MASTER

# Redesigning the distribution network of a newspaper company

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# Redesigning the distribution network of a newspaper company

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# Abstract

As a result of digitalization and the growth of the internet, people can receive the news quicker via digital channels. The printed circulation decline is compensated by the increase in digital reading, but still, advertisement revenues are dropping. Since advertisements revenues are still the major source of revenue for newspapers, distribution costs per copy increase exponentially. In the present work, we deal with a distribution network redesign problem arising in the newspaper industry. This research is performed with the aim of reducing total distribution costs. An MILP is developed to determine which depot locations to use and the vehicle routes to serve carriers from the depots. Six hubs are included which serve the depot locations. Because of the size of the problem, carriers are grouped and a clustering-based heuristic solution approach is developed to solve the problem. The results indicate that costs could be saved by operating the new distribution network design. An implication for managers is, considering the ongoing decrease in newspaper sales, to choose for a mix of large and more smaller depots. This makes it possible to close small depots and shift towards a more centralized distribution network when newspaper demand further decreases.

# Executive summary

The media and content industry is changing. As a result of digitalization and the growth of the internet, people can receive the news quicker via digital channels. The printed circulation decline is compensated by the increase in digital reading, but still, advertisement revenues are dropping. Since advertisements revenues are still the major source of revenue for newspapers, distribution costs per copy increase exponentially.

To counter these effects, de Persgroep Nederland is considering a new design for their newspaper distribution network. In this design, instead of carriers picking up the newspapers at the depot, newspapers are delivered to the carrier homes. In this way, the number of depots could decrease while also decreasing the delivery costs. Therefore, this research aims to answer the following research question:

*How can the design of the distribution network be optimized to deliver newspapers to subscribers with minimal average costs per newspaper while respecting predefined customer service levels and delivery deadlines?*

The two aspects of this research question are the Facility Location Problem (FLP) and Vehicle Routing Problem (VRP). Combined problems are often solved by solving the two problems sequentially. However, several researches have shown that simultaneously considering these two problems provides significant gains compared to separate decisions (Prodhon & Prins, 2014; Nagy & Salhi, 2006). Therefore, they are studied together in this research. However, as the focus in this research is more on strategically locating depots than on the vehicle routes, the decision is made to include approximate routing costs as assignment costs in the FLP.

The most important requirement for managing newspaper delivery constitutes the delivery deadline. Also, there is pressure from the newsroom to incorporate the latest news and thus start the production as late as possible. Leading to a very short time frame for production and distribution. Considering this, the Mixed-Integer Linear Programming (MILP) model constructed in this research is a Location-Routing Problem with Time Windows (LRPTW), with an objective to minimize the total distribution costs. Distribution costs constitute fixed depot costs, vehicle routing costs and costs for primary transport between hubs and depots. The mathematical model determines where to open depots, vehicle routes from the open depots to carriers as well as connections between each depot and a hub while considering depot capacity, vehicle capacity and time window constraints. From the reviewed literature concerning LRPTW, it became clear that the combination of facility location and routing decisions makes the problem very complex and therefore it is practically impossible to solve the problem using exact methods.

Therefore, in this thesis, a heuristic solution approach is developed to reduce the complexity of the problem by applying a clustering procedure for grouping carriers. Using these clusters, routing costs are approximated when serving the cluster from a specific depot. By using these approximate route costs in the objective function of the FLP, facility location as well as assignment decisions have been made. The main idea is to decide about the number and locations of depots to achieve the best possible trade-off between fixed depot costs, vehicle routing costs and costs for primary transport. However, we also have to deal with depot capacity constraints. After determining

the optimal depot locations as well as cluster-to-depot assignments, the vehicle routes from the optimal depot locations to carriers are calculated.

The mathematical model developed is applied to de Persgroep Nederland as a case study and the main trade-offs in the distribution network design have been analyzed. Distribution network designs for each delivery have been evaluated. Comparing the solutions for each delivery day reveals that on Saturday more depots are opened and there is only a small overlap in depot locations between the delivery days. Since most capacity is required on Saturday, this set of depot locations will be operated all week and solutions for the weekdays are recalculated using the new set of depot locations, this output is displayed in table 1. The first part of the distribution network design is to determine the location and number of depot locations. In total, 175 out of 449 depot locations are used in the optimal distribution network design. Looking at the chosen depot locations, it can be concluded that mainly small depots are opened together with some larger depots. The second part is to determine the vehicle routes from the depot locations to carriers, which consists of about 630 vehicle routes on weekdays and about 940 vehicle routes on Saturday. This is due to the higher volume and lower vehicle capacity on Saturday. Considering the vehicle capacity and time window constraints, it can be concluded that most vehicles are fully loaded and carriers receive the newspapers well in advance.

| | **Monday** | **Tuesday** | **Wednesday** | **Thursday** | **Friday** | **Saturday** |
|---|---|---|---|---|---|---|
| **Fixed costs** | €3139.54 | €3139.54 | €3139.54 | €3139.54 | €3139.54 | €3139.54 |
| **Number of open depots** | 175 | 175 | 175 | 175 | 175 | 175 |
| **Costs primary routes** | €7041.75 | €7071.14 | €7135.38 | €7135.38 | €7092.53 | €7183.52 |
| **Costs secondary routes** | €9458.78 | €9337.48 | €9419.65 | €9406.34 | €9281.87 | €11532.51 |
| **Number of secondary routes** | 635 | 626 | 626 | 633 | 637 | 941 |
| **Total costs** | €19640.07 | €19548.16 | €19694.57 | €19681.26 | €19513.94 | €21855.57 |

Table 1: Model output

Lastly, the robustness of the optimal distribution network design has been evaluated using a sensitivity analysis. First of all, the effect of a delay in the arrival of the newspapers at the depots was investigated, a delay of 20 minutes does not result in higher costs because of the slack in the vehicle routes. Nevertheless, more delay results in significantly higher costs. Another tested parameter is the vehicle capacity and its effect on the optimal solution in terms of number of vehicle routes. The vehicle capacity is quite sensitive to the number of vehicle routes. Also, a sensitivity analysis is performed to see the cost changes when violating the depot capacities. This effect is very small. Finally, a scenario analysis has been performed to see the effect of a decrease in newspaper demand on the distribution network design. In case the newspaper demand decreases, total distribution costs also decrease.

Concluding from these analyses, and the fact that all solutions show significant savings compared to the current distribution network, it is recommended to de Persgroep Nederland to implement the new distribution network design. The introduction of secondary routes ensures that fixed costs are replaced by variable costs in the new distribution network design. Considering the ongoing decrease in printed newspaper sales, less carriers need to be supplied in the future, leading to a decrease in the number of secondary routes which eventually decreases total distribution costs. Following this, excess capacity is an important factor in the cost-optimal distribution network design, especially because this enables de Pergsroep Nederland to re-allocate carriers to other depots on a short-term basis without encountering depot capacity constraints. Therefore, the distribution network with some large depots and more smaller depots would be advised to de Persgroep Nederland. Large depots create excess capacity, which makes it possible to close smaller depots and shift towards a more centralized distribution network when newspaper demand further decreases, lowering the fixed costs in the distribution network.

# Preface

This master thesis report remarks the end of my master Operations Management and Logistics at Eindhoven University of Technology. It is the result of an interesting research conducted at de Persgroep Nederland during the last couple of months. Before moving on to the thesis, I want to thank the people who contributed to this project and my years at the university.

Firstly, I want to thank my supervisors for the discussion and feedback during the process, this input has improved the quality of the thesis. Furthermore, I want to thank Albert Nagtegaal and Jelte Zijsling for the opportunity to execute the research at de Persgroep Nederland. Apart from my supervisors, I would like to thank all the colleagues at de Persgroep Nederland who were always there to provide me with data and all the information needed.

With this being said, I can hardly believe that in only a few days, I will not be a student anymore. It has been a little bit more than five years ago when I started my student life and now I am just writing the last words of my master thesis project. I am thankful for everything I learned during my time at the TU/e and the many great people I met. It has been a blast!

*Marc Schmitz*

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# Chapter 1

# Introduction

*"Today's news is tomorrow's history."*

The famous statement above describes the highly perishable nature of newspapers. As a result of digitalization and the growth of the internet, people can receive the news quicker via digital channels. These developments have led to significant changes in the media and content industries. The printed circulation decline is compensated by the increase in digital reading, but still, advertisement revenues are dropping. Since advertisements revenues are still the major source of revenue for newspapers, distribution costs per copy increase exponentially. Knowing that, on average, printing and distribution make up roughly two-thirds of the costs of running a newspaper (Hasle, 2012), a strong urge exists to have an optimized supply chain design.

This project represents a study wherein is sought how the newspaper delivery network of de Persgroep Nederland can be improved. The supply chain design can be improved by deciding upon the locations of depots and vehicle routes. By considering de Persgroep Nederland's newspaper delivery network, an approach that integrates the location, allocation and routing decisions for newspaper delivery is defined. Consequently, this is exactly where lays the academic contribution as well as the added value for de Persgroep Nederland.

## 1.1 Project context

The project context consists of a brief description of de Persgroep Nederland and the current newspaper delivery network. We finalize this section by explaining the observed problems regarding the newspaper distribution process.

### 1.1.1 De Persgroep Nederland

De Persgroep Nederland, formerly known as PCM Uitgevers, is a firm that manages multiple major news-outlets varying from conventional media like newspapers, for example AD and Trouw, to modern media like websites and radio channels, such as Qmusic and Autotrack.nl. It is the biggest newspaper publisher in The Netherlands with a market share of 49.8% (Mediamonitor, 2018) in 2017 on the Dutch newspaper market. Due to the mixture of channels de Persgroep Nederland can be seen as a significant player in the media branch with an average of 9.5 million unique users per month. However, newspapers compose the core business of the company. Every day it delivers newspapers to more than one million subscribers throughout the country, making it an interesting topic to examine.

The newspaper has a several distinctive features that make it stands out from other industries. First, it has a strict delivery deadline since the subscribers expect their newspaper before 7 a.m. the next morning. Second, there is zero inventory in the supply chain. Finally, there is pressure from the newsroom to encourage the start of the production as slowly as possible to incorporate the latest news and there is pressure from the production and distribution to start production as early as possible, leading to a very short time frame for production and distribution. (Sartika, Hisjam, & Sutopo, 2018)

At de Persgroep Nederland, the editorial offices close no later than 22:45. Furthermore, a delivery deadline of 7 a.m. on weekdays and 8 a.m. on Saturday is promised to subscribers. In this timeframe of roughly eight hours, the newspapers are printed in three different locations and transported to six different hubs in the country. From there, different routes depart to supply the local depots from where the newspaper carriers start their tours. This situation is presented in figure 1.1 below, the transport from the printing offices to hubs is called national transport (NT) and the transport from the hubs to the depots is called regional transport (RT).

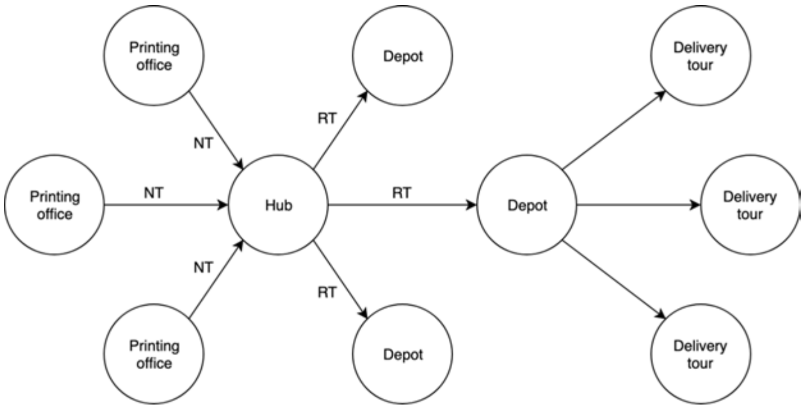



Figure 1.1: Schematic visualization of newspaper distribution process

### 1.1.2 Newspaper delivery network

Currently, there are three levels of delivery centers in the newspaper delivery network: the printing offices, hubs and depots. First, the printing offices will be discussed.

#### Printing offices

The network, as visualized in appendix A, contains three printing offices in Amsterdam, Den Haag and Best. In each printing office, a multiple of different newspaper editions is produced and after that distributed to the whole country. For explanation, the printing office in Amsterdam is taken as an example. After production, the newspapers are packed in bundles varying from 60 to 120 pieces, depending on the number of pages that the newspaper contains that specific day. On Saturday, when newspapers contain more attachments and thus more pages, this amount can reduce to 48 newspapers. These bundles are automatically stacked on pallets. Then, these pallets are placed on a dedicated area in the warehouse and loaded into a truck when the warehouse admits the truck, this is done using forklifts. The warehouse capacity is such that four trucks can be loaded simultaneously. Arrival and departure times of the trucks at the warehouse are registered using QR codes, this data is important as the trucks have to arrive at the hubs before 3 a.m. These trucks are hired using monthly adjustable contracts to be flexible. Very often the national transport route does not require an equivalent of newspaper bundles. If this is the case, the bundles are split, a certain number of newspapers is counted out and added to the large pallet. Four employees are involved in this 'counting' job.

### Hubs

Three of the six hubs in the network are located inside the printing offices (Amsterdam, Best and Den Haag), the other three are external warehouses in Apeldoorn, Breda and Kapelle, all the hubs are visualized in figure 1.2. These hubs distribute the newspapers over the depots assigned to that particular hub to reduce the number of direct routes. This regional transport is done using vans or cars. The pallets are divided for each depot and bundles are split into smaller bundles if necessary. Each depot has a dedicated roll container in the warehouse which is collected by the transporter when it is packed. For efficiency, a transporter may visit multiple depots on his route. The newspapers have to arrive at the depots before 4:30 a.m. and 5 a.m. for smaller depots. Also external deliveries to and from other firms who collaborate on the delivery take place in both the hubs and printing offices. These firms deliver their newspapers to the hubs of de Persgroep Nederland and the other way around. The hub owner is responsible for the delivery of these newspapers.


Figure 1.2: Locations of hubs

### Depots

At the depots, which are rent based on monthly contracts, newspaper carriers gather the newspapers to start their tours from here. Two different types of routes can be distinguished: local delivery tour and local route. The most common type is a local delivery tour in which newspaper delivery is done using either bike or scooter. The local route delivers newspapers to customers that are further located in the area, it supplies additional satellite depots that are not worthwhile to supply with the regional transport and individual point of sales, like supermarkets and one-man areas. A one-man area is a neighborhood that does not have a depot because it is simply not lucrative enough to open a depot there. The local route has a longer travel distance compared to the local delivery tour, therefore it is done using a car. Another characteristic of the local route is that the individual point of sales often requires many newspapers. De Persgroep Nederland currently operates 449 depots as visualized in figure 1.3. There are no depots in Limburg and the northern part of The Netherlands because other companies are responsible for the distribution of newspapers in these parts of the country.


Figure 1.3: Locations of depots

### 1.1.3 Problem statement

Currently, the management of de Persgroep Nederland observes two different trends that hamper the distribution process of newspapers: one is the upward trend in the economy which makes it hard to acquire new newspaper carriers and thus expenses grow. The other trend is a sharp decrease in the sales of printed newspapers, this can be blamed on the digitalization of the society. But there is also a shift in demand, more and more subscribers demand their newspapers only on Saturday and therefore they change their subscription. The demand on Saturday is 20% higher compared than on a regular weekday. As can be seen in figure 1.4, printed newspapers sales have decreased from about 1.6 million printed newspapers per week in 2016 to about 1.2 million in 2019. Those upward and downward trends combined cause the average costs per copy to grow exponentially.

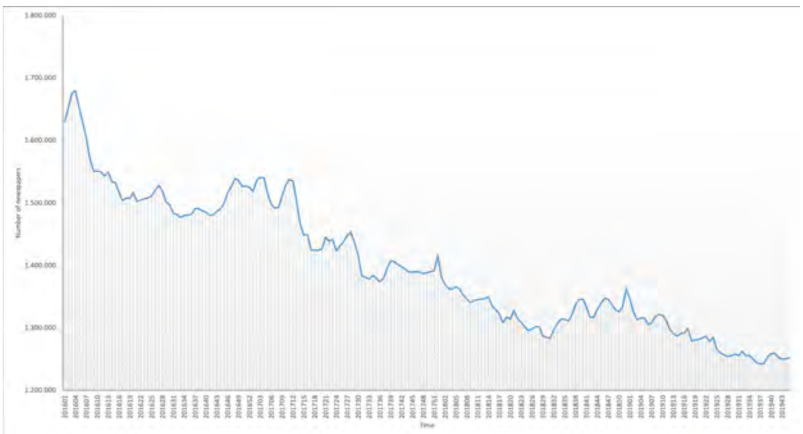
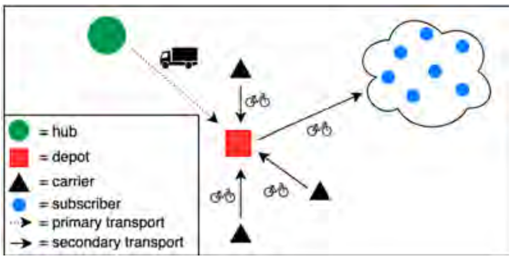
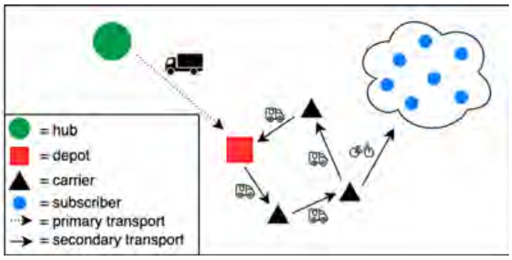


Figure 1.4: Decline in sales of printed newspapers (2016 - present)

Ultimately de Persgroep Nederland is aiming towards lower average costs per copy, which can be achieved via a new logistic structure. De Persgroep Nederland has already done some pilot tests with a new structure for its distribution network. In this new structure, carriers will get the newspapers delivered at home instead of collecting the newspapers at the depot. Therefore, the function of the depot changes completely since it will be used as a consolidation point in the new structure. The transport of newspapers to carriers will be done using either a van or a car, these routes depart from the depots. See figure 1.5b. The hub is indicated by the green circle, the red square indicates the depot, the blue circles are the addresses of subscribers and the carriers are indicated by triangles. Routing is depicted with arrows. For clarification, the old logistic structure is depicted in figure 1.5a.




(a)




(b)

Figure 1.5: Current and new logistic structure

These pilot tests have led to positive results. Therefore, the following problem statement is defined for the research:

*How can the design of the distribution network be optimized to deliver newspapers to subscribers with minimal average costs per newspaper while respecting predefined customer service levels and delivery deadlines?*

### 1.1.4 Scope

After stating the problem statement, this section clarifies the exact scope of the project, that serves as basis for the analysis and design phases. As discussed in the previous section, de Persgroep Nederland wants to investigate if the average costs per newspaper can be lowered by using the new logistic structure for their distribution network. As can be seen in figure 1.6, the distribution network design will be optimized between the locations of hubs and the delivery of the newspapers to subscribers. The time that a carrier requires for the delivery of the newspapers to subscribers will be used as input to calculate the delivery deadline for each carrier.

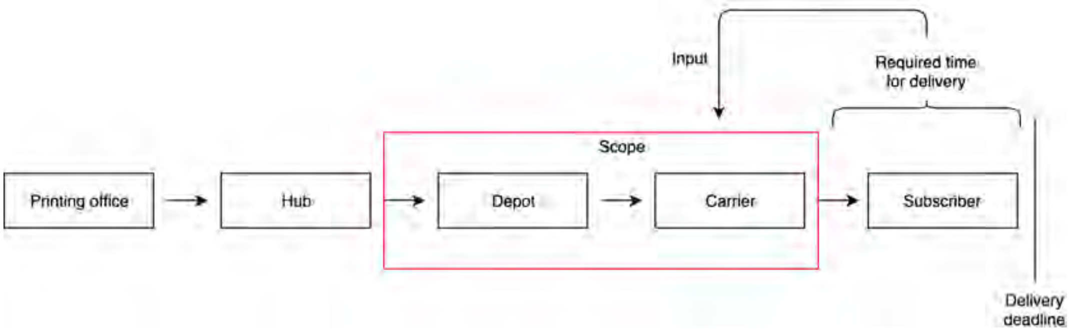



Figure 1.6: Project scope

## 1.2 Research questions

To investigate the problem and answer the problem statement, we exactly need to know the important requirements to manage newspaper delivery. This is important as by respecting these requirements, the network is realistic from an operational point of view. Therefore, the first research question will be defined as:

1. What requirements are important to manage newspaper delivery?

After answering the previous research question, we exactly know the requirements of the newspaper delivery network. The next step is to search for comparable cases and their used network designs in the literature. These can be used to answer the following theoretical question:

2. Which distribution network design models found in literature can be best applied or modified considering the requirements of the industry?

Based on the models derived from literature as well as the requirements regarding newspaper delivery a model will be developed to optimize the newspaper delivery network. Leading to the third research question:

3. How can the optimization problem in the distribution network for delivering newspapers be modeled?

After developing the model, it is time to apply the model. In collaboration with de Persgroep Nederland, data have to be prepared to use the model. Answering the following research question:

4. Which distribution network design would minimize the total costs for distributing newspapers, given a predefined service proposition?

Now that a supply chain design is developed that minimizes the total costs for distribution. The solution will be evaluated and compared with the current supply chain performance, for which a benchmark is created. This will lead to a conclusion and recommendations for the management of de Persgroep Nederland.

## 1.3 Outline of the report

- Chapter 2 identifies whether comparable problems exist in literature. Since this chapter will give an overview of newspaper industry characteristics as well as existing solution methods, it will be used as input for research questions 1 and 2.
- Chapter 3 describes the mathematical model which will be used to optimize the new distribution network design for the delivery of newspapers, and thus answers research question 3.
- Chapter 4 describes the used solution method for solving the mathematical model.
- Chapter 5 focuses on the data preparation which is necessary for making the data suitable to apply the developed solution method of chapter 4.
- Chapter 6 presents the results of the heuristic solution approach applied to the distribution network of de Persgroep Nederland. Furthermore, a sensitivity analysis is conducted to test the performance of the model. Research question 4 will be answered in this chapter.
- Finally, in chapters 7 and 8 conclusions and recommendations will be made.

# Chapter 2

# Literature background

As previously stated, the objective of this research project is to develop a model that optimizes the structure of the supply chain for delivering newspapers to subscribers. In this chapter, the analyzed papers will be presented and discussed. General characteristics of the newspaper industry are discussed first. Followed by an overview of research on supply chain design in the newspaper industry. After this, relevant studies regarding Location-Routing Problems (LRP) are discussed.

## 2.1 Newspaper industry characteristics

*"Today's news is tomorrow's history."*

The statement above describes the perishable nature of newspapers. This causes the time between the start of production and the delivery of the newspapers to subscribers to be shorter than for most industries. It is conventional for newspaper companies to guarantee delivery before 7 a.m. As a consequence of this strict deadline, most production and distribution are carried out at night. Also, there is no inventory because of the perishable characteristic of newspapers and the time-pressure on its production and distribution process (P3L, 2006). These properties make the newspaper industry completely different from other industries. Primary costs in the newspaper supply chain are related to the production of editorial content, capital and operational expenses of running printing facilities as well as vehicle and fuel costs at the distribution level. On average, printing and distribution make up roughly two-thirds of the costs of running a newspaper (Hasle, 2012). Therefore, cost reductions in these parts of the supply chain can be effective. Newspapers all over the world have experienced a decrease in print circulation and a decline in advertising revenues as readers and advertisers are turning to digital media during the past few years (Åkesson, Sørensen, & Eriksson, 2018). Since the newspaper industry experiences these economic pressures, it is of utmost importance to have an optimized supply chain design and a high degree of operational coordination to minimize costs.

## 2.2 Newspaper distribution problem

The literature depicts different methods for solving the newspaper distribution problem, a summary of these studies and applied models is shown in appendix B. This involves the distribution of newspapers to subscribers at minimum cost while getting the correct edition of the newspaper to each subscriber on time. Facility capacity, vehicle capacity, time windows, distances and different editions are interesting parameters which have to be considered, as stated by literature and professionals of the company as well. Jacobsen and Madsen (1980) were the first addressing the combined LRP for the process of distributing newspapers to about 4500 subscribers. They compared three different heuristic solution procedures against the current situation. However, this is the only study that considers the design of vehicle routes as well as decisions on the number and locations of facilities as later researches only focused on the routing part of the newspaper distribution problem. The model most often used is the so-called Vehicle Routing Problem (VRP). Mantel and Fontein (1993) were the first to propose a Mixed-Integer Linear Programming (MILP) formulation for the newspaper distribution problem. The objective is to minimize total traveling time. Capacity constraints for trucks and passenger cars are incorporated as well as constraints on the total time available for distribution, which is different for each edition's region. Hurter and Van Buer (1996) came up with a little bit different MILP formulation for the medium-size newspaper distribution problem with a daily circulation of 15000-50000 newspapers. Their mathematical formulation has the objective to minimize the cost of owning trucks as well as operating costs. They also take into account that newspapers for a route should be ready before the truck leaves, the last DC should be served by the deadline and a zone constraint which restricts the delivery vehicle from transporting more than one type of newspaper. A greedy heuristic followed by an Or-Opt route improvement heuristic has been employed to solve this problem. In a follow-up research, Van Buer, Woodruff, and Olson (1999) show that re-using vehicles by allowing multiple routes per vehicle is the most important way to achieve low-cost solutions. Russell, Chiang, and Zepeda (2008) also analyzed the distribution system of a midsize newspaper company with a daily circulation of 135000-200000 newspapers. However, they modeled the problem as a Time-Constrained Open VRP with Zoning Constraints (OVRPTWZC) which examines the situation where vehicles do not have to return to the depot after the last delivery. A metaheuristic approach is proposed to solve the problem and consists of the following phases: synchronizing loading with production, constructing initial routes and using Tabu Search to improve the routes. Chiang, Russell, Xu, and Zepeda (2009) considered the same medium-size newspaper company. However, they considered the impact of the stochastic nature of various parameters in both production as well as distribution. A two-phase heuristic approach is developed to solve a deterministic version of the stochastic problem. This consists of a much smaller Integer Programming (IP) subproblem together with a Tabu Search metaheuristic for solution improvement. Afterwards, a simulation model is developed to evaluate the robustness of the deterministic solution in a more realistic stochastic environment. Later, Russell (2013) presented a constraint programming and optimization approach for the same problem. The proposed methodology performs better compared to the two-phase approach and Tabu Search metaheuristic. Yang et al. (2016) added a recycling policy to the newspaper distribution problem. To meet all the complex restrictions in such a problem, it has been modelled as an Asymmetric and Clustered VRP with Simultaneous Pickup and Deliveries, Variable Costs and Forbidden Paths (AC-VRP-SPDVCFP). A Discrete Firefly Algorithm is proposed to address the designed model. Archetti, Doerner, and Tricoire (2013) studied the problem of finding an efficient distribution plan to deliver free newspapers from a printing press to about 200 commute options like subway, bus or train stations. This problem has an additional objective to minimize the number of stockouts. The authors give a mathematical formulation and propose solution techniques for the free newspaper delivery problem including a decomposition method, heuristic and exact approaches for the subproblems. Ree and Yoon (1996) considered the implementation of partial deliveries in the newspaper distribution problem arising in a daily newspaper company in Korea. Partial deliveries can be beneficial as they can delay the deadline for delivery by delivering a part of the newspapers earlier to the DC. Only half or full delivery is allowed to restrict the solution space from becoming explosively large. A delivery plan is developed using a branch-and-bound heuristic together with Simulated Annealing. The adoption of the split delivery scheme is also considered by Song, Lee, and Kim (2002). The authors investigated certain well-known heuristics together with a digital map to determine an optimized allocation of newspaper agents to printing plants as well as optimal routes for newspaper delivery. These papers all point to a VRP with Time Windows (VRPTW). Regarding the different editions, most studies simplified the problem by either allowing only one or two types of editions per vehicle or assuming that all copies for one edition fit into one truck. However, it is necessary to deal with the problem of heterogeneous editions per truck as this leads to an interdependence between production and distribution. Böhnlein, Gahm, and Tuma (2009) modeled this problem as a VRPTW with Cluster-Dependent Tour Starts (VRPTWCD) and developed a new metaheuristic including the ideas of Ant Colony Optimization and Tabu Search which can cluster and route simultaneously. This metaheuristic has been applied to a case of one of the largest newspaper companies in Germany with about 1500 unloading points, which resulted in a significant decrease in variable costs. With the latest news being inserted as well as disturbances, the solely solution of a VRP on static production schedules is not sufficient anymore. Therefore, Böhnlein, Schweiger, and Tuma (2011) considered a dynamic variant of the same problem in a later paper. A multi-agent system is used as a solution concept for the dynamic VRPTWCD, which allows for synchronous optimization of two objectives: minimizing variable distribution costs and maximizing customer satisfaction. The authors conclude that if delays are expected in advance, using a lower minimal service level is better to avoid problems concerning the scarceness of vehicles. Unlike all the studies mentioned above that solve the newspaper distribution problem using heuristics, Eraslan and Derya (2010) were the first to come up with an optimal solution for the newspaper delivery problem. The transportation of newspapers is investigated using a Multi-Depot Capacitated VRPTW and optimal delivery routes are determined using an ILP model. Although the literature writes frequently about VRP with additional constraints for time windows, vehicle fleet and different editions. These papers bring up solutions to solve the VRP but do not consider facility location decisions. The additional facility location decision will make the problem harder to solve. Therefore, the next section will focus on other problems in which facility location and routing decisions have to be made simultaneously.

## 2.3 Location-Routing Problems

The idea of combining depot location and vehicle routing problems dates back to the 1960s (Prodhon & Prins, 2014). Early papers on this topic highlight the interdependency of these two types of decisions. However, they could not be integrated due to a lack of development of computers and optimization systems (Maranzana, 1964; Von Boventer, 1969; Webb, 1968). Watson-Gandy and Dohrn (1973) were the first authors who considered customer visits in determining the location of depots by using a non-linear profit function model, in which sales decrease with the distance to the depot. This inspired other authors leading to a growing stream of research on LRP. LRP combine two basic planning tasks in logistics, namely the Facility Location Problem (FLP) and Vehicle Routing Problem (VRP). In LRP, as their name implies, decisions on the location of arbitrary types of facilities (plants, depots, warehouses, hubs, cross-docks, etc.) are jointly taken with decisions on the routing of vehicles (Drexl & Schneider, 2014). Nagy and Salhi (2006) classify the literature on LRP by distinguishing methodologies for deterministic variants, stochastic or dynamic problems, and versions with more complex networks. Later, also other studies classified this problem by reviewing LRP literature (Prodhon & Prins, 2014; Lopes, Ferreira, Santos, & Barreto, 2013; Drexl & Schneider, 2014). As elaborated in section 2.1, newspapers have a strict delivery deadline. Therefore, owing to their relevance to our problem, LRP with Time Windows (LRPTW) will be reviewed in the remainder of this section.

For logistic distributions, it is of utmost importance to maintain efficiency. This can be achieved by cutting their logistics cost, but also by competing on the service qualities (Desrosiers, Dumas, Solomon, & Soumis, 1995). That is why time windows are now almost essential in different businesses. Time windows specify a certain time frame in which a customer has to be visited (Taniguchi, Thompson, Yamada, & van Duin, 2001). If a vehicle arrives before the time window opens it will induce waiting time. If a vehicle made a delay, it diminishes customer satisfaction. These additional costs of early arrival and delay are called penalty costs. If the time window is hard, late arrivals are strictly prohibited while the early arrival is allowed with no extra charge (Ponboon, Qureshi, & Taniguchi, 2016b).

There has been a growing trend in LRPTW literature. Only two studies tried to come up with exact solutions to the LRPTW. Ponboon, Qureshi, and Taniguchi (2016a) proposed a method of decomposing the complex IP formulation into a master and subproblem and contribute a new column generation based algorithm to solve it. Later, Farham, Süral, and Iyigun (2018) enhanced the column generation approach of Ponboon et al. (2016a) by various techniques inspired from the VRPTW and LRP literature to provide better bounds on the objective function value. These algorithms were able to solve instances with 5 candidate facility locations and 50 customers optimally. However, as the problem size increases and time windows become wider, exact algorithms become computationally heavy. Therefore, the combination of exact and metaheuristic approaches as hybrid algorithm is suggested as a solution concept for large scale instances. Schittekat and Sörensen (2009) studied the distribution of spare parts to about 800 car dealers. The authors describe the development of a decision-support tool to support the process of determining a transport network. A Tabu Search procedure is used to solve the LRP, moreover a long-term memory and commercial routing solver are embedded. The results showed an eight percent decrease in costs while keeping the same service level. Gündüz (2011) also proposed a heuristic based on Tabu Search for the Single-Stage LRPTW. However, this Tabu Search heuristic is a bit different in the sense that add, drop and swap moves are restricted to a region and catchment area of the depot. The results showed that a simultaneous decision on depot locating and route planning leads to much better solutions than sequential methods. In a follow-up research, Gündüz and Kadir (2013) proposed a well-arranged Simulated Annealing approach for the same problem and compared it with the Tabu Search algorithm of Gündüz (2011). For most of the test instances, with up to 362 potential depots and 1000 customers, the proposed heuristics led to better solutions in significant shorter computation times. Gharavani and Setak (2015) addressed the LRP with Semi-Soft Time Windows in which a delay in service delivery time results in delay costs. The problem is solved using the Genetic algorithm and Tabu Search algorithm. Experiments on instances with up to 200 customers and 10 depots revealed that the Genetic algorithm is better in terms of objective function value, however the Tabu Search algorithm is better in terms of computation time. In the retail business, a location-routing model is proposed by Aksen and Altinkemer (2008) for the conversion from the traditional brick-and-mortar model to the hybrid click-and-mortar model. Inventory concerns are eliminated as stores are assumed to have unlimited storage capacity. However, time deadlines are considered. A heuristic method is used to determine the initial upper bound. After that, a Lagrangian relaxation attempts to reduce this upper bound in the course of the subgradient iterations of the augmented Lagrangian relaxation. Computational experiments showed that this solution method is not suitable for large-size instances with more than 100 customers as this leads to unfavorably long solution times.

It can be concluded that the addition of routing decisions into the FLP makes the problem way more complex. The LRP is an NP-hard problem since it is a combination of two NP-hard problems, namely, FLP and VRP (Gharavani & Setak, 2015). That's why it is practically impossible to solve LRP using exact methods as real-world problems on a large scale. For that reason, approaches with relaxations or heuristics are desired in this problem. The problem is mostly that there is a limited amount of literature solving LRPTW on a large-scale. The papers of Gündüz show similarities with our problem. Although, their problem is only half the size of our problem.

# Chapter 3

# Problem formulation

We study a three-level distribution network consisting of hubs, depots and newspaper carriers. Newspapers arrive at the hubs, the pallets are divided for each depot and bundles are split into smaller bundles if necessary. After that, the newspapers are transported by trucks to intermediate depots before being sent by either car or van to the carrier homes, as visualized in figure 3.1. De Persgroep Nederland chose for intermediate depots to benefit from economies of scale for long-distance transport from hubs to depots. Starting from a given hub, shipments to the various carriers are consolidated and sent to a given depot that serves these carriers. This full truckload primary transport from hubs to intermediate depots leads to efficiency gains.

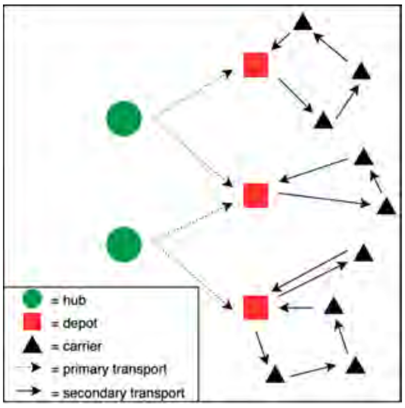



Figure 3.1: Newspaper distribution network

Within this distribution network, different decisions need to be made: the optimal number and locations of the intermediate depots simultaneously with the allocation of carriers to these depots as well as the assignment of depots to hubs and vehicle routes from the depots to carriers need to be determined so as to minimize the total system costs. Whereby the same set of depot locations should be operated on each delivery day. Since location as well as routing decisions are incorporated and time windows are considered for the carriers, the LRPTW is defined. As already explained in section 2, LRPTW is considered as a combination of two well known-problems: Location-Allocation Problem (LRP) and VRPTW. The location-allocation decisions must be solved at the strategic decision level, while vehicle routes are designed at the operational or tactical level. (Prodhon & Prins, 2014)

In the next section, the problem definition as well as the mathematical model for the LRPTW are presented.

## 3.1 Problem definition and mathematical model

We consider a two-stage distribution network where there is an inbound transportation from the hubs to the depots and outbound transportation between the depots and the carriers served by these depots. The locations of carriers and hubs as well as the locations of the potential depot sites are known and expressed by their coordinates. To make the model as close to reality as possible, the following operational constraints are considered:

- The same set of depot locations should be operated on each delivery day.
- Each carrier is assigned to exactly one open depot and served by exactly one vehicle before its deadline.
- Each depot is assigned to exactly one hub.
- Each vehicle is used at most once.
- Each vehicle route begins and ends at the depot, the route starts after the newspapers are available for delivery.
- The vehicle load does not exceed the vehicle capacity.
- The total delivery quantity of the carriers assigned to an open depot does not exceed the depot capacity.

The objective is to find the number and locations of open depots, allocation of carriers to these depots, vehicle routes to the associated carriers and allocation of open depots to hubs that yield minimum total distribution costs. Distribution costs involve the fixed costs for opening depots, transportation costs for the vehicle routes and costs for primary transport between hubs and depots. No inventory costs are included since newspapers are highly perishable products as described in section 1. Furthermore, the following assumptions are made:

- A single type of newspaper is considered. The edition of the newspaper is not important for the model, since the model only deals with the transportation of the newspapers. Therefore, it is assumed that all the required editions are available at the hubs.
- Each carrier has a delivery deadline which depends on the required time for the delivery of newspapers to the subscribers assigned to that specific carrier.
- Newspapers are ready for delivery at the depots at a fixed moment in time. At that point, vehicles can depart from the depots to serve the carriers.
- A homogeneous vehicle fleet is considered

Below, we present an MILP formulation of the LRPTW described above.

We define a distribution network made up of $H$ hubs ($h \in H$), $D$ potential locations for depots ($d \in D$) and $I$ carriers ($i \in I$). Depots serve carriers with $K$ vehicles ($k \in K$) having a capacity $C_k$. Potential depot locations and carriers form a set of nodes $V = D \cup I$. Carriers are associated with a delivery quantity $q_i$ and they have to be served before their deadline $b_i$. Further, each depot has a capacity $Q_d$ and opening costs $F_d$. Finally, traveling costs $c_{ij}$ and the traveling time $t_{ij}$ including service time at node $i$ are associated with the transport between nodes $i$ and $j$. The goal is to determine the location of open depots, assignments of carriers to open depots and open depots to hubs as well as the vehicle routes serving the carriers with minimum overall costs. An overview of all subsets, parameters and variables is provided in table 3.1.

To formulate the LRPTW, the following decision variables are necessary:

$$y_d = \begin{cases} 1 & \text{if depot } d \in D \text{ is open} \\ 0 & \text{otherwise} \end{cases}$$

$$z_{di} = \begin{cases} 1 & \text{if carrier } i \in I \text{ is assigned to depot } d \in D \\ 0 & \text{otherwise} \end{cases}$$

$$w_{hd} = \begin{cases} 1 & \text{if depot } d \in D \text{ is assigned to hub } h \in H \\ 0 & \text{otherwise} \end{cases}$$

$$x_{ij}^k = \begin{cases} 1 & \text{if node } j \in V \text{ is directly visited after node } i \in V \text{ by vehicle } k \in K \\ 0 & \text{otherwise} \end{cases}$$

$$T_i = \text{arrival time at carrier } i \in I$$

The MILP can be stated as follows:

$$\min \quad \sum_{d \in D} F_d \cdot y_d + \sum_{h \in H} \sum_{d \in D} c_{hd} \cdot w_{hd} + \sum_{k \in K} \sum_{i \in V} \sum_{j \in V} c_{ij} \cdot x_{ij}^k \tag{3.1}$$

$$\text{s.t.} \quad \sum_{h \in H} w_{hd} = 1 \qquad \forall d \in D \tag{3.2}$$

$$\sum_{d \in D} z_{di} = 1 \qquad \forall i \in I \tag{3.3}$$

$$\sum_{i \in I} q_i \cdot z_{di} \leq Q_d \cdot y_d \qquad \forall d \in D \tag{3.4}$$

$$\sum_{i \in V} \sum_{j \in I} q_j \cdot x_{ij}^k \leq C_k \qquad \forall K \in K \tag{3.5}$$

$$\sum_{k \in K} \sum_{i \in V} x_{ij}^k = 1 \qquad \forall j \in I \tag{3.6}$$

$$\sum_{j \in V} x_{ij}^k - \sum_{j \in V} x_{ji}^k = 0 \qquad \forall k \in K, i \in V \tag{3.7}$$

$$\sum_{i \in D} \sum_{j \in V} x_{ij}^k \leq 1 \qquad \forall k \in K \tag{3.8}$$

$$\sum_{k \in K} \sum_{i \in N} \sum_{j \in V \setminus N} x_{ij}^k \geq 1 \qquad \forall N \subseteq I, 2 \leq |N| \tag{3.9}$$

$$\sum_{l \in V} (x_{dl}^k + x_{li}^k) \leq z_{di} + 1 \qquad \forall d \in D, i \in I, k \in K \tag{3.10}$$

$$T_i \leq b_i \qquad \forall i \in I \tag{3.11}$$

$$-M(1 - x_{ij}^k) - (T_j - T_i - t_{ij}) \leq 0 \qquad \forall i \in I, j \in I, k \in K \tag{3.12}$$

$$M(1 - x_{ij}^k) - (T_j - T_i - t_{ij}) \geq 0 \qquad \forall i \in I, j \in I, k \in K \tag{3.13}$$

$$-M(1 - x_{dj}^k) - (T_j - t_{dj}) \leq 0 \qquad \forall d \in D, j \in I, k \in K \tag{3.14}$$

$$M(1 - x_{dj}^k) - (T_j - t_{dj}) \geq 0 \qquad \forall d \in D, j \in I, k \in K \tag{3.15}$$

$$x_{ij}^k \in \{0, 1\} \qquad \forall i, j \in V, k \in K \tag{3.16}$$

$$y_d \in \{0, 1\} \qquad \forall d \in D \tag{3.17}$$

$$z_{di} \in \{0, 1\} \qquad \forall d \in D, i \in I \tag{3.18}$$

$$w_{hd} \in \{0, 1\} \qquad \forall h \in H, d \in D \tag{3.19}$$

$$T_i \in \mathbb{R}^+ \qquad \forall i \in I \tag{3.20}$$

The objective function (3.1) is divided into three kinds of costs that have to be minimized. The first part is about the costs for opening depots, the second part are the costs for depot-to-hub assignments and the third part constitutes the routing costs. Constraints (3.2) make sure that every depot is assigned to a hub. Constraints (3.3) and (3.6) make sure that every carrier is assigned to a depot and served by a vehicle. Constraints (3.4)-(3.5) are capacity constraints for the open depots and used vehicles. Continuity of routes is preserved with constraints (3.7). Constraints (3.8) make sure that each vehicle or truck is used at most once. Subtours are eliminated by constraints (3.9). Constraints (3.10) ensure that a carrier is only served by a vehicle assigned to the same open depot. Constraints (3.11) imply that the arrival time at a carrier is before its deadline. Arrival times at the carriers and the starting times of the routes are determined by inequalities (3.12)-(3.15). Finally, constraints (3.16)-(3.20) state the binary variables and non-negative time variables.

The simultaneous introduction of depot capacity, vehicle capacity and time windows constraints makes the problem closer to real-life requirements but also implies that an optimal solution requires a significant amount of trade-offs which make the problem computationally difficult. Therefore, only very small scale instances can be solved with commercial solvers. Given that we deal with 6 hubs, 449 capacitated depots and about 4600 carriers, considering an exact location-routing approach would be computationally intractable. This is why we develop an heuristic solution procedure which will be outlined in the next chapter.

| **Indices and sets** | |
|---|---|
| $H$ | The set of hubs, indexed by $h$ |
| $D$ | The set of potential locations for depots, indexed by $d$ |
| $I$ | The set of carriers, indexed by $i$ |
| $K$ | The set of vehicles, indexed by $k$ |
| $V$ | The set of nodes, $D \cup I$ |

| **Parameters** | |
|---|---|
| $C_k$ | Capacity of vehicle $k \in K$ |
| $Q_d$ | Capacity of depot $d \in D$ |
| $F_d$ | Opening costs of depot $d \in D$ |
| $c_{ij}$ | Routing costs from node $i \in V$ to node $j \in V$ |
| $t_{ij}$ | Travelling time from node $i \in V$ to node $j \in V$, including service time at $i$ |
| $q_i$ | Delivery quantity of carrier $i \in I$ |
| $b_i$ | Delivery deadline of carrier $i \in I$ |

| **Variables** | |
|---|---|
| $y_d$ | Binary variable to determine whether depot $d \in D$ is opened or not |
| $z_{di}$ | Binary variable to determine whether carrier $i \in I$ is assigned to depot $d \in D$ or not |
| $w_{hd}$ | Binary variable to determine whether depot $d \in D$ is assigned to hub $h \in H$ or not |
| $x_{ij}^k$ | Binary variable to determine whether node $j \in V$ is directly visited after node $i \in V$ by vehicle $k \in K$ |
| $T_i$ | Arrival time at carrier $i \in I$ |

Table 3.1: Model subsets, parameters and variables

# Chapter 4

# Heuristic solution approach

By adding the complexity of time window constraints into the LRP, an effective solution method must be developed to deal with the combination of location-allocation and routing simultaneously which is already NP-hard (Dror, 1994). Due to this complexity, exact methods can only solve relatively small instances of the LRPTW. As a result, literature considering LRPTW frequently writes about heuristic approaches, as outlined in section 2. Nagy and Salhi (2006) classify these heuristics based on how the relationship between the location-allocation and routing subproblems is modeled in the solution method:

- Sequential methods: First solve the location-allocation problem and then solve the routing problem based on the depot locations found.

- Clustering based methods: Partition the customers into clusters and locate a depot for each cluster.

- Iterative methods: Decompose the problem into two sub problems. These sub problems are iteratively solved, information is exchanged between the phases.

- Hierarchical methods: Treat the location-allocation problem as the main problem and routing as a subordinate problem.

For the new logistic structure under consideration to be working correctly, it is really important that the depots are strategically located between hubs and carriers. Therefore, the LAP is more important than the routing problem. Thus, the LAP is treated as the main problem and the routing subproblems are basically the costs incurred by choosing a specific set of depot locations. For this reason, a hierarchical solution method will be developed to solve the problem. For a detailed overview of the notation used in this chapter, the reader is referred to table 3.1.

The location-allocation problem will be outlined in the next section.

## 4.1 Location-Allocation Problem

The location-allocation model is a general model for allocating carriers to capacitated depots and assigning each opened depot to a hub respectively. Besides the fixed costs for opening depots, the assignment costs are also important cost figures. However, these assignments costs are assumed to be represented by direct transportation, which is the case when a vehicle departing from a depot visits only one carrier and then returns to the depot. The LAP is presented below:

$$\min \quad \sum_{d\in D} F_d \cdot y_d + \sum_{h\in H}\sum_{d\in D} c_{hd} \cdot w_{hd} + \sum_{d\in D}\sum_{i\in I} c_{di} \cdot z_{di} \tag{4.1}$$

$$\text{s.t.} \quad \sum_{h\in H} w_{hd} = 1 \qquad \forall d \in D \tag{4.2}$$

$$\sum_{d\in D} z_{di} = 1 \qquad \forall i \in I \tag{4.3}$$

$$\sum_{i\in I} q_i \cdot z_{di} \leq Q_d \cdot y_d \qquad \forall d \in D \tag{4.4}$$

$$y_d \in \{0,1\} \qquad \forall d \in D \tag{4.5}$$

$$z_{di} \in \{0,1\} \qquad \forall d \in D, i \in I \tag{4.6}$$

$$w_{hd} \in \{0,1\} \qquad \forall h \in H, d \in D \tag{4.7}$$

The objective (4.1) is to minimize the sum of depot opening and assignment costs, while respecting depot capacity constraints (4.4). Constraints (4.2) and (4.3) ensure that each carrier is allocated to exactly one open depot and each depot is assigned to a hub. The binary decision variables are defined by (4.5)-(4.7).

## 4.2 A realistic structure for the assignment costs

In the general LAP outlined above, the costs for assigning carriers to depots and linking each open depot to a hub are based on direct transport. For the transport between hubs and depots, this assumption is valid since the delivery quantities to depots are large enough to allow for full truck-load transport. However, as the individual demands of carriers are relatively small, de Persgroep Nederland groups the deliveries from depot to carriers, leading to a routing problem. In such cases, the vehicle routes have a great impact on the overall cost of a solution. As mentioned before, the routing decisions are basically the costs incurred by choosing a specific set of depot locations. Therefore, in a realistic point of view, the assignment costs should be dependent upon the costs for the routes to serve the carriers assigned to a specific depot. It's impossible to come up with a value for the incremental routing costs when assigning a single carrier to a specific depot.

Considering this interdependency between the location-allocation and routing decisions, we introduce an clustering algorithm. The idea is to identify a set of feasible clusters with carriers. Where feasible means that:

- The number of newspapers in one cluster can be assigned to a single vehicle.
- There exists a route connecting the carriers in the cluster that satisfies all the delivery deadlines.

Moreover, for a cluster to be cost-effective, the distance traveled by the vehicle throughout the cluster should be kept as low as possible. With these clusters, routing costs can be approximated when serving the cluster from a specific depot.

### 4.2.1 Clustering algorithm

Dondo and Cerdá (2007) developed a clustering algorithm to solve a routing problem considering vehicle capacity and time window constraints, see algorithm 1 below. Inputs for the clustering algorithm are the set of carrier nodes ($I$), travel distances ($d_{ij}$) and times between carriers ($t_{ij}$), service times ($st_i$), delivery quantities ($q_i$) and time windows ($[a_i, b_i]$). The earliest arrival time $a_i$ for each carrier is the same and equal to the moment that the newspapers are ready for delivery at the depot. Finally, the maximum distance between any pair of carriers in the same cluster

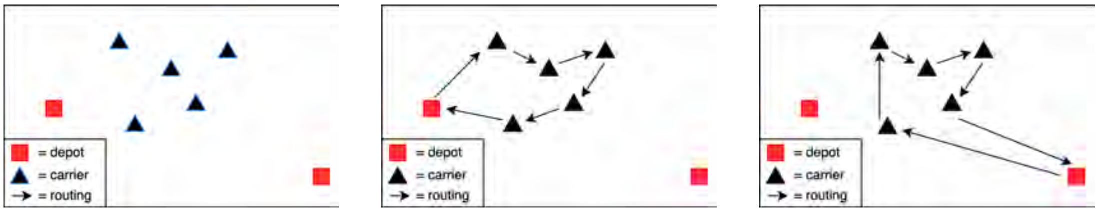
($d^{max}$) has to be set to prevent the algorithm from clustering carriers located very far apart. In our case, to keep the distance traveled by the vehicle throughout the cluster low, this value is set to 10 kilometers. The list with carriers $L$ is properly sorted in step (1) to generate feasible, cost-effective clusters. Before adding another carrier to the cluster, its feasibility is checked regarding the maximum distance to other carriers in the cluster, vehicle capacity and time window constraints (steps 6-8). The following variables are specified for each cluster: cluster time window and cluster service time. The cluster time window is specified by the earliest service start time at cluster $G_n$ ($aG_n$) which is given by $min_{i \in G_n} a_i$ and the latest service start time for $G_n$ ($bG_n$) defined as the minimum of ($bG_n, b_i$). With these variables, the time windows for the current carriers in $G_n$ are all satisfied. Each time a new carrier is added to a cluster, the cluster time window parameters ($aG_n, bG_n$) are updated. Furthermore, the cluster service time ($stG_n$) includes not only the service time at the carriers but also the travel times throughout the cluster.

**Algorithm 1** Clustering algorithm

1: Create list $L$ with carriers and sort them by increasing values of the delivery deadlines.
2: Choose the maximum distance between any pair of carriers in the same cluster ($d^{max}$).
3: Create list $K_n$ belonging to the next cluster $G_n$ to be created.
4: Pick the first carrier $i$ from list $L$ and place it at the bottom of list $K_n$. Initialize the parameters of cluster $G_n$:
$aG_n \leftarrow a_i \qquad qG_n \leftarrow q_i$
$bG_n \leftarrow b_i \qquad stG_n \leftarrow st_i$
5: Delete carrier $i$ from list $L$, make a copy of list $L$ and call it list $L'$.
6: Pick the first carrier $j$ from list $L'$ and verify that the current load to pick up from cluster $G_n$ plus $q_j$ does not exceed the vehicle capacity. If the vehicle capacity is exceeded, delete $j$ from list $L'$ and repeat step (6). Otherwise, proceed to the next step.
7: Compute the distances between $j$ and other carriers in list $K_n$. If these distances are smaller than $d^{max}$, proceed to the next step. Otherwise, delete carrier $j$ from list $L'$ and return to step (6).
8: Check whether the following time window constraint is satisfied:
$aG_n + stG_n + t_{ij} \leq max(bG_n, b_j)$
If not, delete $j$ from list $L'$ and return to step (6). Otherwise, proceed to the next step.
9: place carrier $j$ at the bottom of list $K_n$ and update the parameters for cluster $G_n$:
$qG_n \leftarrow qG_n + q_j \qquad stG_n \leftarrow max(stG_n + t_{ij} + st_j, a_j + st_j - a_i)$
If $bG_n \geq b_j$, then:
$bG_n \leftarrow b_j$
Otherwise, $bG_n$ remains unchanged. Delete carrier $j$ from lists $L$ and $L'$ and proceed to the next step.
10: If list $L'$ is empty, save list $K_n$ defining the cluster $G_n$ and proceed to the next step. Otherwise, return to step (6).
11: Repeat steps (3)-(10) until the list $L$ is empty.

### 4.2.2 Traveling Salesman Problem with Time Windows

For each of these clusters we can calculate the routing costs by solving a Traveling Salesman Problem with Time Windows (TSPTW) in case the cluster is assigned to a specific depot. This situation is visualized in figure 4.1 below, a cluster with five carriers can be assigned to two different depots. The routing is different in case the cluster is assigned to another depot, see figures 4.1b and 4.1c, which results in different costs for these routes.




(a) (b) (c)

Figure 4.1: Vehicle routing cluster-to-depot assignment

Below, we present an MILP formulation of the TSPTW:

Let $V$ be the set consisting of carriers inside the specific cluster, $d$ represents depot under consideration. Besides the notation and variables already defined in section 3, the following decision variable is necessary to formulate the TSPTW:

$$x_{ij} = \begin{cases} 1 & \text{if node } j \in V \cup \{d\} \text{ is directly visited after node } i \in V \cup \{d\} \\ 0 & \text{otherwise} \end{cases}$$

The MILP can be stated as follows:

$$\min \sum_{i \in V \cup \{d\}} \sum_{j \in V \cup \{d\}} c_{ij} x_{ij} \tag{4.8}$$

$$\text{s.t.} \sum_{j \in V \cup \{d\}, j \neq i} x_{ij} = 1 \qquad \forall i \in V \cup \{d\} \tag{4.9}$$

$$\sum_{i \in V \cup \{d\}, i \neq j} x_{ij} = 1 \qquad \forall j \in V \cup \{d\} \tag{4.10}$$

$$\sum_{i \in N} \sum_{j \in V \cup \{d\} \setminus N, j \neq i} x_{ij} \geq 1 \qquad \forall N \subseteq V, 2 \leq |N| \tag{4.11}$$

$$T_i \leq b_i \qquad \forall i \in V \tag{4.12}$$

$$-M(1 - x_{ij}) - (T_j - T_i - t_{ij}) \leq 0 \qquad \forall i, j \in V \tag{4.13}$$

$$M(1 - x_{ij}) - (T_j - T_i - t_{ij}) \geq 0 \qquad \forall i, j \in V \tag{4.14}$$

$$-M(1 - x_{dj}) - (T_j - t_{dj}) \leq 0 \qquad j \in V \tag{4.15}$$

$$M(1 - x_{dj}) - (T_j - t_{dj}) \geq 0 \qquad j \in V \tag{4.16}$$

$$x_{ij} \in \{0, 1\} \qquad \forall i, j \in V \cup \{d\} \tag{4.17}$$

$$T_i \in \mathbb{R}^+ \qquad \forall i \in V \cup \{d\} \tag{4.18}$$

The model above designs a least cost route from one depot to a set of carriers. The objective function (4.8) minimizes the cost of the route. Constraints (4.9) and (4.10) state that every carrier and depot must be visited exactly once. Constraints (4.11) eliminate sub tours. Constraints (4.12) state the delivery deadlines for carriers. Arrival times at the carriers and the starting time of the route are determined by inequalities (4.13)-(4.16). Finally, constraints (4.17)-(4.18) state the binary variables and non-negative time variables.

Considering the problem's NP-hard complexity and the fact that exact approaches can not solve the problem in a reasonable amount of time when considering realistic instances, the use of heuristics is essential in order to solve the problem (Da Silva & Urrutia, 2010). Solomon (1987) studied a number of heuristics including savings algorithm, time-oriented nearest neighbor algorithm, insertion algorithm and time-oriented sweep algorithm for routing problems with time window constraints and additionally constructed a set of benchmark problems to compare the solution procedures. For our problem, since the routing problem just serves as guidance for the location-allocation decisions, there is no need to come up with an optimal solution. However, it is rather important to come up with a reasonable solution. Therefore, a simple heuristic is sufficient for solving the TSPTW. Considering this and Solomon's comparison, the time-oriented nearest neighbor heuristic will be used to solve the TSPTW for each cluster-to-depot assignment.

The nearest-neighbor heuristic starts every route by finding the unrouted carrier closest, in terms of distance, to the depot. At every subsequent iteration, the algorithm searches for a feasible carrier closest to the carrier last added to the route. Feasibility is checked with respect to time window constraints. See algorithm 2.

**Algorithm 2** Time-oriented nearest neighbor heuristic TSPTW

```
Initialize all carriers i ∈ V as unvisited
Start route from depot d
a = d
while not(allCarriersVisited(carrierVisited)) do
    for each unvisited carrier do
        Pick carrier i with lowest distance_ai
        if feasible with respect to time windows then
            Add carrier i to route
            carrierVisited[i] = True, a = i
Add depot d at the end of route
```

The objective values of the TSPTW solutions for all the cluster-to-depot assignments serve as input for the LAP in the name of assignment costs, denoted as $\hat{c}_{dg}$ where $d$ is the depot ($d \in D$) and $g$ represents the cluster ($g \in G$).

## 4.3 Solution approach

With the assignment costs expressed in terms of routing costs, the final step is a model that selects the best combination of depots and assignments of clusters to these depots as well as assignments of depots to hubs into a complete solution.

The notation of the LAP defined in section 4.1 needs some further modification since clusters with carriers will be assigned to depots instead of single carriers. Let $G$ be the set of clusters, together with the new assignment costs $\hat{c}_{dg}$, this leads to the following revised LAP:

$$\min \quad \sum_{d \in D} F_d \cdot y_d + \sum_{h \in H} \sum_{d \in D} c_{hd} \cdot w_{hd} + \sum_{d \in D} \sum_{g \in G} \hat{c}_{dg} \cdot z_{dg} \tag{4.19}$$

$$\text{s.t.} \quad \sum_{h \in H} w_{hd} = 1 \qquad \forall d \in D \tag{4.20}$$

$$\sum_{d \in D} z_{dg} = 1 \qquad \forall g \in G \tag{4.21}$$

$$\sum_{g \in G} q_g \cdot z_{dg} \leq Q_d \cdot y_d \qquad \forall d \in D \tag{4.22}$$

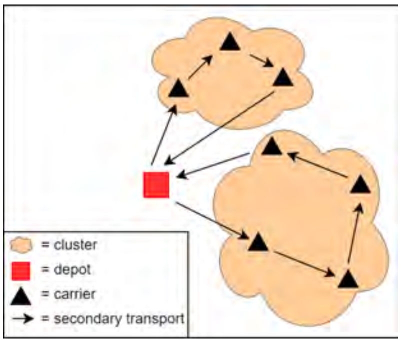
$$y_d \in \{0,1\} \qquad \forall d \in D \tag{4.23}$$

$$z_{dg} \in \{0,1\} \qquad \forall d \in D, g \in G \tag{4.24}$$

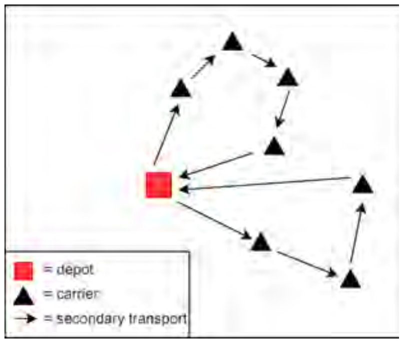
$$w_{hd} \in \{0,1\} \qquad \forall h \in H, d \in D \tag{4.25}$$

For more details about the LAP, the reader is referred to section 4.1. This problem can be optimally solved using commercial solvers.

What follows from the LAP are depot-to-hub as well as cluster-to-depot assignments. The cluster-to-depot assignments together with the routes inside the clusters are visualized in figure 4.2a. Since one carrier of a cluster is very close to the carriers in the other cluster, it could be possible that routes can be further optimized by considering the individual carriers assigned to the specific depot, see figure 4.2b.




(a)




(b)

Figure 4.2: Cluster-to-depot assignment routes

To further optimize the routing decisions, a routing problem needs to be solved for each open depot $d$ which has a set of carriers $V$ assigned to it. This leads to the following VRPTW:

$$\min \sum_{k\in K}\sum_{i\in V\cup\{d\}}\sum_{j\in V\cup\{d\}} c_{ij}x_{ijk} \tag{4.26}$$

$$\text{s.t.} \sum_{i\in V\cup\{d\}}\sum_{j\in V} q_j \cdot x_{ij}^k \leq C_k \qquad \forall K \in K \tag{4.27}$$

$$\sum_{k\in K}\sum_{i\in V\cup\{d\}} x_{ij}^k = 1 \qquad \forall j \in V \tag{4.28}$$

$$\sum_{j\in V\cup\{d\}} x_{ij}^k - \sum_{j\in V\cup\{d\}} x_{ji}^k = 0 \qquad \forall k \in K, i \in V \tag{4.29}$$

$$\sum_{j\in V\cup\{d\}} x_{dj}^k = 1 \qquad \forall k \in K \tag{4.30}$$

$$\sum_{i\in V\cup\{d\}} x_{id}^k = 1 \qquad \forall k \in K \tag{4.31}$$

$$\sum_{k\in K}\sum_{i\in N}\sum_{j\in V\cup\{d\}\setminus N} x_{ij}^k \geq 1 \qquad \forall N \subseteq I, 2 \leq |N| \tag{4.32}$$

$$T_i \leq b_i \qquad \forall i \in V \tag{4.33}$$

$$-M(1-x_{ij}^k) - (T_j - T_i - t_{ij}) \leq 0 \qquad \forall i \in V, j \in V, k \in K \tag{4.34}$$

$$M(1-x_{ij}^k) - (T_j - T_i - t_{ij}) \geq 0 \qquad \forall i \in V, j \in V, k \in K \tag{4.35}$$

$$-M(1-x_{dj}^k) - (T_j - t_{dj}) \leq 0 \qquad \forall j \in V, k \in K \tag{4.36}$$

$$M(1-x_{dj}^k) - (T_j - t_{dj}) \geq 0 \qquad \forall j \in V, k \in K \tag{4.37}$$

$$x_{ij}^k \in \{0,1\} \qquad \forall i,j \in V \cup \{d\}, k \in K \tag{4.38}$$

$$T_i \in \mathbb{R}^+ \qquad \forall i \in V \cup \{d\} \tag{4.39}$$

The model above designs least cost routes from one depot to a set of carriers. The objective function (4.26) minimizes the total cost incurred by the fleet of vehicles. Constraints (4.28) ensures that each carrier is visited exactly once, and (4.27) are the vehicle capacity constraints. The constraints (4.29)-(4.31) ensure that each vehicle starts and ends its route at the depot, and after arriving at a carrier the vehicle leaves again. Constraints (4.32) eliminates sub tours. Constraints (4.33) state the delivery deadlines for carriers. Arrival times at the carriers and the starting time of the route are determined by inequalities (4.34)-(4.37). Finally, constraints (4.38)-(4.39) state the binary variables and non-negative time variables.

Just like TSPTW, the VRPTW is also NP-hard problem. Therefore, also for this problem, the time-oriented nearest neighbor heuristic will be used to solve the problem. However, the nearest neighbor heuristic for the TSPTW needs some modification to account for the design of multiple routes in the VRPTW. After initializing all the empty vehicles and carriers, an empty vehicle is taken. This vehicle starts at the depot and all the carriers that have not been visited yet are evaluated, now the carrier with the lowest distance from the depot is added to the route. From this carrier, all other unvisited carriers are evaluated and the one with the lowest distance is added to the route in case its insertion is feasible with respect to time windows. This step is repeated until vehicle capacity is reached. In this case, the vehicle returns to the depot. If not all carriers in the segment are assigned to a route, the algorithm starts over with a new route and all the steps are repeated. See algorithm 3.

**Algorithm 3** Time-oriented nearest neighbor heuristic VRPTW

Initialize all the empty vehicles $k \in K$
Initialize all carriers $i \in V$ as unvisited
**while** $not(allCarriersVisited(carrierVisited))$ **do**
  Start route $r$ with an empty vehicle $k$ starting from depot $d$
  Add unvisited carrier $i$ with lowest $t_{di}$ to route $r$
  *carrierVisited[i] = True, a = i*
  **while** $vehicleLoad \leq vehicleCapacity$ **do**
    Pick unvisited carrier $i$ with lowest $distance_{ai}$
    **if** feasible with respect to time windows **then**
      Add carrier $i$ to route $r$
      *carrierVisited[i] = True, a = i*
  Add depot $d$ at the end of route $r$

## 4.4 Concluding remarks

This section described all the undertaken steps to solve the problem in detail. Summarizing, the heuristic solution approach consists of the following steps:

1. Cluster the carriers using clustering algorithm
2. Calculate assignment costs for each cluster-to-depot link by solving TSPTW
3. Solve LAP with these assignment costs and the designed clusters
4. Solve VRPTW for each open depot in the LAP solution

# Chapter 5

# Data

To determine the best distribution network design for the problem of de Persgroep Nederland, we first need to acquire data about their distribution process. This chapter provides an overview of the relevant data.

## 5.1 Data analysis

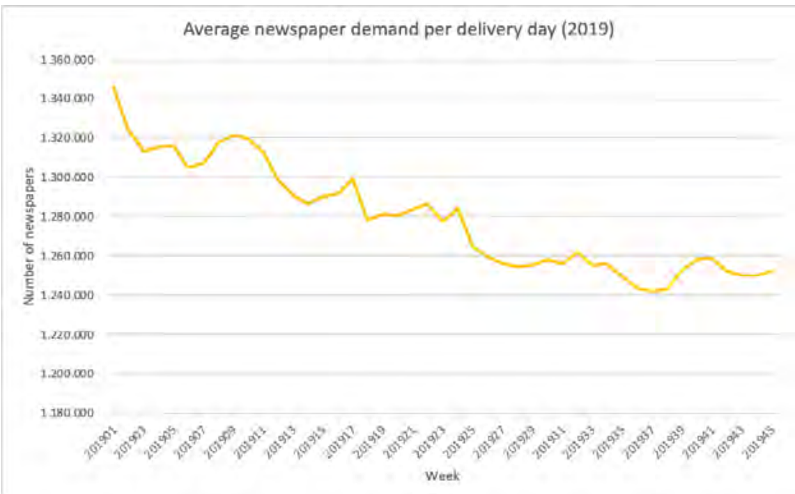



Figure 5.1: Average newspaper demand per delivery day (2019)

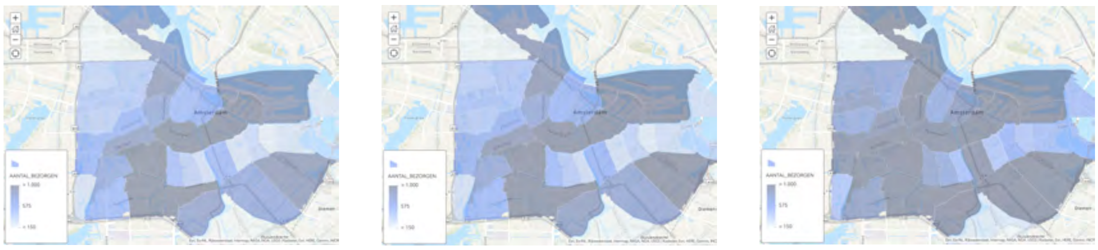
Newspaper delivery is all based on newspapers demanded by subscribers. A demand distribution, in terms of average newspaper demand per delivery day, for each week in 2019 (up to week 45) is visualized in figure 5.1. Again, a decrease in the sales of printed newspapers can be seen.

De Persgroep Nederland has provided one week of data in order to conduct a case study. The characteristics of the different days throughout the week can be found in table 5.1. There are differences among the different days throughout the week, Tuesday and Wednesday are the quietest days of the week and from Thursday to Saturday, the number of subscribers, and thus the newspaper demand, increases drastically. As expected, the demand on Saturday is about 20% higher compared to a weekday. These demand values are lower compared to the ones in figure 5.1 above, since newspapers delivered to subscribers in rural areas by means of vehicles are out of scope for the case study.

| | Monday | Tuesday | Wednesday | Thursday | Friday | Saturday |
|---|---|---|---|---|---|---|
| **# Newspapers** | 879261 | 870419 | 870424 | 886828 | 898049 | 1078425 |
| **# Subscribers** | 809685 | 800850 | 800857 | 817053 | 828293 | 1007603 |
| **# Carriers** | 4576 | 4583 | 4571 | 4567 | 4560 | 4576 |

Table 5.1: Data characteristics

Also when taking a deeper look at the newspaper demand per zip code on each of the delivery days, see appendix C, it can be seen that there are only minor differences in the newspaper demand from Monday to Friday. However, on Saturday, the newspaper demand is way higher and also more zip codes are involved. A region where this effect is visible is Amsterdam, see figure 5.2. The colors of the zip codes are the same on Monday and Thursday, but on Saturday the zip codes are darker, indicating that the newspaper demand is higher. Furthermore, the demand region is extended to other zip codes on Saturday, as can be seen in the lower part of Amsterdam. From table 5.1 can be deduced that the number of carriers on each of the delivery days is about the same. Obviously, this makes the Saturday a challenging day since a lot more newspapers have to be delivered with about the same number of carriers. Because of this, de Persgroep Nederland promises newspaper delivery before 8 a.m. on Saturday, whereas the delivery deadline on weekdays is set to 7 a.m.



(a) Monday (b) Thursday (c) Saturday

Figure 5.2: Newspaper demand per zip code in Amsterdam

## 5.2 Data preparation

### 5.2.1 Newspaper demand and delivery deadlines

The available data for a few subscribers is shown in table 5.2. Each subscriber is linked to a depot ($d$), this link determines to which depot the newspapers should be transported such that the carrier responsible for the specific subscriber can pick up the newspapers there. Obviously, this existing link is ignored in our model since the aim is to determine where to open depot locations and which subscribers to serve from these depot locations. Moreover, each subscriber assigned to a segment (OID), which comprises a few streets with subscribers. Also, data regarding the demanded number of newspapers (#) and geographical data about the subscribers' location, Longitude and Latitude, are available.

| $d$ | Depot name | OID | OID name | # | Longitude | Latitude |
|---|---|---|---|---|---|---|
| 1821200 | DP LELYSTAD | 70821201 | 1201 ATOL | 1 | 5.49275 | 52.513108 |
| 3760400 | DP ALMELO NOORD | 5760513 | AADORP 513 | 1 | 6.626869 | 52.372561 |
| 3436371 | DP AAGTEKERKE | 3436371 | AAGTEKERKE 1 | 1 | 3.507148 | 51.54713 |
| 3530100 | DP ZALTBOMMEL | 3530870 | AALST 1 | 2 | 5.131012 | 51.784891 |

Table 5.2: Example of subscribers' data

These newspapers are delivered by carriers to the subscribers. Also for the carriers, different data is provided as shown in table 5.3, whereby each carrier has an unique personnel number ($i$).

Carriers are, just like subscribers, linked to a depot ($d$), where they pick up the newspapers, and segment (OID) in which they serve different subscribers. The data set also contains geographical data about the carrier's location (Longitude and Latitude).

| $i$ | $d$ | Depot name | OID | OID name | Longitude | Latitude |
|---|---|---|---|---|---|---|
| 19572412 | 1821200 | DP LELYSTAD | 70821201 | 1201 ATOL 3 | 5.489947 | 52.498794 |
| 19892006 | 3760400 | DP ALMELO NOORD | 5760301 | ALMELO NOORD 301 | 6.687556 | 52.379309 |
| 10310677 | 3436371 | DP AAGTEKERKE | 3436371 | AAGTEKERKE 1 | 3.612686 | 51.487603 |
| 15565231 | 3530100 | DP ZALTBOMMEL | 3530101 | ZALTBOMMEL WIJK 01 | 5.234251 | 51.80445 |

Table 5.3: Example of carriers' data

Finally, there is data available about the segments with subscribers, see table 5.4. Every delivery day, each segment is served by a specific carrier ($i$) and has a delivery time depending on the size of the segment in terms of newspaper demand and distance.

| OID | $i$ | Delivery time |
|---|---|---|
| 1280101 | 18167591 | 9 |
| 1280111 | 19469355 | 3 |
| 1280801 | 9597357 | 8 |
| 1280849 | 1858467 | 26 |

Table 5.4: Example of segments' data

In the new logistic structure, newspapers will be delivered to the carrier homes. Therefore, for each subscriber in a segment, the demand is summed up to construct a segment-level aggregated data. Using this, a new data set with all the carriers and the required information will be created by combining the three previously discussed data sets, as visualized in table 5.5. The $q_i$ column contains the number of newspapers that should be delivered to the carrier, which is equal to the sum of newspaper demands in segments served by that specific carrier. The delivery deadline ($b_i$) for each carrier is calculated by subtracting the required time to deliver newspapers in the segments served by that specific carrier from the delivery deadline promised to subscribers.

| $i$ | $d$ | $q_i$ | $b_i$ | Longitude | Latitude |
|---|---|---|---|---|---|
| 7232038 | 1385100 | 1428 | 270 | 5.463684 | 52.179451 |
| 20282452 | 3524500 | 360 | 360 | 5.369357 | 51.721349 |
| 13166650 | 3512100 | 960 | 309 | 4.924436 | 51.591512 |
| 16354916 | 3833100 | 206 | 380 | 6.127342 | 52.795858 |

Table 5.5: Example of combined data set

### 5.2.2 Depot locations

The network design also requires possible locations to open depots. As stated in section 1, de Persgroep Nederland currently operates 449 depots. For all these locations the following data is available:

| $d$ | Depot name | Longitude | Latitude | M$^2$ | $F_d$ | $Q_d$ |
|---|---|---|---|---|---|---|
| 3565300 | DP EINDHOVEN-GESTEL | 5.471068 | 51.432022 | 25 | 200 | 2420 |
| 1247100 | DP ZWAMMERDAM | 4.7293590 | 52.1050590 | 6 | 50 | 330 |
| 3772100 | DP DALFSEN | 6.2603710 | 52.5203740 | 20 | 250 | 1870 |
| 3653100 | DP NYMEGEN MIDDEN | 5.8442880 | 51.8318220 | 100 | 609.93 | 10670 |

Table 5.6: Example depot locations data set

As can be seen in table 5.6 above, these locations all vary in size (M$^2$). Furthermore, the monthly rent ($F_d$) for all these locations is different as it is based on their geographical location. The capacity ($Q_d$) for each possible depot location is calculated using the following formula: $(M^2 - V) \cdot 110$, where $V$ is space reserved for facilities in the depot, such as toilets, and 110 is the assumed number of newspapers that can be handled per square meter. This value is set to 110 based on experience and in consultation with the management of de Persgroep Nederland. The monthly rent can be converted to daily depot opening costs as follows: $F_d \cdot \frac{12}{307}$, where 307 equals the number of delivery days in a year.

### 5.2.3 Vehicle routing

Besides the data related to carriers and depot locations, input values for the vehicle routing are required. Many different types of vehicles are used for transportation of newspapers, from small personal cars to large trucks, depending on the required number of newspapers for the route. For the distribution from depots to carriers, it is common to use a van with a loading capacity of 750 kg. We have therefore chosen to use this type of vehicle for all of the vehicle fleet. Input data for these calculations are given in table 5.7. As already explained in section 1.1.2, newspapers contain more attachments and thus more pages on Saturday, making them heavier compared to weekday newspapers.

| | Weekday | Saturday |
|---|---|---|
| **Vehicle loading capacity** | 750 kg | 750 kg |
| **Avg. weight for one newspaper copy** | 500 gram | 650 gram |

Table 5.7: Vehicle capacity input

The resulting vehicle capacities ($C_k$) are 1500 and 1200 newspapers per vehicle respectively.

The distribution costs consist of two variable cost elements, one part depends on the traveled distance and the other on the route duration. The coordinates of hub locations, depot locations and carriers are used to calculate distances ($d_{ij}$) as well as travel times ($t_{ij}$). This is done with software (Python) with support of a library *googlemaps*, calculating the values just like Google Maps does. Table 5.8 shows the additional data needed to find routing costs ($c_{ij}$). These parameters are also used by de Persgroep Nederland to calculate the payments to logistics suppliers.

| | Hub-depot | Depot-carrier |
|---|---|---|
| **Costs per km** | €0.25 | €0.19 |
| **Costs per hour** | €17.00 | €10.60 |
| **Preparation time for route** | 30 min | 10 min |
| **Unloading time per stop** | 10 min | 2 min |

Table 5.8: Routing cost input

# Chapter 6

# Model results

Given the input values described in section 5, a series of computational experiments are conducted to analyze the performance of our heuristic solution approach. We employed the Python programming language to implement the MILP models and the commercial solver Gurobi version 8.0.0 to solve it. We carried out all the tests on an Intel(R) Core(TM) i5-7360U @ 2.3 GHz and 8.0 GB in RAM. First, the algorithm will be applied to the reference data sets of our case-study. The performance will be compared to the current performance and different solutions will be evaluated. After presenting the results, a sensitivity analysis and a scenario analysis are performed.

## 6.1 Distribution network design

The numerical results of the optimal distribution network design are presented in table 6.1. One of the decisions the model had to make was the number and locations of depots to open in between the hubs and the carriers. Given the routing costs in the clusters, it resulted for all weekdays in about the same number of open depots. On Saturday, the number of open depots is higher. Looking at which depots are opened, see figure 6.1, where the color indicates on how many delivery days the specific depot is opened. It can be concluded that only 81 depots are opened on each delivery day, resulting in a small overlap. In order to operate the distribution network during all days of the week, 249 depots need to be opened. When looking at the number of secondary routes, it is remarkable that there are so much more routes on Saturday relative to the difference in newspaper demand. This can be explained by the fact that the vehicle capacity on Saturday is lower as already explained in section 5.2.

| | **Monday** | **Tuesday** | **Wednesday** | **Thursday** | **Friday** | **Saturday** |
|---|---|---|---|---|---|---|
| **Fixed costs** | €2677.72 | €2626.07 | €2635.16 | €2668.92 | €2786.44 | €3139.54 |
| **Number of open depots** | 152 | 154 | 154 | 152 | 156 | 175 |
| **Costs primary routes** | €6487.49 | €6474.30 | €6525.08 | €6431.25 | €6560.46 | €7183.52 |
| **Costs secondary routes** | €9362.31 | €9389.36 | €9430.59 | €9549.39 | €8992.33 | €11532.51 |
| **Number of secondary routes** | 623 | 618 | 621 | 630 | 612 | 941 |
| **Total costs** | €18572.52 | €18489.73 | €18590.83 | €18649.56 | €18339.23 | €21855.57 |
| **Computation time** | 7:17 hrs | 10:13 hrs | 7:06 hrs | 8:09 hrs | 15:54 hrs | 18:56 hrs |

Table 6.1: Distribution network design solutions

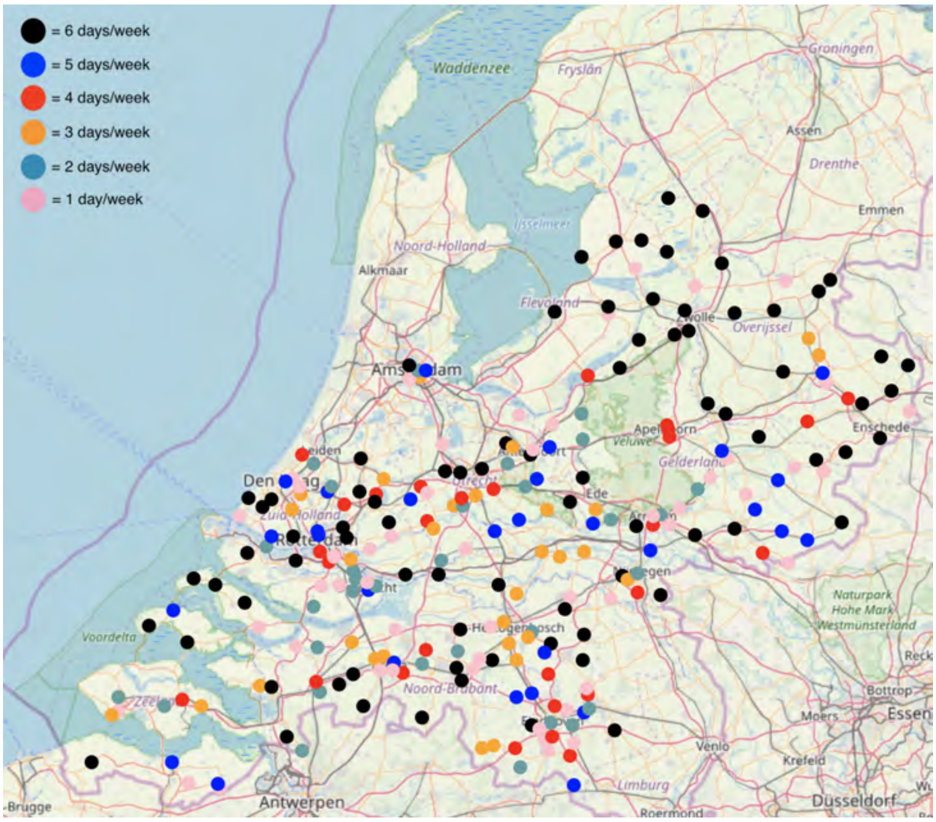
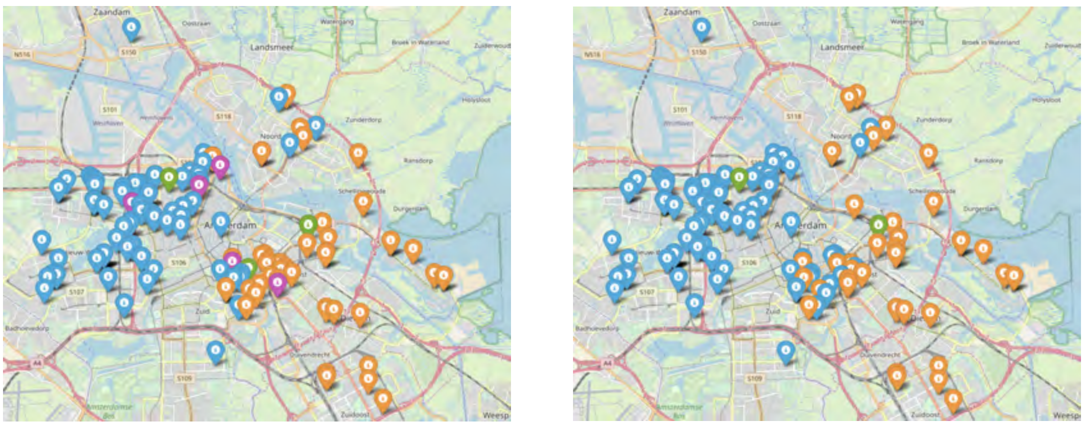



Figure 6.1: Open depot locations

After having discussed the open depots, the carrier-to-depot assignments will be explored in more detail. In section 5.1, the differences in newspaper demand per zip code in Amsterdam between weekdays and Saturday were visualized. It would be interesting to see how this influences the distribution network design. As can be seen in figure 6.2, the amount of carriers that need to be supplied is the same between Monday, Thursday and Saturday. However, because the newspaper demand on Saturday is higher, additional depots are opened resulting in five open depots on Saturday. On Monday and Thursday, three and two depots are opened respectively. The colors indicate by which depot the carriers are supplied.



(a) Monday (b) Thursday

(c) Saturday

Figure 6.2: Open depot locations Amsterdam

Following the fact that the set of depot locations differs significantly between the different days of the week and considering that it is inconvenient to rent a depot location just for one delivery day per week, it is necessary to find a set of depot locations that can be operated all week as already mentioned in section 3. Since most capacity is required on Saturday, it is reasonable to use these depot locations on each delivery day. Obviously, by using these depot locations, solutions for the weekdays are not optimal anymore. However, with the requirement that the same set of depot locations should be operated all week and to use depot locations as efficient as possible, this still results in an optimal solution for the entire week. This changes the numerical results for weekdays as presented in table 6.2. In total, 175 out of 449 depot locations are used in the optimal distribution network design. Of course, the number of open depots, and thus fixed costs, are the same for each day. There are minor differences in the costs for primary routes between the delivery days due to the fact that some depot locations are still not used on weekdays. Furthermore, the shift to a sub optimal set of depots on weekdays leads to additional secondary routes. Logically, this results in higher costs for secondary routes on Monday and Friday. However, costs for secondary routes decrease on Tuesday, Wednesday and Friday. This decrease can be explained by the fact that because more depots are opened than required, depots are located closer to the carriers, which decreases the average route length, resulting in lower costs for secondary routes. Still, the increase in the number of depot locations as well as the number of secondary routes results in more total costs, about six percent, on weekdays compared to the best solutions.

| | **Monday** | **Tuesday** | **Wednesday** | **Thursday** | **Friday** | **Saturday** |
|---|---|---|---|---|---|---|
| **Fixed costs** | €3139.54 | €3139.54 | €3139.54 | €3139.54 | €3139.54 | €3139.54 |
| **Number of open depots** | 175 | 175 | 175 | 175 | 175 | 175 |
| **Costs primary routes** | €7041.75 | €7071.14 | €7135.38 | €7135.38 | €7092.53 | €7183.52 |
| **Costs secondary routes** | €9458.78 | €9337.48 | €9419.65 | €9406.34 | €9281.87 | €11532.51 |
| **Number of secondary routes** | 635 | 626 | 626 | 633 | 637 | 941 |
| **Total costs** | €19640.07 | €19548.16 | €19694.57 | €19681.26 | €19513.94 | €21855.57 |

Table 6.2: Distribution network design solutions with Saturday depot locations

Looking at the chosen depot locations, it can be concluded that mainly small depots together with some larger depots are opened, see figure 6.3. Some depots are used for supplying a lot of carriers, e.g. Houten Noord and Zwijndrecht, whereas others are only serving a small amount of carriers, e.g. Oldemarkt and Gramsbergen. The model uses the latter ones to serve carriers located very far in the northern part of the country. Apparently, is is cheaper to open depots Oldemarkt and Gramsbergen and to allocate a few carriers to it, than to allocate these carriers to another depot and incur extra costs for vehicle routes.

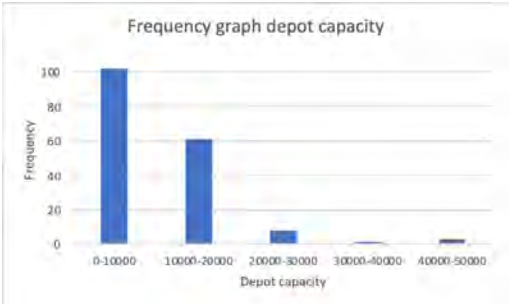



Figure 6.3: Frequency graph capacity of open depot locations

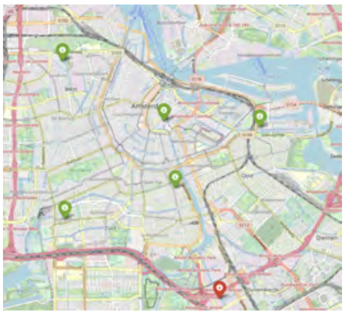


Figure 6.4: Open depot locations together with hub Amsterdam

The fact that mainly small depots are opened raises the question whether it would be beneficial to substitute these small depots by one larger depot and serve all the carriers from this location. For example in Amsterdam, see figure 6.4, the hub (red) is located very close to the open depot locations. Since the city centre of Amsterdam is very busy and the streets are narrow, using the hub as large size depot could be a viable option. When replacing the five open depot locations by the hub, extra routing costs of €140.69 are incurred, since carriers are further away. However, fixed costs (€151.05) are saved because five depots are disestablished. Altogether this would save about 10 euros on Saturday. Considering that also time is saved since carriers are directly supplied from the hub, this option creates flexibility. Also in Breda, shifting the activities of four depots to the hub saves about €35 on Saturday. On weekdays this could lead to even more savings since more depots than required are opened. Hence, depot capacity utilization is less efficient on weekdays.

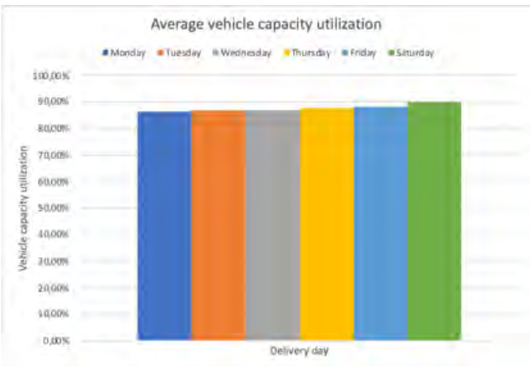
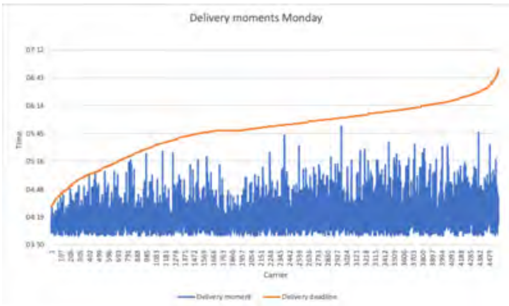


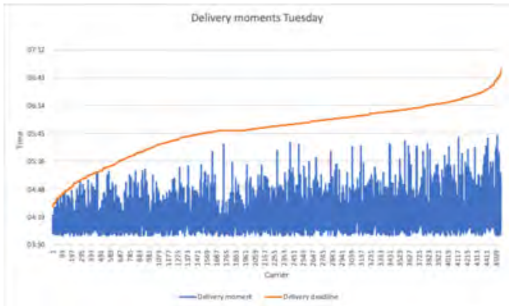

Figure 6.5: Average vehicle capacity utilization

The second part constitutes the vehicle routes from the depot locations to carriers, which consists of about 630 vehicle routes on weekdays and about 940 vehicle routes on Saturday. This is due to the higher volume and lower vehicle capacity on Saturday. The average vehicle capacity utilization on each delivery day is depicted in figure 6.5. From this figure can be concluded that vehicles are in general fully loaded.

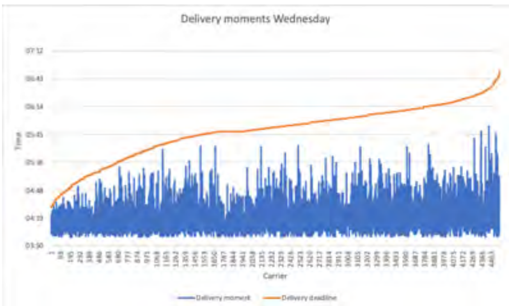
The delivery moments for each carrier (depicted in blue) together with the delivery deadlines (depicted in orange) are visualized in figure 6.6. Carriers are sorted according to their delivery deadline, which explains the upward trend in the orange line. From these figures can be concluded that in general, time constraints are not tight, hence carriers receive the newspapers well in advance. Especially on Saturday there are large differences between the delivery moments and delivery deadlines, since vehicle routes are on average shorter due to a lower vehicle capacity and larger volumes shipped to carriers. Bottlenecks in the distribution network design are mainly caused by the carriers that have a very early delivery deadline because they serve a wide area with subscribers. For example, on Monday 7.5 percent of the carriers have a delivery deadline between 4:30 and 5 a.m. Most of these carriers receive the newspapers just in time as can be seen in the left part of figures 6.6a-6.6e.



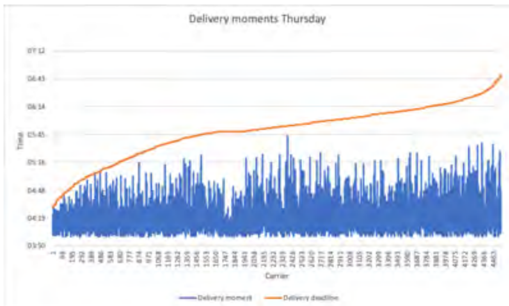

(a) Monday



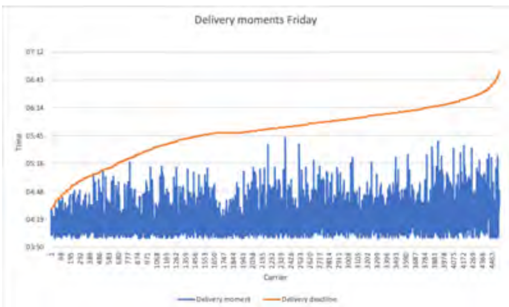

(b) Tuesday



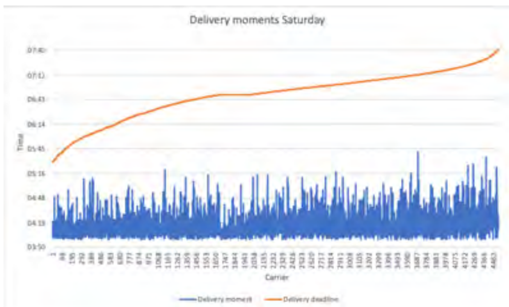

(c) Wednesday




(d) Thursday




(e) Friday




(f) Saturday

Figure 6.6: Tightness of time constraints

After having discussed all the details of the new distribution network design, the new distribution network will be compared to the current distribution network, see table 6.3. As earlier explained, carriers pick up the newspapers by bicycle at the depots in the current situation, therefore a lot of depots are operated. Leading to high fixed costs on each delivery day. Also, because of this, there are no costs for secondary routes. However, there are costs for primary transport since a lot of depots have to be supplied by the hubs. When comparing the new distribution network design solution with the current situation, it can be concluded that less depots are opened since, by introducing vehicle routes, there is no need to open depots very close to carriers any more. This leads to a sharp decrease in fixed costs, however extra costs for secondary routes are incurred. Also, because of the decrease in the number of open depots, costs for primary routes decrease. Altogether, about €26000 per week can be saved by using the new distribution network design.

| | **Monday** | **Tuesday** | **Wednesday** | **Thursday** | **Friday** | **Saturday** |
|---|---|---|---|---|---|---|
| *Current situation* | | | | | | |
| **Fixed costs** | €10937.44 | €10937.44 | €10937.44 | €10937.44 | €10937.44 | €10937.44 |
| **Number of open depots** | 454 | 454 | 454 | 454 | 454 | 454 |
| **Costs primary routes** | €13184.40 | €13184.40 | €13184.40 | €13184.40 | €13284.46 | €14388.46 |
| **Total costs** | €24121.84 | €24121.84 | €24121.84 | €24121.84 | €24221.90 | €25325.90 |
| *New situation* | | | | | | |
| **Fixed costs** | €3139.54 | €3139.54 | €3139.54 | €3139.54 | €3139.54 | €3139.54 |
| **Number of open depots** | 175 | 175 | 175 | 175 | 175 | 175 |
| **Costs primary routes** | €7041.75 | €7071.14 | €7135.38 | €7135.38 | €7092.53 | €7183.52 |
| **Costs secondary routes** | €9458.78 | €9337.48 | €9419.65 | €9406.34 | €9281.87 | €11532.51 |
| **Number of secondary routes** | 635 | 626 | 626 | 633 | 637 | 941 |
| **Total costs** | €19640.07 | €19548.16 | €19694.57 | €19681.26 | €19513.94 | €21855.57 |
| *Difference* | | | | | | |
| **Fixed costs difference** | -€7797.90 | -€7797.90 | -€7797.90 | -€7797.90 | -€7797.90 | -€7797.90 |
| **Costs primary routes difference** | -€6142.65 | -€6113.26 | -€6049.02 | -€6049.02 | -€6191.93 | -€7204.94 |
| **Costs secondary routes difference** | €9458.78 | €9337.48 | €9419.65 | €9406.34 | €9281.87 | €11532.51 |
| **Total costs difference** | -€4481.77 | -€4573.68 | -€4427.27 | -€4440.58 | -€4707.96 | -€3470.33 |

Table 6.3: Comparison distribution costs current and new situation

## 6.2 Sensitivity and scenario analysis

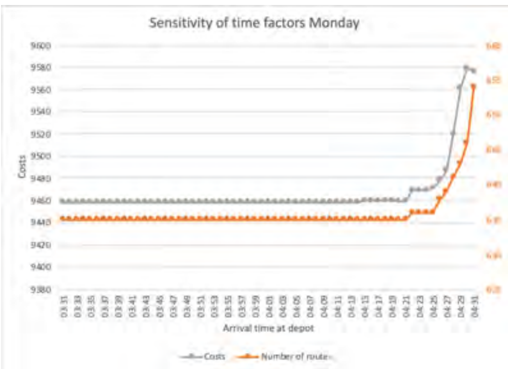
The sensitivity analysis explains how changes in parameters influence the distribution network design that results from the above described models. Simulations tailored to every delivery day will be run in different configurations such that the optimal result can be put in perspective. Finally, a scenario analysis in terms of a controlled experiment is executed to check for changing circumstances of de Persgroep Nederland.

### 6.2.1 Sensitivity analysis

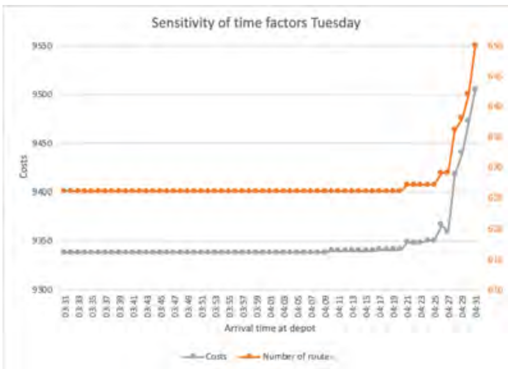
In order to check the sensitivity of the model based on certain parameters, input parameters are changed. These input parameters are the time factors related to the moment that newspapers are ready for delivery at the depots, vehicle capacities and depot capacities. Note that the solution and costs in each analysis is presented compared to the distribution network design solutions presented in table 6.2.

#### Time factors

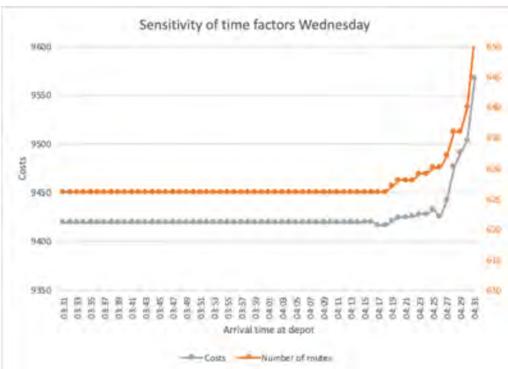
The most important performance measure in the distribution network of de Persgroep Nederland is the timely delivery of newspapers to the subscribers. In order to ensure this, newspapers should arrive at the depot on time. The moment that newspapers are ready for delivery at the depot is set to 4 a.m. in the model. In the sensitivity analysis, the effect of earlier and later arrival of the newspapers at the depots is analyzed. The results for each delivery day are presented in figure 6.7. The values on the horizontal axis refer to the moment that the newspapers are ready for delivery at the depot, costs flow is depicted with the grey line and the orange line represents the number of routes.



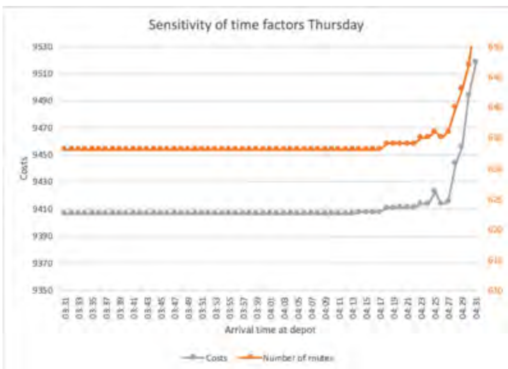

(a) Monday



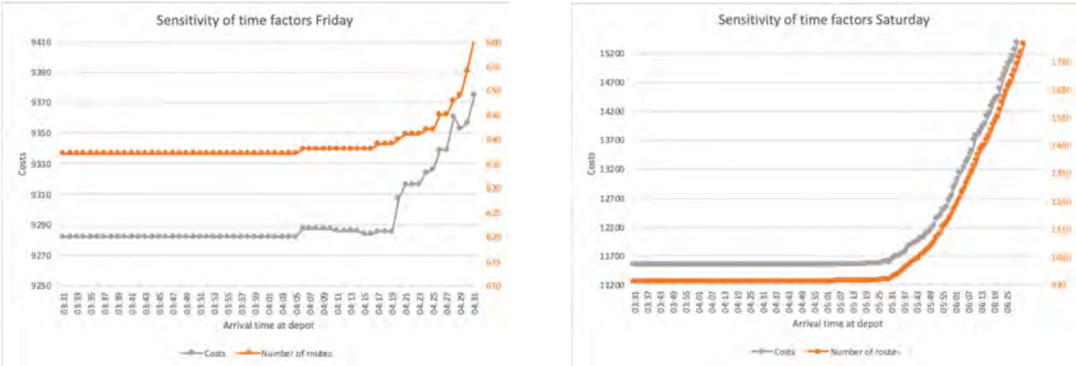

(b) Tuesday




(c) Wednesday




(d) Thursday




(e) Friday (f) Saturday

Figure 6.7: Sensitivity analysis of time factors

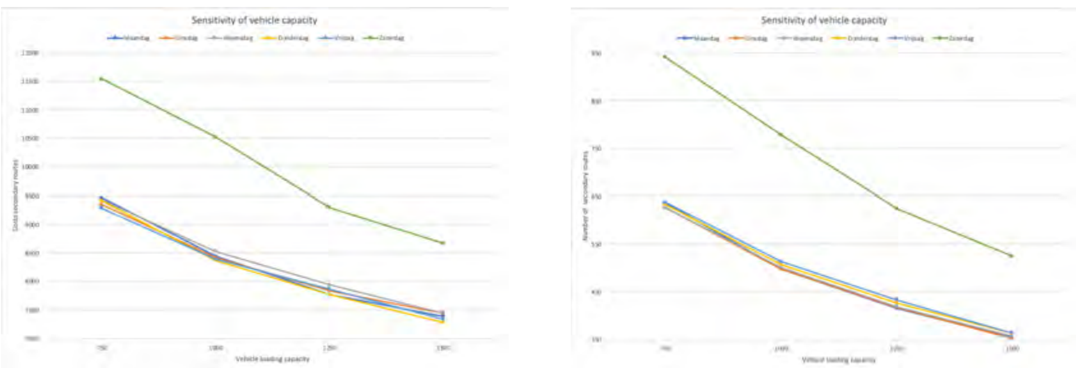
Neither total costs nor the number of routes change when the newspapers are dropped earlier at the depots. This can be explained by the fact that the vehicle capacity limits the number of carriers that can be served in one route, therefore earlier arrival at the depot does not lead to different routes. When delaying the time factor, very little change occurs until 4:20 a.m. After that, the number of routes, and thus total costs, increases exponentially. Since some carriers have to receive the newspapers very early, extra routes may be necessary to serve all the carriers on time in case newspapers arrive later at the depot. On Saturday, no change occurs until 5:30 a.m., since routes are on average shorter due to the lower vehicle capacity. Also, there is more flexibility because of the higher volumes shipped to carriers as already shown in figure 6.6f.

### Vehicle capacity

The fact that vehicles are in general fully loaded raises the question how a change in vehicle capacity affects the optimal solution in terms of number of secondary routes. The effect of the vehicle capacity is reviewed for the following input values:

| | | | | |
|---|---|---|---|---|
| **Vehicle loading capacity** | 750 kg | 1000 kg | 1250 kg | 1500 kg |
| **Vehicle capacity weekday** | 1500 | 2000 | 2500 | 3000 |
| **Vehicle capacity Saturday** | 1200 | 1500 | 1900 | 2300 |

Table 6.4: Vehicle capacity input for sensitivity analysis




(a) Costs secondary routes (b) Number of secondary routes

Figure 6.8: Sensitivity analysis of vehicle capacity

The vehicle capacity was initially set to 1500 newspapers on weekdays and 1200 newspapers on Saturday, as discussed in section 5.2.3. The effect of changing this parameter on the number of secondary routes as well as the costs for secondary routes is shown in figure 6.8. The number of secondary routes, and thus the costs for secondary routes, decreases if the vehicle capacity is increased. This decrease is steeper in the beginning, because when the vehicle capacity is further increased, time windows become a restriction and not more carriers can be delivered from one vehicle. Hence, the vehicle capacity is quite sensitive to the number of secondary routes.

**Depot capacity**

Other restrictions in the model are the depot capacities. If we relax these restrictions, it can be identified where installing excess capacity would be beneficial. Violation of depot capacity constraints will be allowed through penalty costs. First the setting of the penalty parameter related to the depot capacities will be explained. After that, the configuration of the distribution network will be analyzed.

As already mentioned, each unit above the depot capacity is penalized by a given amount in the objective function. If the penalty costs are set to a huge value relative to the depot opening costs, the constraint will only be violated when there is no other solution to reach feasibility. However, the penalty costs should be set to a value that makes violating the constraint possible only if there is some opportunity to save costs. This is the case if we choose to set the penalty equal to the unit capacity cost. Figure 6.9 illustrates the total depot cost as a function of the depot volume. This situation means that if the depot volume is greater than the depot capacity ($Q_d$), we pay an unit cost equal to $\frac{F_d}{Q_d}$, $F_d$ is the depot opening cost and $Q_d$ is the depot capacity. On the other hand, if the depot volume is less than the depot capacity, then regardless to the quantity, costs equal to the depot opening cost ($F_d$) have to be paid.

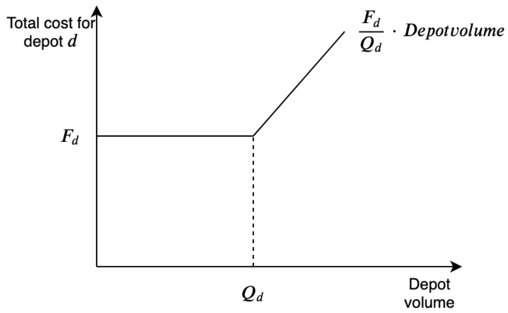



Figure 6.9: Total depot cost as a function of the volume

When comparing the distribution costs for the model with depot capacity constraints and the model where depot capacity constraints can be violated (table 6.5), it can be concluded that about €800 per week can be saved by installing excess capacity at some depots. Obviously, these savings are mainly the result of a reduction in costs for secondary routes since carriers are assigned to another depot if this saves costs. Fixed costs increase due to the penalty costs for excess capacity and costs for primary routes change because different volumes need to be transported to the depots. Altogether, the depot capacity is not a limiting factor since its effect on the costs is very small, however installing excess capacity at some depot locations can be beneficial.

| | Monday | Tuesday | Wednesday | Thursday | Friday | Saturday |
|---|---|---|---|---|---|---|
| *Depot capacity constraints* | | | | | | |
| **Fixed costs** | €3139.54 | €3139.54 | €3139.54 | €3139.54 | €3139.54 | €3139.54 |
| **Number of open depots** | 175 | 175 | 175 | 175 | 175 | 175 |
| **Costs primary routes** | €7041.75 | €7071.14 | €7135.38 | €7135.38 | €7092.53 | €7183.52 |
| **Costs secondary routes** | €9458.78 | €9337.48 | €9419.65 | €9406.34 | €9281.87 | €11532.51 |
| **Number of secondary routes** | 635 | 626 | 626 | 633 | 637 | 941 |
| **Total costs** | €19640.07 | €19548.16 | €19694.57 | €19681.26 | €19513.94 | €21855.57 |
| *Depot capacity violation* | | | | | | |
| **Fixed costs** | €3147.29 | €3153.40 | €3156.14 | €3165.45 | €3160.93 | €3189.36 |
| **Number of open depots** | 175 | 175 | 175 | 175 | 175 | 175 |
| **Costs primary routes** | €7075.62 | €7072.85 | €7126.40 | €7126.40 | €7126.40 | €7178.40 |
| **Costs secondary routes** | €9212.39 | €9198.52 | €9263.52 | €9287.68 | €9146.03 | €11303.40 |
| **Number of secondary routes** | 634 | 622 | 626 | 634 | 638 | 945 |
| **Total costs** | €19442.30 | €19424.77 | €19546.06 | €19579.53 | €19433.36 | €21671.16 |
| *Difference* | | | | | | |
| **Fixed costs difference** | €7.75 | €13.86 | €16.60 | €25.91 | €21.39 | €49.82 |
| **Costs primary routes difference** | €33.87 | €1.71 | -€8.98 | -€8.98 | €34.05 | -€5.12 |
| **Costs secondary routes difference** | -€246.39 | -€138.96 | -€156.13 | -€118.66 | -€135.84 | -€229.11 |
| **Total costs difference** | -€197.77 | -€123.39 | -€148.51 | -€101.73 | -€80.58 | -€184.41 |

Table 6.5: Comparison distribution costs depot capacity constraints and depot capacity violation

The depot locations with exceeded depot capacity are outlined in table 6.6. The values in the table indicate how much the depot capacity is exceeded on each delivery day. In case there is no value shown for a certain day or depot, it means that the depot capacity is not exceeded. The capacity of depot locations in the upper part of the table is exceeded on each delivery day, whereas the capacity of depot locations at the bottom is exceeded only on one of the delivery days. From the table can be concluded that on Saturday, the capacity of many depot locations is exceeded, this can be explained by the fact that more capacity is required on Saturday. The depot locations in Gramsbergen, Mynsheerenland, Leende and Tilburg are exceeded on each of the delivery days, indicating that these depot locations are relatively cheap compared to other depot locations nearby as well as conveniently located towards carriers. Noticeably high values are the depot volumes for Gramsbergen on Thursday, which is 3.5 times higher than the depot capacity and Woudenberg on Friday, which is 2.5 times higher than the depot capacity.

| Facility | Monday | Tuesday | Wednesday | Thursday | Friday | Saturday |
|---|---|---|---|---|---|---|
| DP GRAMSBERGEN | 94.54 % | 46.96 % | 93.03 % | 359.39 % | 101.51 % | 74.85 % |
| DP MYNSHEERENLAND | 1.31 % | 159.79 % | 192.32 % | 202.52 % | 39.60 % | 139.70 % |
| DP LEENDE | 26.57 % | 25.94 % | 33.71 % | 33.99 % | 35.03 % | 47.62 % |
| DP TILBURG ZO | 7.08 % | 15.10 % | 5.97 % | 17.11 % | 62.41 % | 107.83 % |
| DP OSSENDRECHT | | 55.76 % | 55.76 % | 108.18 % | 107.73 % | 53.86 % |
| DP DALFSEN | | 22.03 % | 25.24 % | 26.10 % | 27.97 % | 41.93 % |
| DP WOUDENBERG | 39.62 % | 54.47 % | | 88.41 % | 239.24 % | 118.48 % |
| DP HAAREN | 5.31 % | 2.22 % | | 3.49 % | | |
| DP REEUWYK BRUG | | | 25.33 % | 26.61 % | | 22.52 % |
| DP CAPELLE AD IJSSEL | 5.34 % | 5.47 % | 14.85 % | | | |
| DP DE BILT | | | | | 0.23 % | 5.27 % |
| DP UTRECHT LOMBOK | | | | 31.33 % | | 60.84 % |
| DP CAPELLE SCHOLLEVAAR | | | | | 21.31 % | 16.14 % |
| DP VELDHOVEN NORENBERG | | | | | 6.62 % | 0.57 % |
| DP BREDA WEST | | | | | | 8.87 % |
| DP OOTMARSUM | | | | | | 5.82 % |
| DP LUNTEREN | 40.51 % | | | | | |
| DP DOETINCHEM DICHTEREN | | | 2.63 % | | | |
| DP DIEPENVEEN | 28.01 % | | | | | |
| DP BEST | | | | | | 2.16 % |
| DP ASD DE PIJP | | | | | | 8.90 % |
| DP ST OEDENRODE | | | 1.74 % | | | |
| DP ZEVENHUIZEN ZH | | | | | | 6.12 % |
| DP RUCPHEN | | | | | 2.21 % | |
| DP ERP | 0.43 % | | | | | |
| DP HARDERWYK | | | | | | 9.30 % |
| DP ENSCHEDE-ZUID | | | | | | 3.88 % |
| DP DELFT NOORD WEST | | | | | | 0.28 % |
| DP WATERINGEN | | | | | | 4.24 % |
| DP ZOETERMEER WEST | | | | | | 23.55 % |
| DP SINT JANSTEEN | | | | | | 1.12 % |
| DP OIRSCHOT | | | | | | 40.74 % |
| DP DRONTEN ZUID | | | | | 4.26 % | |

Table 6.6: Depot locations with exceeded depot capacity

To conclude, the sensitivity analysis performed in this section shows the effect of changing parameters on the distribution network design. Drastic changes in the costs for secondary routes and number of vehicles can only be seen after a delay of 20 minutes. The vehicle capacity is quite sensitive to the number of secondary routes. Furthermore, changes in depot capacity have little effect on the distribution network design so the model is robust for these changes.

### 6.2.2 Scenario analysis

Besides the sensitivity analysis performed in the previous subsection, a scenario analysis is conducted to see the effect of changing circumstances on the output of the model. The distribution network design is heavily dependent upon the newspaper demand. As earlier explained, a relevant issue for de Persgroep Nederland is the ongoing decrease in newspaper demand. Therefore, the newspaper demand values are changed to gain useful insights in the distribution network design for potential future scenarios. Note that, apart from the newspaper demand inputs, the other input parameters have the default value and remain unchanged.

| | **Monday** | **Tuesday** | **Wednesday** | **Thursday** | **Friday** | **Saturday** |
|---|---|---|---|---|---|---|
| **# Newspapers base case** | 879261 | 870419 | 870424 | 886828 | 898049 | 1078425 |
| **# Carriers base case** | 4576 | 4583 | 4571 | 4567 | 4560 | 4576 |
| **# Newspapers decreased demand** | 676744 | 671137 | 671412 | 683807 | 691843 | 833210 |
| **# Carriers decreased demand** | 3394 | 3396 | 3385 | 3379 | 3371 | 3385 |

Table 6.7: Data characteristics decreased demand scenario

In order to create a realistic future scenario with respect to the decrease in newspaper demand, data regarding the newspaper demand per zip code for the year 2019 has been compared with the newspaper demand per zip code in 2017 and 2018. The average change in newspaper demand per zip code over these two years has been taken to generate a scenario with decreased newspaper demand. Using this information, data points are randomly removed or, in case of an increase in newspaper demand, artificial data points are added in the zip code region. Table 6.7 summarizes how this new scenario is different from the base case. The newspaper demand on each delivery day is decreased with about 23% and subsequently the number of carriers.

| | **Monday** | **Tuesday** | **Wednesday** | **Thursday** | **Friday** | **Saturday** |
|---|---|---|---|---|---|---|
| **Fixed costs** | €2287.44 | €2268.00 | €2273.28 | €2236.22 | €2271.59 | €2570.33 |
| **Number of open depots** | 137 | 136 | 141 | 136 | 143 | 143 |
| **Costs primary routes** | €5958.64 | €5953.54 | €6148.08 | €5989.87 | €6053.41 | €6070.03 |
| **Costs secondary routes** | €7579.89 | €7514.05 | €7454.86 | €7665.44 | €7644.41 | €9370.88 |
| **Number of secondary routes** | 525 | 523 | 529 | 533 | 540 | 778 |
| **Total costs** | €15825.97 | €15735.59 | €15876.22 | €15891.46 | €15969.41 | €18011.24 |

Table 6.8: Distribution network design solutions decreased demand

Distribution network design solutions for the scenario with decreased newspaper demand are outlined in table 6.8. Comparing these solutions with the solutions of table 6.1, the decrease in newspaper demand leads to a significant decrease in total costs, see figure 6.10. Fixed costs decrease since less depots are opened, subsequently costs for primary routes decrease. Also, because less carriers need to be supplied, the number of secondary routes and thus costs for secondary routes decrease. Altogether, total costs decrease on average with about 18%.

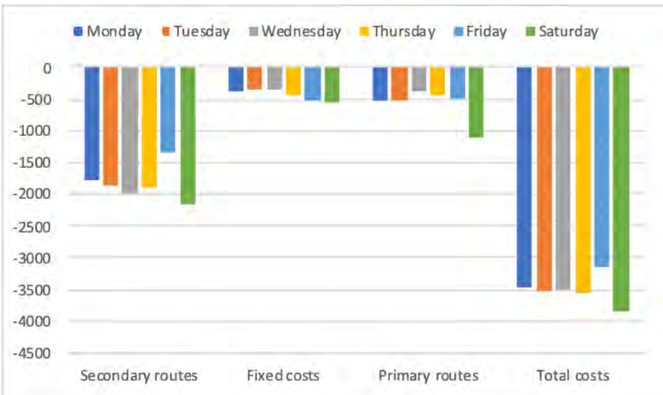
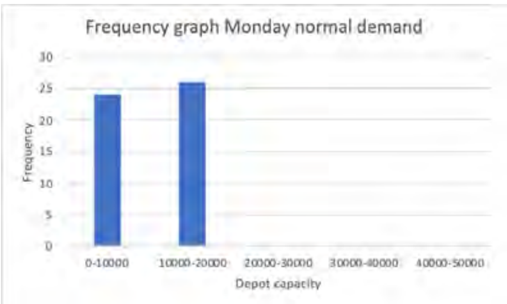
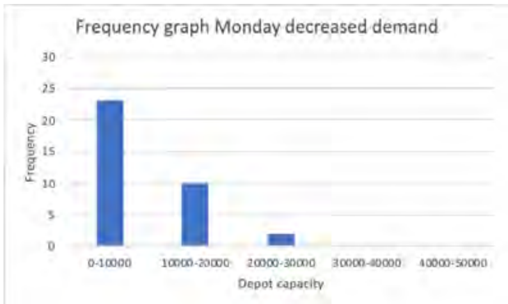



Figure 6.10: Distribution costs comparison base case and decreased demand case

Besides the change in costs, it is interesting to compare which depots are opened in the base case and the case with decreased demand. Graphical representations are shown in appendix D, where the colors indicate whether the depot is opened in one of the cases or both cases. From these figures can be concluded that most of the depots are kept in the scenario with decreased demand. Obviously, also some depot locations are closed. These are closed for two reasons: Since the depot location is not needed anymore or because the depot location is substituted by another depot nearby. A comparison of the non-overlapping depots on Monday is shown in figure 6.11. From this figure, and in general, can be concluded that mainly small depots disappear from the solution and larger depots remain in the scenario with decreased demand.




(a) Monday base case




(b) Monday decreased demand

Figure 6.11: Comparison open depot locations Monday base case and decreased demand

## 6.3 Quality of heuristic solution approach

In the present subsection, we assess the performance of the heuristic solution approach investigated in section 4 as compared to the reference solution given by Gurobi for the original MIP. The computation time was limited to 4 hours for the reference solution. In order to do this, multiple small size instances are created. These instances have the following characteristics:

| | Hubs | Depots | Carriers |
|---|---|---|---|
| **Instance1** | 1 | 2 | 14 |
| **Instance2** | 1 | 3 | 37 |
| **Instance3** | 1 | 4 | 50 |
| **Instance4** | 1 | 8 | 91 |
| **Instance7** | 1 | 17 | 168 |
| **Instance8** | 1 | 32 | 262 |
| **Instance5** | 1 | 43 | 386 |
| **Instance6** | 2 | 120 | 1083 |

Table 6.9: Characteristics of small size instances

Table 6.10 shows computation times in minutes as well as the solution quality of the heuristic approach and of the solver output for the original MIP. Solution quality is measured as the relative difference between the heuristic solution and the lower bound produced by Gurobi applied to the original MIP with a computation time limit of 4 hours. In fact, this information is useful to analyze the performance of the heuristic solution approach as compared to the exact one. Overall, table 6.10 shows that the heuristic solution approach leads to significantly shorter running times. However, it shows very high deviations from the original MIP solutions. Also, instances 2 and 3 can not be optimally solved by Gurobi within 4 hours as shown in the 'Gap' column. For instance 4, no objective is found within 4 hours. From instance 5 onwards, the size of the problem becomes too large for Gurobi to solve the problem. Hence, solution quality can not be evaluated as no reference solution was found.

From this analysis can be concluded that, although it does not come up with good solutions, the heuristic solution approach is able to solve large instances within polynomial time.

| | **Heuristic solution** | | **Gurobi applied to the original MIP** | | | | **Solution quality** |
|---|---|---|---|---|---|---|---|
| **Instance** | **Obj** | **CPU** | **Obj** | **Lower bound** | **Gap** | **CPU** | |
| 1 | €99.75 | 0.06 | €82.29 | €82.29 | 0.0 | 70.30 | 41.89 |
| 2 | €165.34 | 0.13 | €120.69 | €91.57 | 24 | 240 | 80.6 |
| 3 | €214.33 | 0.19 | €176.03 | €119.02 | 32 | 240 | 80.07 |
| 4 | €394.62 | 0.58 | | €198.82 | | 240 | 98.30 |
| 7 | €855.37 | 1.21 | Out of memory | | | | |
| 8 | €1534.41 | 3.43 | Out of memory | | | | |
| 5 | €2332.94 | 7.14 | Out of memory | | | | |
| 6 | €6718.27 | 38.07 | Out of memory | | | | |

Table 6.10: CPU (min) and solution quality (%) heuristic solution approach

# Chapter 7

# Conclusion

Distribution costs per copy increase exponentially since the media and content industry is changing as a result of digitalization and the growth of the internet. Therefore, this research was aimed at investigating how total distribution costs could be reduced by delivering newspapers to carrier homes. It was aimed at determining potential depot locations as well as vehicle routes in a cost-efficient manner. One main research question has been formulated in chapter 1 that must be answered to consider the research's goal achieved:

*How can the design of the distribution network be optimized to deliver newspapers to subscribers with minimal average costs per newspaper while respecting predefined customer service levels and delivery deadlines?*

The first step was to get an insight into the important requirements for managing newspaper delivery. The most important requirement constitutes the delivery deadline. Second, there is pressure from the newsroom to incorporate the latest news and thus start the production as late as possible. Leading to a very short time frame for production and distribution. Finally, there is zero inventory in the supply chain. Considering this, the MILP model constructed in this research is an LRPTW, with an objective to minimize the total distribution costs. Distribution costs constitute fixed depot costs, vehicle routing costs and costs for primary transport between hubs and depots. The mathematical model determines where to open depots, vehicle routes from the open depots to carriers as well as connections between each depot and a hub while considering depot capacity, vehicle capacity and time window constraints. From the reviewed literature concerning LRPTW, it became clear that the combination of facility location and routing decisions makes the problem very complex and therefore it is practically impossible to solve the problem using exact methods. Therefore, a heuristic solution approach has been developed to reduce the complexity of the problem by applying a clustering procedure for grouping carriers. Using these clusters, routing costs are approximated when serving the cluster from a specific depot. By using these approximate route costs in the objective function of the FLP, facility location as well as assignment decisions have been made. The main idea is to decide about the number and locations of depots to achieve the best possible trade-off between fixed depot costs, vehicle routing costs and costs for primary transport. The mathematical model developed is applied to de Persgroep Nederland as a case study and the main trade-offs in the distribution network design have been analyzed. Distribution network designs for each delivery have been evaluated. Comparing the solutions for each delivery day reveals that on Saturday more depots are opened and there is only a small overlap in depot locations between the delivery days. Since most capacity is required on Saturday, this set of depot locations will be operated all week and solutions for the weekdays are recalculated using the new set of depot locations. The first part of the distribution network design is to determine the location and number of depot locations. In total, 175 out of 449 depot locations are used in the optimal distribution network design. Looking at the chosen depot locations, it can be concluded that mainly small depots are opened together with some larger depots. The second part is to determine the vehicle routes from the depot locations to carriers, which consists of about 630 vehicle routes on weekdays and about 940 vehicle routes on Saturday. This is due to the higher volume and lower vehicle capacity on Saturday. Considering the vehicle capacity and time window constraints, it can be concluded that most vehicles are fully loaded and carriers receive the newspapers well in advance. A comparison between the new distribution network and the current distribution network has revealed that all solutions show significant savings. These savings are mainly related to the fact that fewer depots are needed in the new distribution network design, however additional costs for secondary routes are incurred. Also, the robustness of the optimal distribution network design has been evaluated using a sensitivity analysis. From this sensitivity analysis, we can draw some conclusions. First of all, the effect of a delay in the arrival of the newspapers at the depots was investigated, a delay of 20 minutes does not result in higher costs because of the slack in the vehicle routes. Nevertheless, more delay results in significantly higher costs since more vehicle routes are required to serve all the carriers on time. Second, the vehicle capacity is quite sensitive to the number of vehicle routes. When increasing the vehicle capacity, the number of vehicle routes decreases, leading to lower costs for the vehicle routes. Second, a sensitivity analysis is performed to see the cost changes when violating the depot capacities. This effect is very small. Still, from this analysis can be deduced where it would be most beneficial to increase the capacity. Also, a scenario analysis has been performed to see the effect of a decrease in newspaper demand on the distribution network design. In case the newspaper demand decreases by 23% and subsequently the number of carriers, total distribution costs decrease by 18%. This is because the number of vehicle routes decreases and fewer depots are required. Comparing the depots, it can be concluded that mainly small depots disappear from the solution. Finally, the quality of the heuristic solution approach has been analyzed, it can be concluded that, although the heuristic does not come up with good solutions, it is able to solve large scale instances within polynomial time.

Concluding from these analyses, and the fact that all solutions show significant savings compared to the current distribution network, it is recommended to de Persgroep Nederland to implement the new distribution network design. The introduction of secondary routes ensures that fixed costs are replaced by variable costs in the new distribution network design. Considering the ongoing decrease in newspaper sales, less carriers need to be supplied in the future, leading to a decrease in the number of secondary routes which eventually decreases total costs for newspaper distribution as shown in the scenario analysis. Following this, excess capacity is an important factor in the cost-optimal distribution network design, especially because this enables de Pergsroep Nederland to re-allocate carriers to other depots on a short-term basis without encountering depot capacity constraints. Therefore, the distribution network with some large depots and more smaller depots would be advised to de Persgroep Nederland. Large depots create excess capacity, which makes it possible to close smaller depots and shift towards a more centralized distribution network when newspaper demand further decreases, lowering the fixed costs in the distribution network. Ultimately, using the hub as large depot should be considered, directly supplying carriers from the hub saves time which creates flexibility. This option could also lead to even more savings in some areas as discussed in section 6.1. Other benefits of using less depots are the reduction in uncertainty and variability by diminishing the number of stages in the distribution network (Ghaderi, Dullaert, & van Amstel, 2016). Also, the overhead costs can be lower, since the operations are less distributed, managing the structure and processes becomes more centralized.

# Chapter 8

# Discussion

This final section discusses the recommendations for de Persgroep Nederland towards implementing the new distribution network design. Furthermore, the limitations of this research as well as directions for future research are presented.

## 8.1 Limitations

Even though the structure of the newspaper distribution network appears simple, the size of the problem combined with the various restrictions makes the system complex. To be able to solve to model and optimize the problem, a lot of simplifications and assumptions are made throughout this research and including too many causes the model to not represent the real world as accurate as desired.

First of all, as in most researches, the unavailability of data is a limitation. The data set with depot locations was lacking data about depot capacities. The depot capacities in terms of volume were derived by multiplying the surface of a depot with the number of newspaper that can be handled per square meter. The number of newspapers that can be handled per square meter is estimated based on expert knowledge, which make the depot capacities less accurate. In future research, data unavailability is always likely to be an issue.

A major part of the inaccuracy in the modeling comes from simplifying the reality into simpler, solvable parameters and variables. One of these simplifications that is drastically different from the real world, is that the inclusion of different newspaper editions is neglected. In reality, multiple editions are distributed to different subscribers and in some cases, different editions are demanded by the same subscriber. Because the inclusion of multiple editions increases the problem size by adding several variables, only one type of newspaper is assumed. If multiple editions were to be distributed, the results would not have been distinctively different. This is because, for the scope of this research, transportation from depots to carriers, the different editions don't have a lot of impact since they are all about the same size and have the same weight. Therefore, it is reasonable to assume that all the required editions are available at the depot.

For the transport between hubs and depots, direct transport using one type of truck is assumed. In some cases, it could be possible that a logistics supplier delivers newspapers to multiple depots. Obviously, multiple types of trucks can be used for this transport, which all have their own cost components. But this was substituted by using the average costs for all the vehicles. Also, single usage of vehicles is assumed in the model. However, in reality, it could be possible that a logistic supplier returns to the depot after visiting the last carrier in the route to start with a second route. Because, the compensations paid to logistic suppliers only depend on the driven distance and traveled time, this does not make any difference for the costs in our model.

As mentioned repetitively throughout the thesis, reduction regarding the size of the problem is also needed. By clustering carriers together, the number of nodes is drastically reduced, which lowers the computation time. The use of clusters, in general, has not been evaluated. However, we have tried to cluster the carriers in the most realistic way possible by implying vehicle capacity, time window as well as maximum distance constraints. The location of all carriers is available and in most cases, they are located in a way that makes it reasonable to assume that if one is visited, the inclusion of the nearby carriers on the same route is logical. The main problem with the use of clusters is that the routing inside each cluster is not optimized, but rather estimated inaccurately. We have tried to overcome this problem by approximating the routing costs using the concept of time-oriented nearest neighbor algorithm to design the routes. Larger clusters make the model less realistic. This is because when the clusters include a large number of carriers, the center of the cluster is representing the actual carrier locations less accurate since they are more spread out. It is clear that when using clustering as a problem reduction technique, it all comes down to a compromise between problem size and computation time.

Newspapers delivered by car to subscribers in remote areas were not taken into account when designing the new distribution network. This means that the savings could be too optimistic. However, a delivery route that supplies carriers may be combined with the delivery of newspapers to subscribers in remote areas. Therefore, these costs can be compensated, which means that the new distribution network still results in significant savings.

## 8.2 Directions for future research

Based on the limitations and other findings of the research some directions for further research are provided.

The proposed heuristic solution method is a simple, common-sense procedure which is based on the clustering method. As a future research direction, a more extensive study may be conducted to develop a more sophisticated heuristic which will improve the solution quality.

Another suggestion for future research is the influence of a lower number of depots on the arrival time of the newspapers at the depots. Another possibility is the influence of the production schedule on the distribution of newspapers. Some researchers already studied the synchronization between production and distribution in a newspaper distribution problem (Russell et al., 2008).

This research focused on distribution network design decisions for decreasing the costs of the network, while further research can focus on other decisions that the de Persgroep Nederland should make to increase the flexibility. De Persgroep Nederland can, for example, consider other modalities for the delivery of newspapers to subscribers to decrease the delivery time.

An extensive study should also be performed regarding the consequences of a lower number of depots together with delivery routes to carriers. This research already showed positive results regarding this distribution network design. However, since this only constitutes a minor part of the total supply chain, further research can study all effects on other parts of the supply chain.

## 8.3 Recommendations

As de Persgroep Nederland is moving towards implementing the new distribution network design there are some points to consider. Therefore, this section provides some recommendations.

The results of this research advise de Persgroep Nederland to implement the new distribution network design because it leads to significant savings. For making this implementation successful de Persgroep Nederland needs to have its data complete and correct all the time. The model provides the most efficient depot locations and assignments of carriers to these depots.

De Persgroep Nederland should further evaluate the available data to make sure that an exact model can be developed for calculating the capacity of the depots. These exact depot capacities will improve the correctness of the model. Thereby, the depot capacity is based on the surface of the depot. Because the function of the depot changes to a consolidation point in the new distribution network, the depot capacity is related to the maximum number of newspapers that can be processed in the specific depot in a way that all vehicle routes depart on time. Therefore, de Persgroep Nederland can base the capacity, besides the surface, on the number of people working at the depot.

Regarding the depots, because the function of a depot completely changes in the new situation. De Persgroep Nederland should assess whether the layout of the depot is suitable for the case where multiple vehicle routes depart from the depots. Furthermore, in the new situation more labor may be required at the depot to count the newspaper for each vehicle route. Since labor is not considered in the model, de Persgroep Nederland should investigate whether additional labor is required. To get rid of this counting job, it could also be a good idea to produce the newspapers on segment level. Right now, they are produced on edition level and therefore, a lot of manpower is required for this counting job. It is recommended to further analyze the influence of the production on the distribution of the newspapers.

Also, since the new distribution network design is heavily dependent upon the availability of logistic suppliers for the vehicle routes along carriers. De Persgroep Nederland should ensure that sufficient logistics suppliers are available all the time. In the current situation, there are already vehicle routes serving subscribers in remote areas. De Persgroep Nederland should optimize the new vehicle routes together with these existing routes. Also, increasing the vehicle capacity could be a viable option to reduce the number of vehicle routes, however de Persgroep Nederland should first investigate whether it is allowed to enter residential districts with such large vehicles at night.

Finally, this research indicates that delivering newspapers to carriers will lead to savings. Before a decision is made, de Persgroep Nederland should test the effect of this on other parts of the distribution network. For example, newspapers delivered by car to subscribers in remote areas were not taken into account. De Persgroep Nederland should investigate how these routes can be implemented in the new distribution network, this requires further investigation.

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# Appendix A

# Distribution network of de Persgroep Nederland

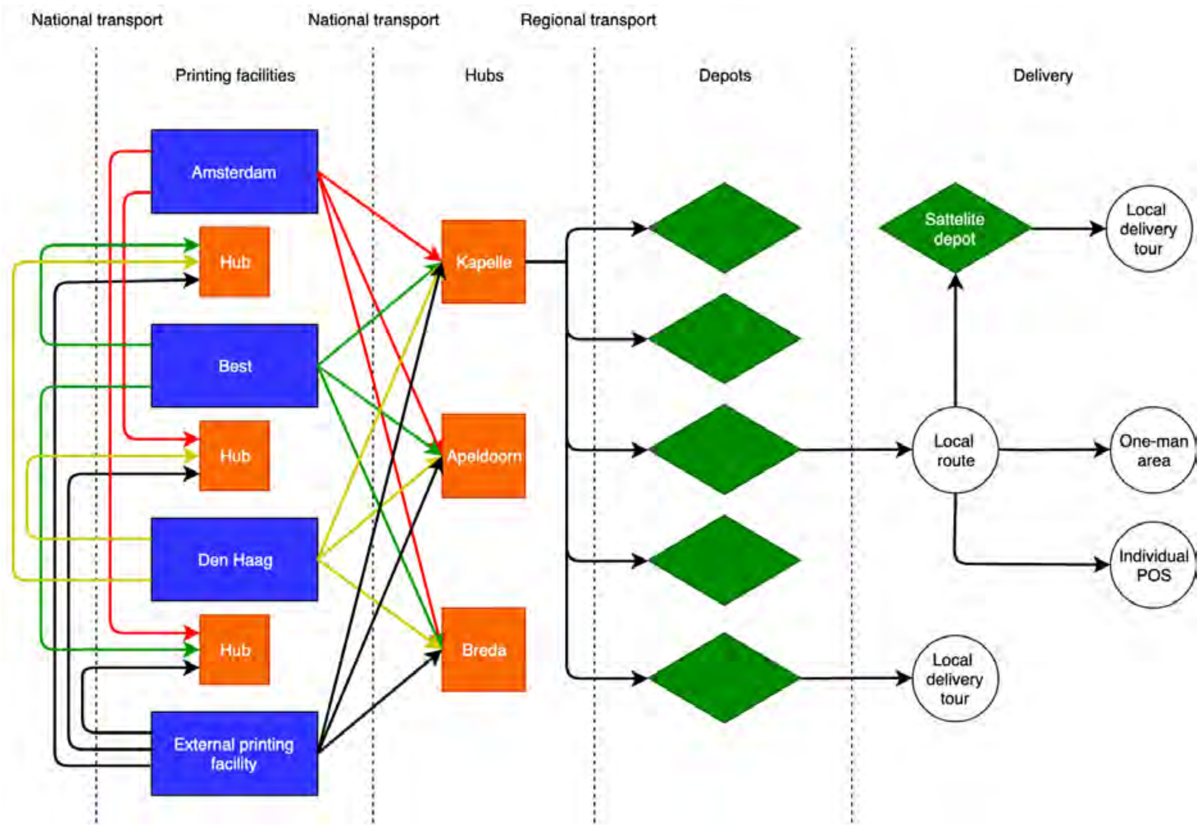



Figure A.1: Distribution network of de Persgroep Nederland

# Appendix B

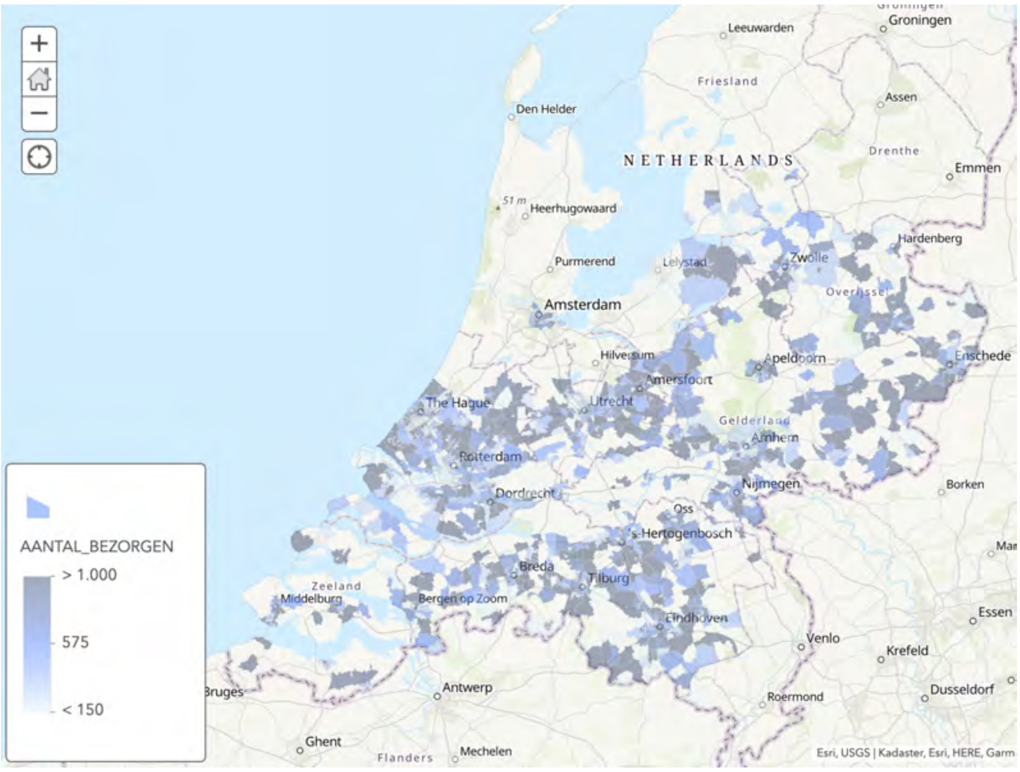
# Newspaper distribution problem literature overview

| Paper | Echelon | Capacity | Deadline | Edition | Routing | Facility location | Objective | Solution method | Heuristic / Exact |
|---|---|---|---|---|---|---|---|---|---|
| Mantel and Fontein (1993) | 1 | X | X | | X | | Travelling time | Clarke and Wright's savings technique | Heuristic |
| Hurter and Van Buer (1996) | 1 | X | X | X | X | | Costs | Greedy + Or-Opt | Heuristic |
| Van Buer et al. (1999) | 1 | X | X | X | X | | Costs | Heuristic search algorithms | Heuristic |
| Boonkleaw (2009) | 1 | X | X | | X | | Total travel time | Modified sweep algorithm | Heuristic |
| Böhnlein et al. (2009) | 1 | X | X | X | X | | Costs | Combined methaheuristic of Ant Colony optimization and Tabu Search | Heuristic |
| Böhnlein et al. (2011) | 1 | X | X | X | X | | Costs, service level | Multi-agent system | Heuristic |
| Russell et al. (2008) | 1 | X | X | X | X | | Distance, number of vehicles | Sequential insertion + tabu search | Heuristic |
| Chiang et al. (2009) | 1 | X | X | X | X | | Costs | IP subproblem + tabu search | Heuristic |
| Russell (2013) | 1 | X | X | X | X | | Distance | Constraint programming | Heuristic |
| Ree and Yoon (1996) | 1 | X | X | | X | | Lateness | Branch-and-bound + simulated annealing | Heuristic |
| Song et al. (2002) | 1 | X | X | X | X | | Costs | Modified clarke and Wright's savings technique | Heuristic |
| Eraslan and Derya (2010) | 1 | X | X | | X | | Costs | Multi-depot capacitated VRPTW | Exact |
| Archetti et al. (2013) | 2 | X | X | | X | | Number of trips | Hybrid algorithm | Exact |
| Yang et al. (2016) | 2 | | | | X | | Costs | Discrete firefly algorithm | Heuristic |
| Jacobsen and Madsen (1980) | 1 & 2 | X | X | | X | X | Costs | TTH, ALA-SAV, SAV-DROP | Heuristic |

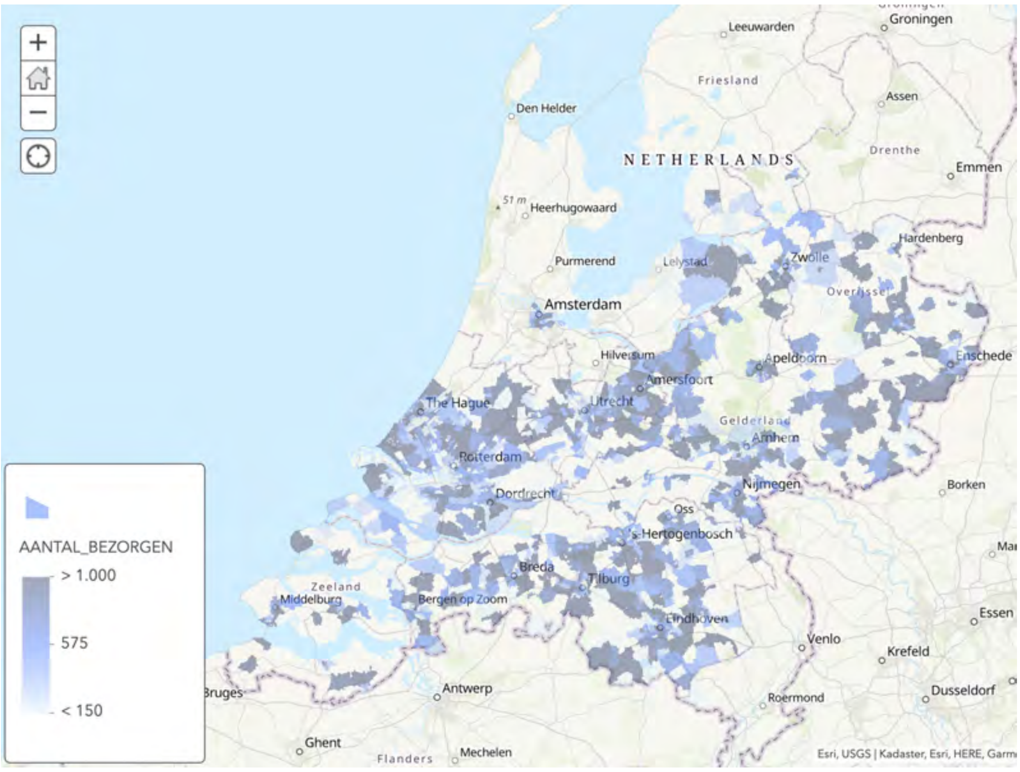
Table B.1: Newspaper distribution problem literature overview

# Appendix C

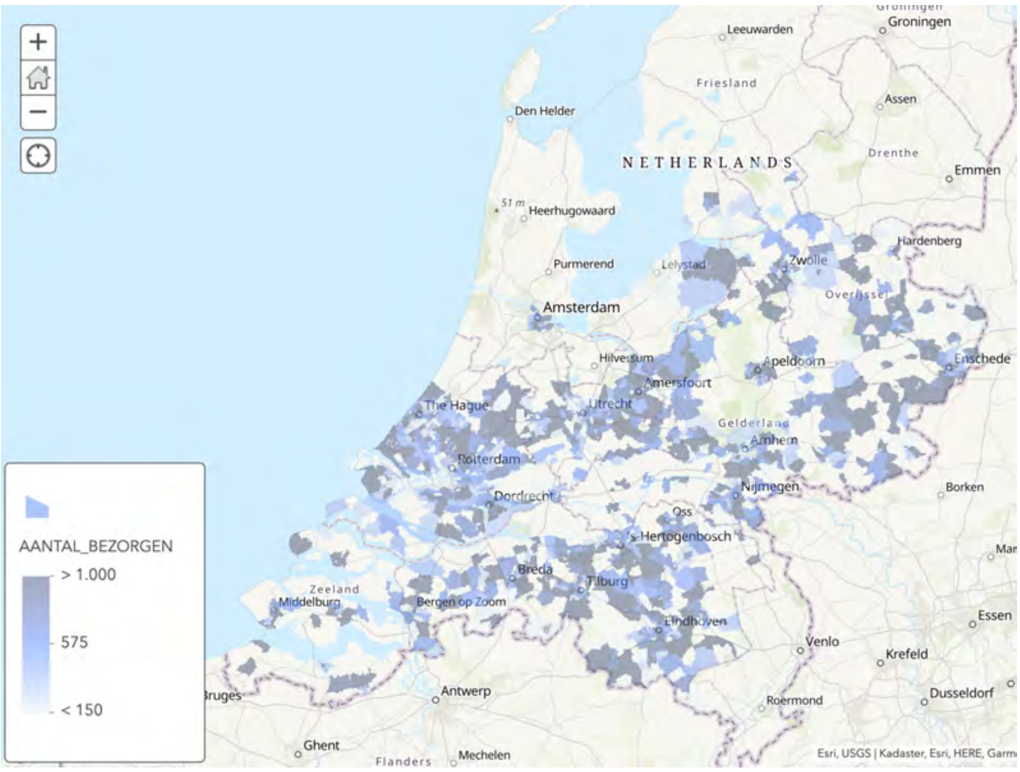
# Newspaper demand per zip code



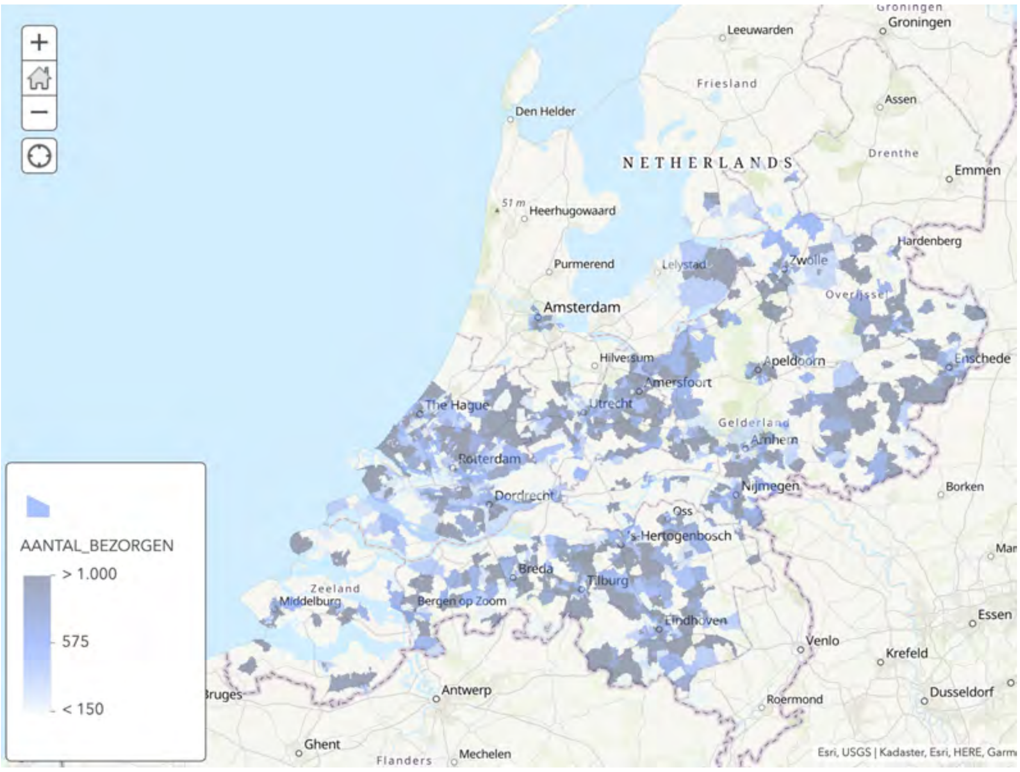

(a) Monday



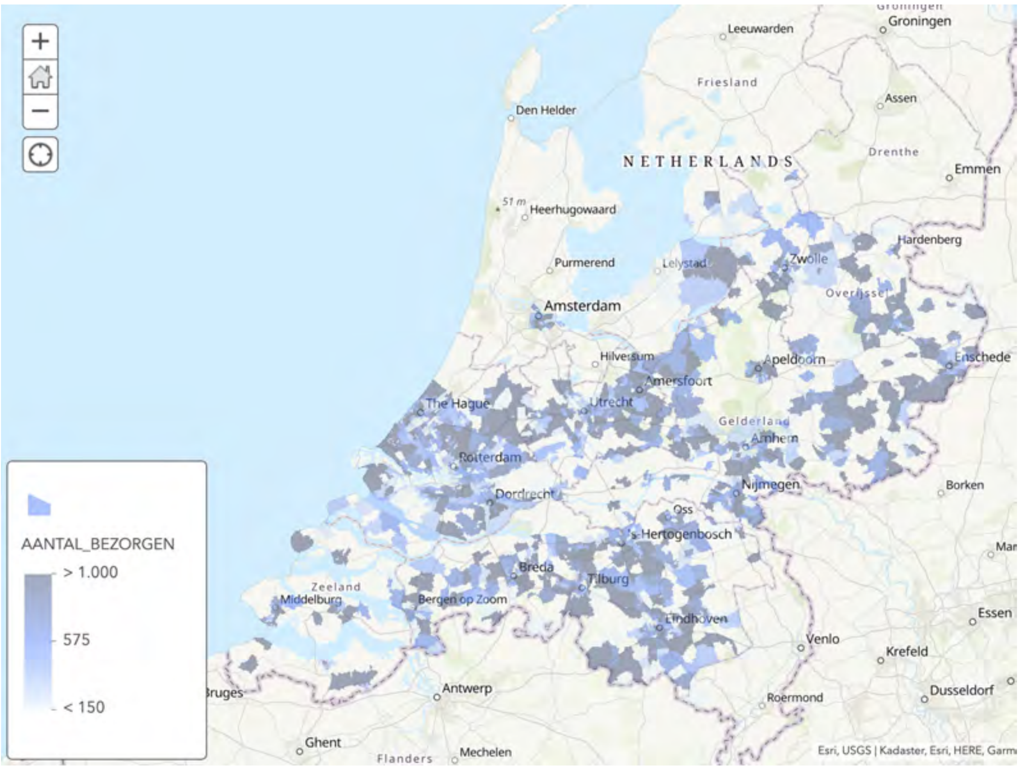

(b) Tuesday



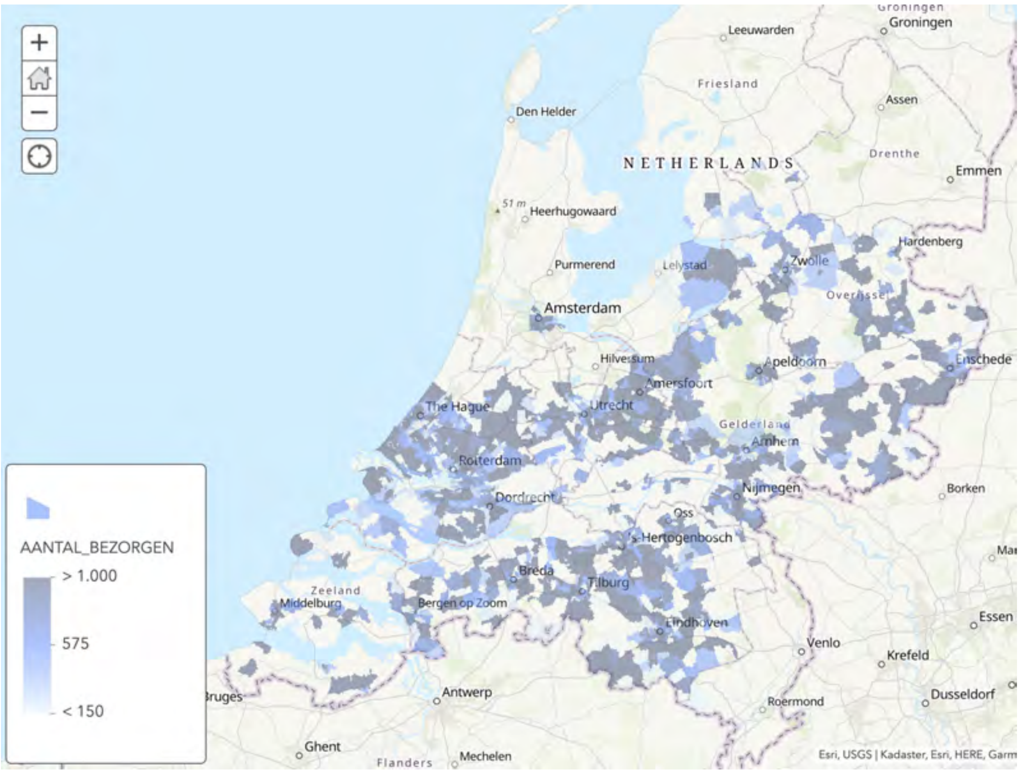

(c) Wednesday




(d) Thursday




(e) Friday

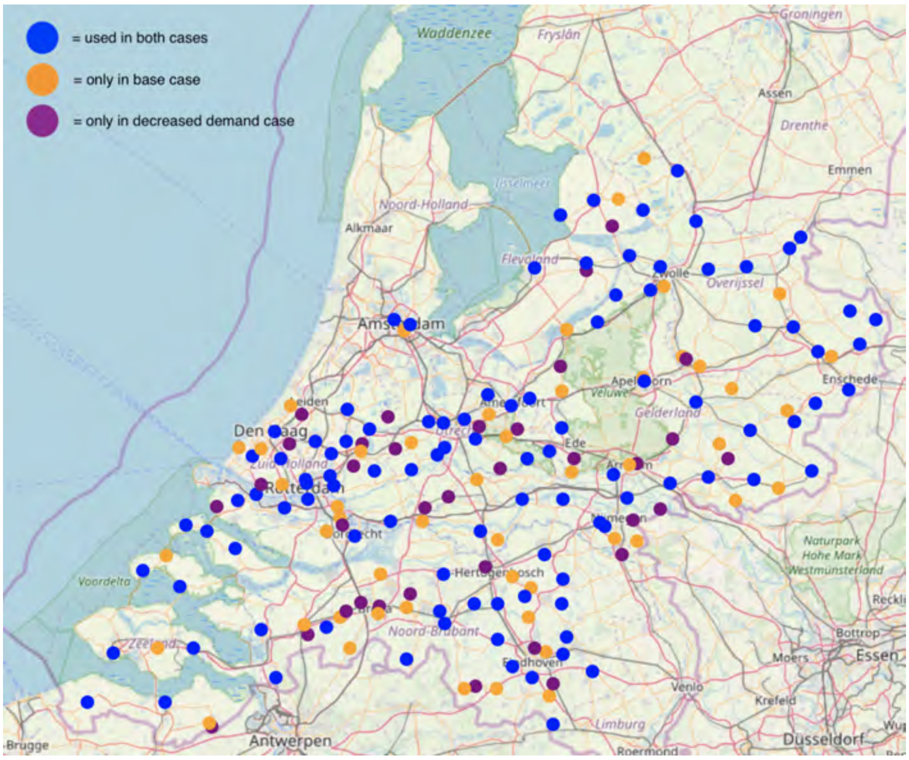



(f) Saturday

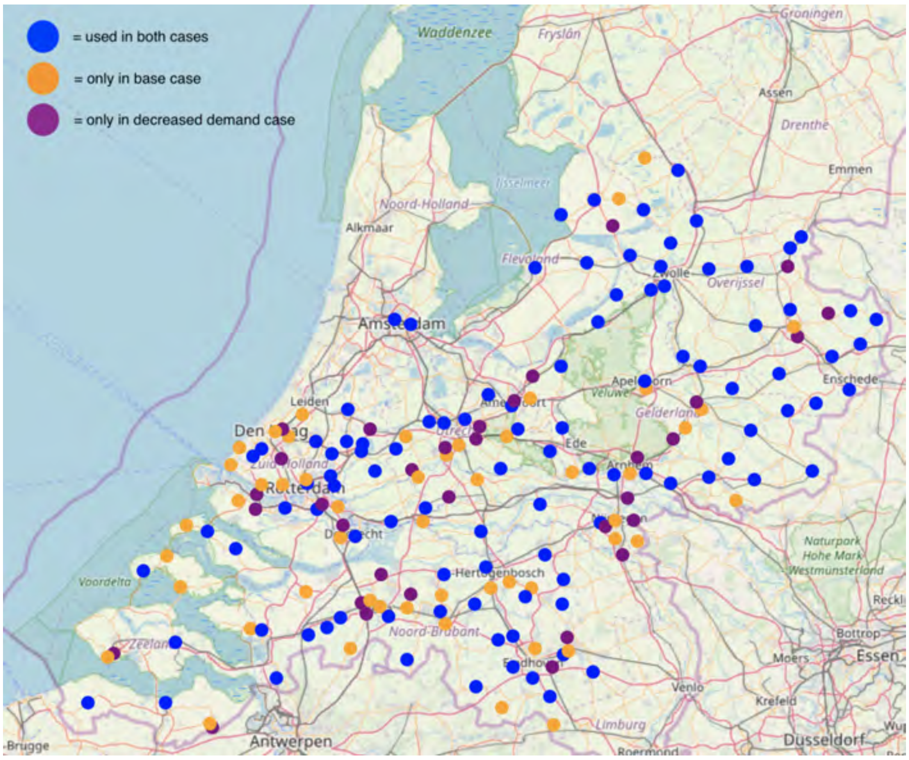
Figure C.1: Newspaper demand per zip code region

# Appendix D

# Comparison open depot locations base case and decreased demand




(a) Monday

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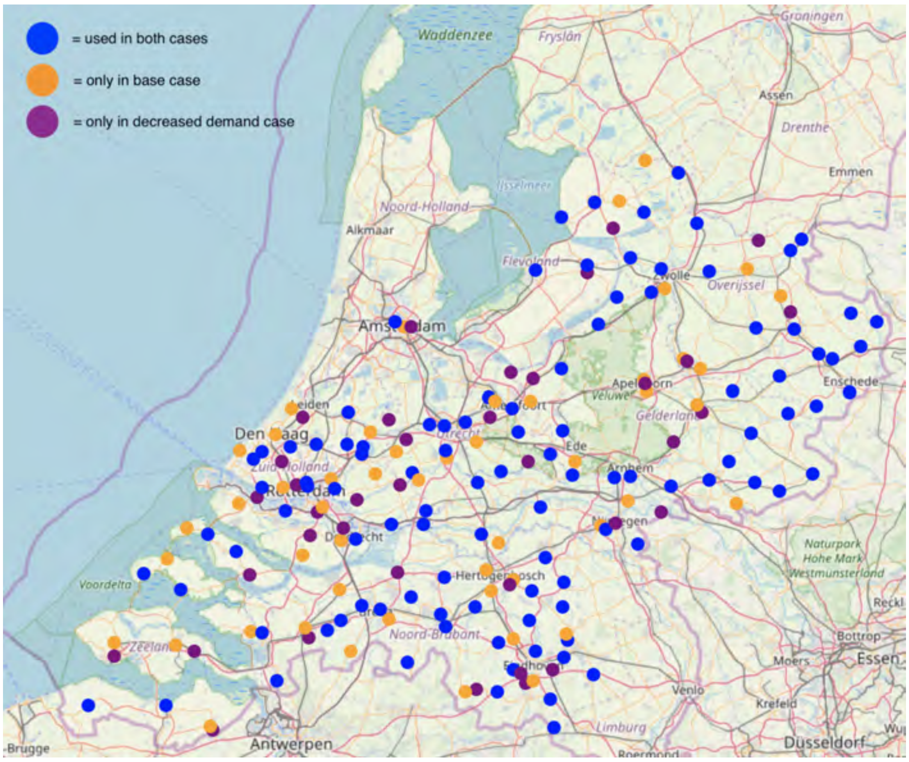
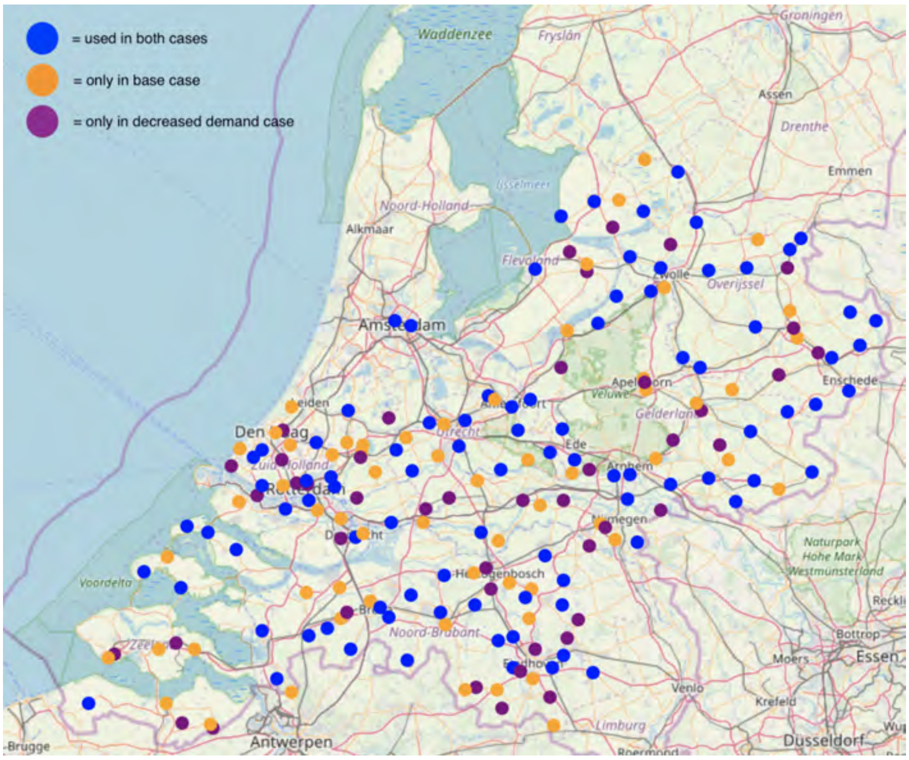
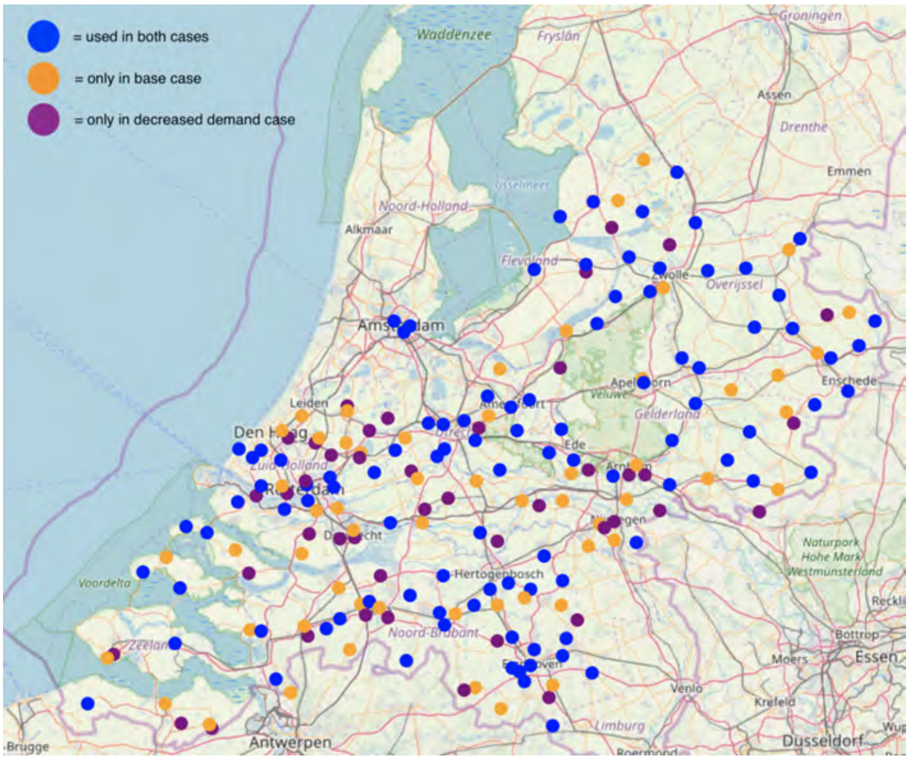


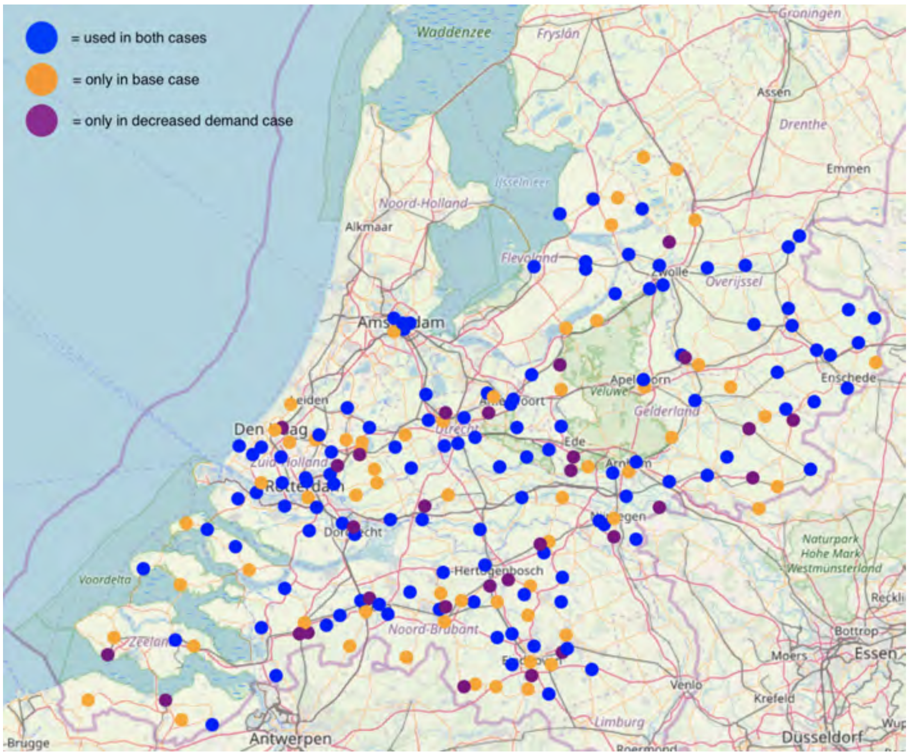

(c) Wednesday




(d) Thursday




(e) Friday




(f) Saturday

Figure D.1: Comparison open depot locations base case and decreased demand