month to Millingen aan de Rijn?

   ☐ __________ times per day / week / month

6. How often do you pick up parcels per day / week / month in Millingen aan de Rijn?

   ☐ __________ times per day / week / month

   ☐ Is delivery and pick up in Millingen aan de Rijn usually done in the same trip? **Yes / No**

7. Who are your delivery customers in Millingen aan de Rijn?

   - ☐ ________ (%) Inhabitants of Millingen aan de Rijn
   - ☐ ________ (%) Shopkeepers in Millingen aan de Rijn
   - ☐ ________ (%) Companies in Millingen aan de Rijn
   - ☐ ________ (%) Other ________________

8. Who are your pick up customers in Millingen aan de Rijn?

   - ☐ ________ (%) Inhabitants of Millingen aan de Rijn
   - ☐ ________ (%) Shopkeepers in Millingen aan de Rijn
   - ☐ ________ (%) Companies in Millingen aan de Rijn
   - ☐ ________ (%) Other ________________

9. Who are your pick up customers for Millingen aan de Rijn?

   - ☐ ________ (%) Webshops
   - ☐ ________ (%) Retailers
   - ☐ ________ (%) Wholesalers
   - ☐ ________ (%) Producers
   - ☐ ________ (%) Other

10. Around what time do you usually enter Millingen aan de rijn, and around what time do you usually exit Millingen aan de Rijn?

    - ☐ Time of entry: ____________________
    - ☐ Time of exit: ____________________

11. How full is your vehicle on average at the beginning of the trip (in which also Millingen aan de Rijn is delivered), as a percentage of the load volume?

    - ☐ Load factor at beginning of the trip: ____________________%

12. Which part of the total load is destined for Millingen aan de Rijn? __________%

13. What is the volume that is delivered per delivery to Millingen aan de Rijn?

☐ Parcels/crates	Sent: __________	Retour: __________
☐ Rolcontainers	Sent: __________	Retour: __________
☐ Pallets	Sent: __________	Retour: __________
☐ Fashion racks	Sent: __________	Retour: __________
☐ Unpackaged	Sent: __________	Retour: __________
☐ Other:__________	Sent: __________	Retour: __________

14. In which city/cities do you load the vehicle with parcels for Millingen aan de Rijn?

- ☐ City name(s):
  ____
  ____

15. In which cities do you also deliver (in the same trip)?

- ☐ Cities before Millingen aan de Rijn:
  ____
  ____

- ☐ Cities after Millingen aan de Rijn
  ____
  ____

16. How long does your total trip takes (in hours)? ________________Hour

17. How long is your total trip in kilometers? ________________Kilometer

18. How many stops do you have on average in a total trip in which Millingen aan de Rijn is also delivered?

- ☐ Number of stops total trip: _________________
- ☐ Number of stops in Millingen aan de Rijn: _________________

19. How long does a stop takes on average in Millingen aan de Rijn? __________ minutes

20. Which delivery time does your company guarantee for delivering parcels?

- ☐ ____

Thank you for your participation in my research.

Sincerely, Tijs Jansen *TU Eindhoven*
t.a.m.jansen@student.tue.nl
06-128 096 44

Appendix C

Coloured Petri Nets

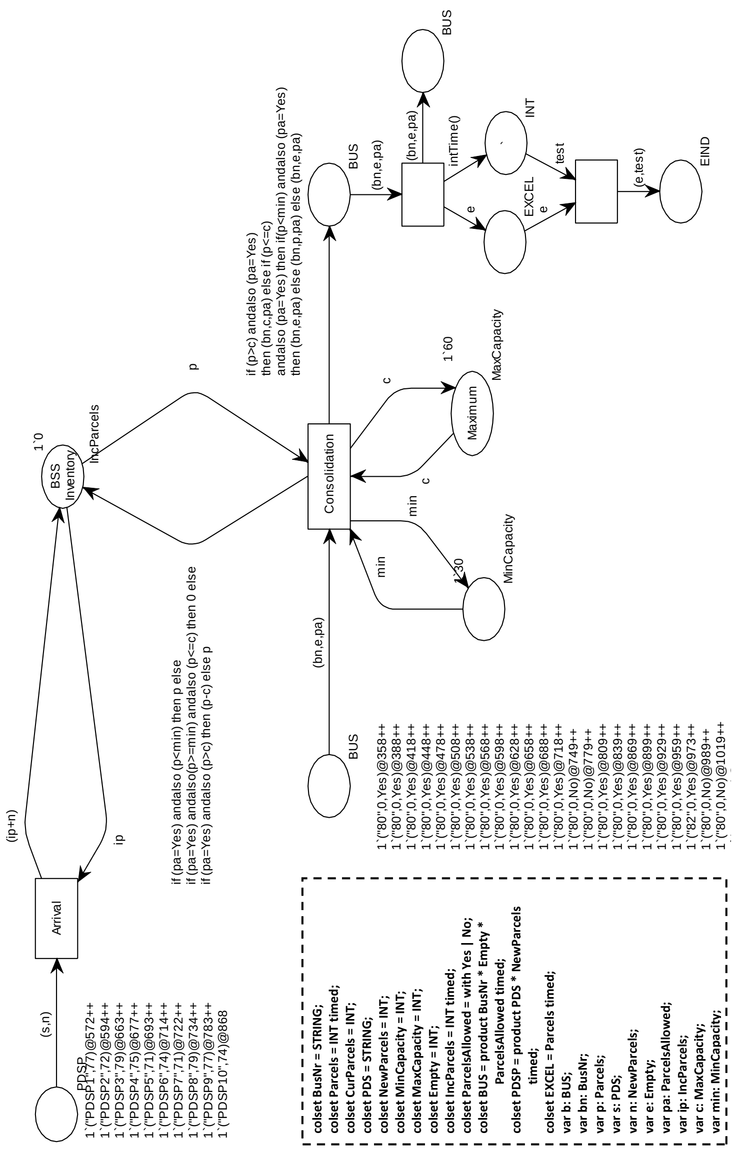

Figure C.1: Coloured Petri Net Model matching supply and demand with line buses

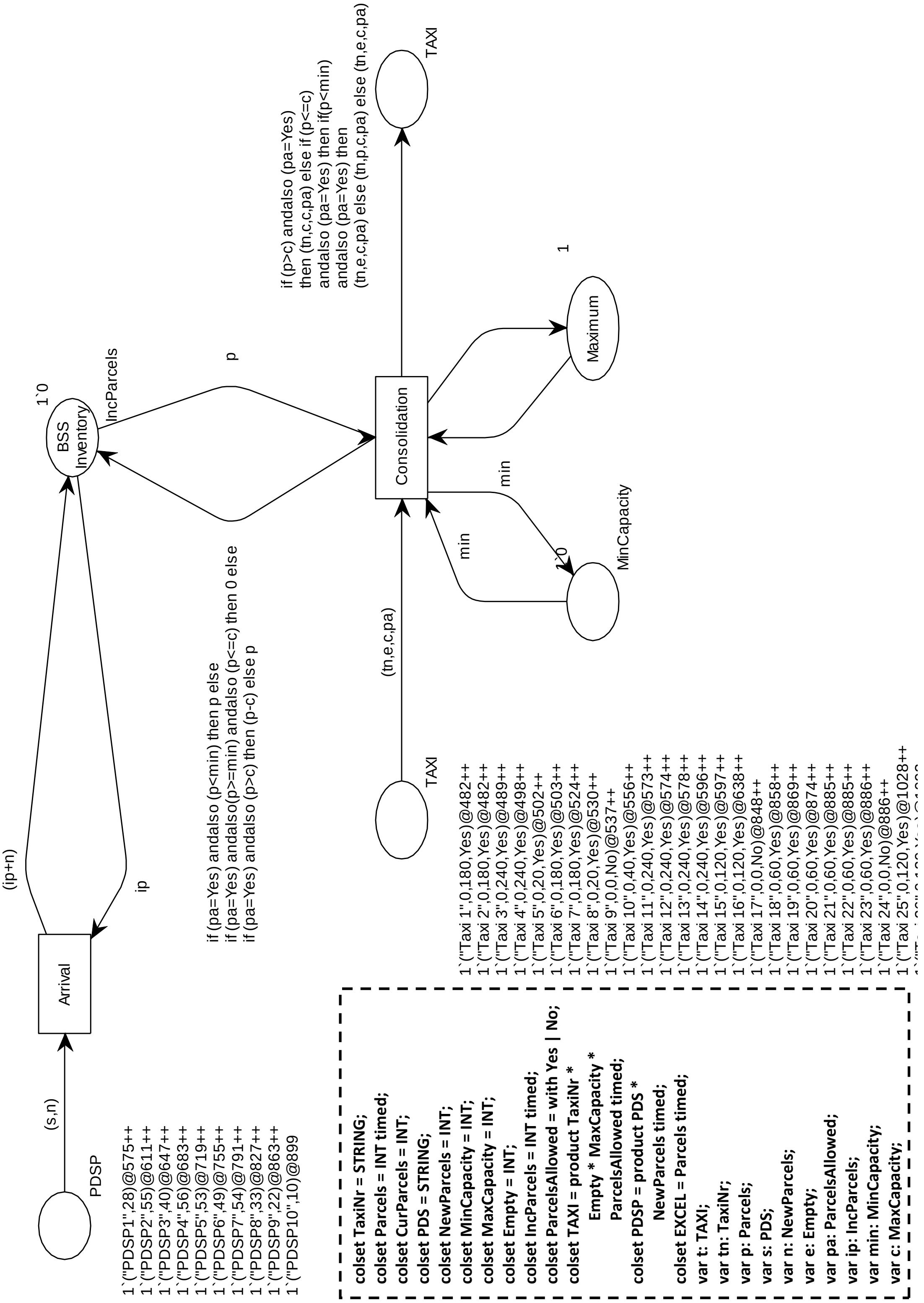

Figure C.2: Coloured Petri Net Model matching supply and demand with taxis

Appendix D

Simulation Model

D.1 Example of arrivals with realistic distribution

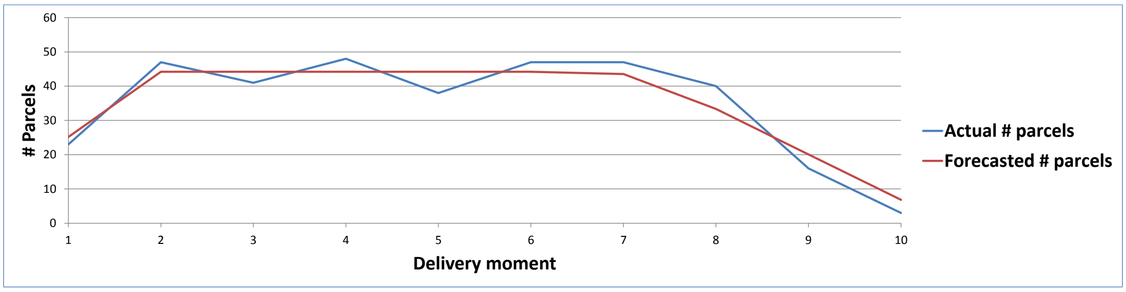

Figure D.1: Forecasted number of parcels compared to the model outcome number of parcels

Delivery moment	From	To	Arrival @ UCC	Duration (min)	# Parcels	# parcels forecasted	Percentage	Forecast (probability)
1	9:00	9:36	9:35	36	20	25	6%	7%
2	9:36	10:12	10:11	36	50	44	14%	13%
3	10:12	10:48	10:47	36	47	44	13%	13%
4	10:48	11:24	11:23	36	40	44	11%	13%
5	11:24	12:00	11:59	36	49	44	14%	13%
6	12:00	12:36	12:35	36	41	44	12%	13%
7	12:36	13:12	13:11	36	42	44	12%	12%
8	13:12	13:48	13:47	36	30	33	9%	10%
9	13:48	14:24	14:23	36	22	20	6%	6%
10	14:24	15:00	14:59	36	9	7	3%	2%
Total					350	350	100%	100%

Table D.1: Calculation table for realistic distributed arrivals

Appendix E

Results of sensitivity analysis

E.1 Undelivered parcels

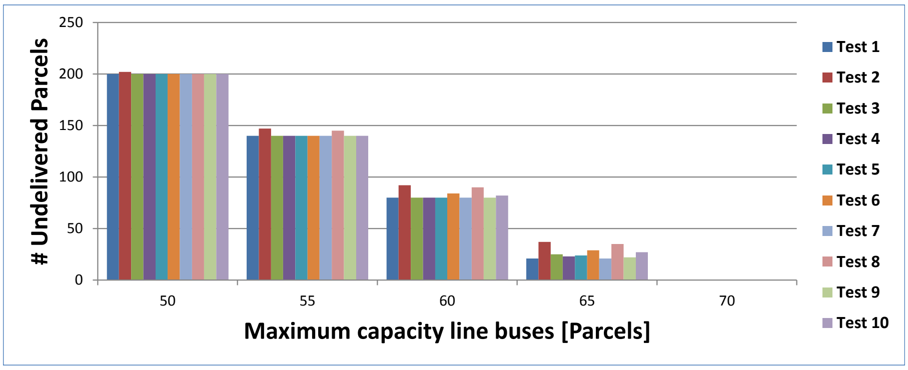

Figure E.1: Undelivered parcels with daily demand of 800 parcels

E.2 Inventory positions at the LSC

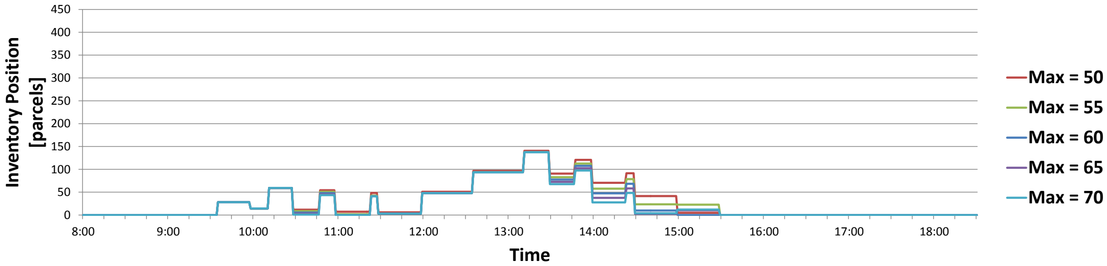

Figure E.2: Inventory positions at the LSC with daily demand of 350 parcels

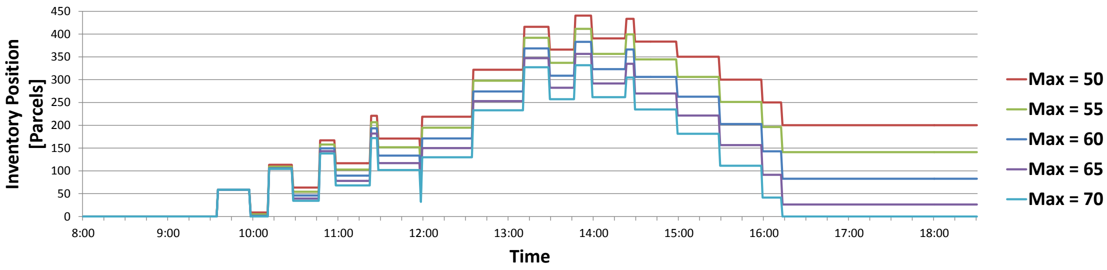

Figure E.3: Inventory positions at the LSC with daily demand of 800 parcels

E.3 Bus line utilizations

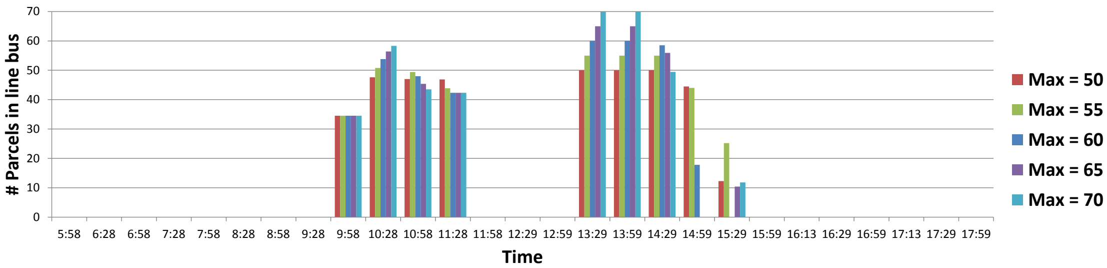

Figure E.4: Line bus utilizations with daily demand of 350 parcels

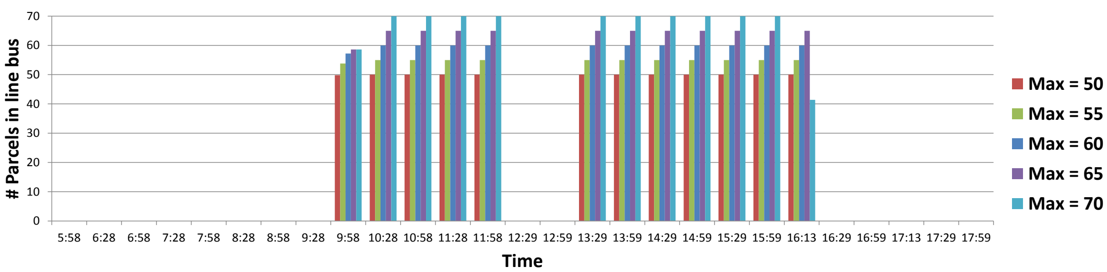

Figure E.5: Line bus utilizations with daily demand of 800 parcels

E.4 Waiting times for parcels at the LSC

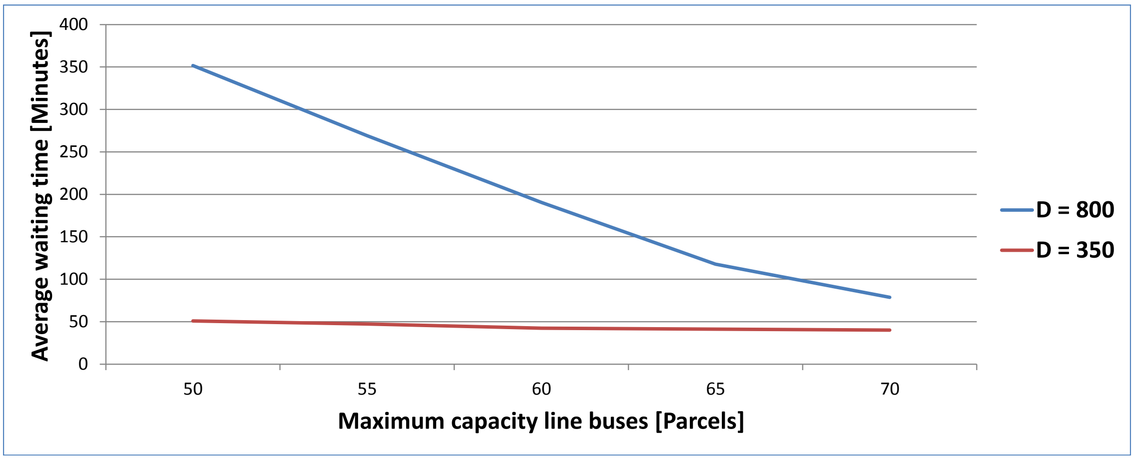

Figure E.6: Waiting times parcels at the LSC with daily demand of 350 parcels and 800 parcels