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„Vendor managed inventory and routing optimisation

for free newspaper delivery“

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1. Introduction

The problem we are looking at is a real life problem about delivering free daily newspapers.

Introduced in Austria in 2001, free daily newspapers play a major role in the media landscape. The newspaper we are looking at was first published in September 2004 and in the beginning distributed only in Vienna, later also in Lower Austria, Linz and Wels[1]. In 2009 the free newspaper reached more than 450,000 readers in Vienna and 667,000 all over Austria.[2] In the second half of 2009 they had 506,000 printed copies[3] which makes it the second biggest newspaper in the country.

The newspapers are placed in boxes at underground and tramway stations, super markets, bakeries, retirement homes and at public places.

The aim of this master thesis is to create a distribution plan according to the number of pages of the newspaper. We use simple route construction and improvement heuristics and we will see how they work in practice.

First I will present the related literature and define the problem. Then the details of our real life problem are given and the solution methods and the implementation is presented. In the end I will show the computational results in detail.

[1] cs. wikipedia
[2] cs. Regioprint, (2009)
[3] cs. ÖAK, (2009)

2. Literature Review

I will give general information about Vehicle Routing Problems and concentrate my literature review on Inventory Routing Problems that propose a decomposition of the problem into scheduling and routing, what we do in a similar way.

2.1. The Vehicle Routing Problem

In the last decades the vehicle routing problem (VRP) has been studied extensively. The reason for this may be the practical relevance of the problem but also its complexity and difficulty.

The VRP is an extension of the Travelling Salesman Problem (TSP) and contains two separate problems: first an assignment of customers to vehicles and second the determination of the vehicles minimum cost cycle for visiting all customers assigned to that vehicle. The problem was first introduced by Dantzig and Ramser in 1959. They looked at the distribution of fuel and developed a mathematical formulation and an algorithm to solve the problem.

The classical VRP is defined on an undirected graph $G = (V,A)$ where $V = \{0, 1, . . . , n\}$ is the vertex set and $A = \{(i, j) : i, j \in V, i \neq j\}$ is the arc set. At the depot (Vertex 0) are located m identical vehicles of capacity Q. All customers except the depot have a non-negative demand $q_i \leq Q$. A cost matrix c_{ij} is defined on A. The problem consists of determining a set of m vehicle routes that start and end at the depot. Each customer can only be visited by exactly one vehicle and the total demand of any route must not exceed Q. The objective is the minimization of the total routing cost.[4]

[4] Laporte, (2007), p. 1

2.1.1. Variations

In practice there are a lot of variations of the VRP[5] :

Time Windows

In the Vehicle Routing Problem with Time Windows (VRPTW) the customers must be visited in a given time window $[a_i, b_i]$. The vehicles are allowed to arrive before the beginning of the time window and can wait for service but must arrive before the end of the time window.

This type of problem is very common in distribution management like beverage and food delivery, newspaper delivery or waste collection.

Periodic

A lot of real life planning situations need a longer term view of the problem to solve it efficiently.

The Periodic Vehicle Routing Problem (PVRP) looks at a planning horizon of t days, in which every customer i must be visited at frequency c_t in a set C_t of a possible combination of visit days.[6]

Examples for periodic problems in real life are the distribution of oil, fuel and industrial gases and recyclable paper collection.

Multi-Depot

In the Multi-Depot Vehicle Routing Problem (MDVRP) the vehicles can choose between several depots. But the vehicles are then assigned to the chosen depot and the routes always start and end there. There are also some versions of the problem where the vehicles can choose their start and end depot.

[5] cs. Scheurer, (2004), p. 13ff
[6] cs. Cordeau et al. (2002), p. 37

Heterogeneous fleet

Despite the fact that most theoretic models assume a homogeneous fleet, in real life this is not true. The Vehicle Routing Problem with Heterogeneous Fleet (VRPHE) and the Fleet Size and Mix Vehicle Routing Problem (FSMVRP) allow vehicles with different capacities and features. The main difference between the two models lies in the number of available vehicles: the VRPHE tries to find the best use for a given vehicle fleet and the FSMVRP tries to find the best fleet within a set of vehicle types.[7]

Multi Trip

In the case of Multi Trip Vehicle Routing Problems (MTVRP) the vehicles can perform several trips, while not exceeding a maximum time restriction. This leads to a better usage of resources and also a reduction of the number of vehicles needed for the distribution. The problem has to include the vehicles service and travel time but also waiting and loading times at the depot.

In practice this type of problem can be found in the distribution of building materials to near building sites, the collection of raw milk in small areas or the distribution with vehicles of small capacities.

Pickup and Delivery

Pickup and Delivery problems look at cases where goods have to be picked up at one place and delivered to another one. If persons are the transported goods the problem is called Dial-a-Ride. The information of the demanded amount of goods in the VRP is replaced by the places for pickup and delivery.

[7] cs. Bankhofer et al., (2006), p. 7

2.1.2. Solution Methods

Exact Algorithms

Finding the exact solution for a VRP is one of the most difficult tasks in Operations Research. The algorithms for exactly solving a VRP are either based on branch-and-bound, dynamic programming or integer linear programming (ILP). For bigger problems such algorithms are not very useful because they need a heavy mathematical programming machinery and computing solutions in reasonable time is not possible. The best exact algorithms can only handle up to 100 customers.[8]

Classical heuristics

Classical heuristics are divided into constructive heuristics and improvement heuristics. First we need a feasible start solution that is produced by the constructive heuristic. In a second step the improvement heuristic tries to find better solutions in the neighborhood of the start solution until no more improvement can be achieved.

The quality of the solution can be measured by the computation of several reference instances and the comparison with the best known values produced by metaheuristics.[9]

Metaheuristics

Within the last 15 years a lot of metaheuristics were developed for the VRP and significant progress could be achieved. They explore the solution space beyond the local minimum and can find further improvements. Metaheuristics use procedures from classical construction and improvement heuristics and can be classified in three categories: local search, population search and learning mechanisms. The best metaheuristics use local search or genetic search or a combination of those two mechanisms and produce solutions that are within 1% of the best known solution values.[10]

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[8] cs. Laporte, (2007), p. 2
[9] cs. Laporte, (2007), p. 6
[10] cs. Laporte, (2007), p. 9ff

A good overview of recent work on Vehicle Routing and the Inventory Routing Problem can be found in Cordeau et al. (2004).[11] They present and formulate the most important types of vehicle routing and inventory routing problems and give an insight into different solution approaches and describe several algorithms and heuristics.

2.2. Inventory Routing

Kleywegt et al. (2000) characterize the different Inventory Routing problems by demand, vehicle fleet, time horizon, deliveries and contribution and give an overview of related work.

Reference	Demands	Vehicles	Horizon	Delivery	Contribution
Bell et al. (1983)	Deterministic	Limited	Long	Multiple	Policy
Federgruen and Zipkin (1984)	Stochastic	Limited	Short	Multiple	Policy
Golden, Assad and Dahl (1984)	Stochastic	Limited	Short	Multiple	Policy
Blumenfeld et al. (1985, 1991)	Deterministic	Unlimited	Long	Direct	Policy
Burns et al. (1985)	Deterministic	Unlimited	Long	Direct, Multiple	Policy
Dror, Ball and Golden (1985)	Deterministic	Limited	Short	Multiple	Policy
Dror and Ball (1987)	Stochastic	Limited	Reduced	Multiple	Policy
Cohen and Lee (1988)	Stochastic	Unlimited	Long	Direct	Policy
Benjamin (1989)	Deterministic	Unlimited	Long	Direct	Policy
Chien, Balakrishnan and Wong (1989)	Deterministic	Limited	Reduced	Multiple	Policy
Anily and Federgruen (1990)	Deterministic	Unlimited	Long	Multiple	Bound, Policy
Gallego and Simchi-Levi (1990)	Deterministic	Unlimited	Long	Direct	Bound
Trudeau and Dror (1992)	Stochastic	Limited	Reduced	Multiple	Policy
Anily and Federgruen (1993)	Stochastic	Unlimited	Long	Multiple	Bound, Policy
Chien (1993)	Stochastic	Unlimited	Long	Direct	Policy
Minkoff (1993)	Stochastic	Unlimited	Long	Multiple	Policy
Pyke and Cohen (1993, 1993)	Stochastic	Unlimited	Long	Direct	Policy
Chandra and Fisher (1994)	Deterministic	Unlimited	Long	Multiple	Policy
Bassok and Ernst (1995)	Stochastic	Unlimited	Short	Multiple	Policy
Dror and Trudeau (1996)	Stochastic	Unlimited	Long	Direct	Policy
Bard et al. (1997)	Stochastic	Limited	Reduced	Multiple	Policy
Barnes-Schuster and Bassok (1997)	Stochastic	Unlimited	Long	Direct	Bound, Policy
Jaillet et al. (1997)	Stochastic	Limited	Reduced	Multiple	Policy
Campbell et al. (1998)	Deterministic	Limited	Short	Multiple	Policy
Chan, Federgruen and Simchi-Levi (1998)	Deterministic	Unlimited	Long	Multiple	Bound, Policy
Christiansen and Nygreen (1998a, 1998b,1999)	Deterministic	Limited	Long	Multiple	Policy
Berman and Larson (1999)	Stochastic	Unlimited	Short	Multiple	Policy
Fumero and Vercellis (1999)	Deterministic	Limited	Long	Multiple	Policy
Reiman, Rubio and Wein (1999)	Stochastic	Limited	Long	Direct, Multiple	Policy
Çetinkaya and Lee (2000)	Stochastic	Unlimited	Long	Multiple	Policy
Kleywegt, Nori and Savelsbergh (2000)	Stochastic	Limited	Long	Direct, Multiple	Policy

Figure 1: Characteristics of the inventory routing problem considered by researchers[12]

[11] cs. Cordeau et al., (2004), p. 39ff
[12] Source: Kleywegt et al., (2000), p. 8

2.2.1. Single day models

The early work on the Inventory Routing Problem put their focus on single day models, where the problem is optimized in single-day slices. Putting the focus on a horizon of only one day was found to be much too short. Leaving aside all deliveries except those necessary today eventually creates infeasibilities in the future, and overlooks good opportunities today. Single day approaches simplify the problem greatly.[13]

2.2.2. Periodic Routing

Periodic routing takes a long term look at the problem and creates a day schedule for every day in the planning horizon that can be repeated infinitely. Because of the stochastic nature of the problem general strategic decisions like determining the fleet size can be based on such an approach rather than short-term planning decisions.[14]

2.2.3. Multi Period models

Though computationally more intensive, multiday models have become more popular because they produce better-quality solutions but also because modern computer systems can solve bigger problems in reasonable time. The solution approaches differ in how they model the effects of short-term decisions on the long-term and in the selection of customers for short term decisions.[15]

Bard et al. (1998) look at an inventory routing problem with a central supplier and additional satellite facilities where the vehicles can reload if they run out of products and continue their

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[13] cs. Campbell, Savelsbergh, (2004), p. 490
[14] cs. Campbell, Savelsbergh, (2004), p. 490
[15] cs. Campbell, Savelsbergh, (2004), p. 490

route. They decompose the problem over the planning horizon to solve only daily instead of multiday VRPs. [16]

A time horizon of two weeks is used to select customers with optimal delivery within this time horizon. Afterwards they are assigned to a given day with the objective of minimizing the incremental costs of serving all customers. From these results only the first week is implemented and for each day the VRP is solved with the objective of minimizing the total distance. The resulting delivery routes are improved by inter route exchanges.
They developed three different solution heuristics to solve the problem, namely a randomized CW algorithm, GRASP algorithm and a Modified Sweep algorithm. In their analysis they investigate the tradeoff between distance and annual costs.

Their work was extended in Jaillet et al. (2001) to consider more of the long term costs. They incorporate long-term delivery costs on an annual time base into shorter, bi–weekly rolling planning horizons. [17]

Campbell and Savelsbergh (2004) use a decomposition approach to solve large scale real life instances of the IRP, in particular distributing gases from plants to customers. They propose several methods to create delivery plans. For example the Early Method tries to deliver to customers as early as possible, the Late Method as late as possible. The Greedy Method tries to deliver as much as possible to a customer under the consideration of the proceeding customers and finally the Maximum Usage Method delivers the maximum amount to the customers with the highest usage rates.
Using one of these methods creates a *k*-day delivery schedule that is followed by routing and scheduling heuristics in phase two. [18]

Savelsbergh and Song (2007) introduce the inventory routing problem with continuous moves. For a real life problem, that has some real life limitations and extensions, like limited product availability or multi-day tours, they develop a randomized greedy algorithm to

[16] cs. Bard et al., (1998), p.189 ff
[17] cs. Jaillet et al., (2002), p. 296
[18] cs. Campbell, Savelsbergh, (2004), p. 488ff

produce a delivery schedule and a volume optimization model that maximizes the total volume of products delivered over the planning horizon. [19]

Gaur and Fisher (2002) look at a periodic routing problem at a supermarket chain. Their solution approach tries to build weekly delivery schedules and determine vehicle routes at minimum costs. Customers are assigned to regions or clusters, following a fixed partition policy. They propose the randomized sequential matching algorithm (RSMA) that repeats the generalized minimum weight matching algorithm and a randomized splitting of clusters. The supermarket chain greatly benefits from integrating inventory control and vehicle routing: They could reduce lead time and increase replenishment frequency, and thus provide an advantage against their competitors in the industry. [20]

Riberio and Lourenco (2003) highlight the advantages of integrating processes along the supply chain. To solve the case of two types of customers, weekly visits and no information on inventory levels they propose an Iterated Local Search based solution method for the Multi Period Inventory Routing problem with stochastic and deterministic demand The routes are build on a week planning period and the objective of minimizing the costs for transportation, inventory, stockout costs and fixed vehicle costs at the end of the week. [21]

Heuristic approach:

- Step 1: Initial solution The inventory problem (delivery day and quantity)
- Step 2: Solve VRP for each day in planning horizon
- Step 3: Calculate delivery costs
- Step 4: Recalculate delivery days and quantities with setup costs
- Step 5: Repeat step 2
- Step 6: Repeat steps 3 to 6

[19] cs. Savelsbergh, Song, (2007), p. 1748ff
[20] cs. Gaur, Fisher, (2004), p. 813ff
[21] cs. Riberio, Laurenco,(2003), p. 14ff

For a stochastic Inventory Routing Problem Kleywegtet al. (2002) formulate a Markov decision process model. They try to incorporate sales revenues, production costs and inventory costs to maximize the expected discount value over an infinite time horizon. Their solution approach decomposes the overall problem into smaller sub-problems that are easier to solve and provide an accurate representation of a portion of the whole problem. In a first step they construct direct delivery routes as initial routes. Then, for each existing route, the customers are ranked by the value of adding the customer to the route, and the most promising move is executed until no more improvement can be achieved.[22]

More recently Chiou (2005) works on an urban logistics network with a single depot and numerous retailers facing deterministic demand rates and variable lead times. As a solution approach he proposes a new strategy to determine inventory replenishments while achieving a minimization of the total inventory and transportation costs.[23]

Al-Ameri et al. (2008) design a dynamic vendor managed inventory system, optimizing the entire supply chain in terms of production planning, distribution strategy and inventory management.

They try a direct solution approach, that needs far too much time, an iterative approach that was not able to handle distributed demand data and a forward rolling time horizon approach that worked best and could handle the detailed model in reasonable CPU time.[24]

Coene et al. (2008) use two different decomposition approaches for their case study on a real life waste management problem. The two different methods either assign customers to days and then solve the VRP or the other way around. [25]

[22] cs. Kleywegt et al., (2002), p.2ff
[23] cs. Chiou, (2005), p. 3038ff
[24] cs. Al-Ameri et al., (2008), p. 1019ff
[25] cs. Coene et al., (2008), p. 14

Another solution for a waste collection VRP is presented by Kim et al. (2008). In addition to the classical objectives, minimizing the number of vehicles and travelling time, they also take a look at the route compactness and workload balancing of a solution. They develop and implement a clustering based algorithm to solve the real life problem. As a route construction method they extend an insertion heuristic developed by Salomon. [26]

Toriello et al. (2009) also use time decomposition for a multi period model. With the combination of mixed integer programming and dynamic programming techniques they solve the single period subproblems in reasonable computational time without lowering the solution quality.[27]

[26] cs. Kim et al., (2006), p. 3624ff
[27] cs. Toriello et al., (2009), p. 17ff

2.3. Problem Definition[28]

The inventory routing problem (IRP) is concerned with the repeated distribution of a single product from a single facility, to a set of n customers over the planning horizon of length T. Every customer can hold a maximum inventory C_i and consumes the product at an individual rate u (volume a day) that is constant.

At time 0 the inventory at all stations is 0.

A fleet of homogeneous vehicles, with capacity B is available for the distribution of the product.

The objective is to minimize the average daily distribution costs during the planning horizon without causing stock outs at any of the customers.

To solve the problem three decisions have to be made:

1. When to serve a customer
2. How much to deliver to a customer when served
3. Which delivery routes to use

In our case we look at a single day multiperiod IRP. The planning horizon is a single day, divided into three periods. Some stations have to be visited only once a day, the biggest stations in every period of the planning horizon.

[28] Cordeau et al., (2004), p. 40ff

3. Real Life Newspaper Delivery Problem

In our real life problem we deliver free newspapers to underground and tramway stations, the airport, public places, bakeries, supermarkets and retirement homes. Because of changing page numbers the problem has to be performed every day. Every station has to be visited at least once a day and maximum three times. The vehicle routes start and end at the depot and provide several stations with a certain amount of newspapers. Each stations has a given capacity and demand. The vehicles have a given capacity and can perform several routes. The depot has a given production rate.

Our goal is to deliver all produced newspapers to the stations while using as few vehicles and trips as possible.

3.1. Problem Details

Fleet

The fleet is homogenous. The vehicles can perform several routes a day. They start at the depot, visit different stations until they run out of newspapers or reach a time limit. For our computation we suppose a common transportation vehicle, like VW Caddy or Citroen Berlingo, with a maximum load of 600 kg.

Time Horizon

We look at the time between 1.00 a.m. when the newspaper production starts, and 10.00 a.m., when the last newspapers should leave the boxes.

- Production horizon starts at 1.00 a.m. and ends at 7.00
- Distribution horizon starts at 4.00 a.m. and ends at 9.00
- Consumption horizon starts at 5.00 a.m. and ends at 10.00 a.m.

For the computation we concentrate on the time between 4.00 a.m., when the distribution horizon starts, and 10.00 a.m., when the consumption horizon ends and all newspapers should be taken out of the boxes. We divide our planning horizon into 3 periods of each 2 hours.

Depot

The depot is located in Faradaygasse 3, 1030 Vienna.

The depot has a production rate of 40,000 newspapers per hour that are available only at the end of the hour.

After 3 hours of production the inventory at the beginning of distribution horizon is 120,000 newspapers.

The total daily production is 240,000 newspapers.

The inventory at the end of distribution horizon should be 0.

Newspapers are packed in batches of 50 units.

Time Limits

In the first and in the last period the maximum tour-length is 60 minutes. This makes sure that all stations are visited before consumption starts at 5 a.m. and that the latest possible time for visiting a station is 9 a.m.

Stations

At each station the newspapers are stored in boxes of 4 different sizes (2,4,8,10 batches) or at a so called "Abwurfplatz".

At one station there can be several boxes. Most underground stations have one box at every entrance. To make the improvement heuristic work the boxes demands are summed up for every station.

We suppose that it needs an average of 1 minute to fill a box, so according to the number of boxes at a station we get the stations service time.

All stations should be provided before 5.00 a.m. and can only be visited until 9.00 a.m.

The consumption rate for a given period and station is known and constant.

Stock outs should be avoided before and should occur at 10.00 a.m.

Station Demand

- The consumption horizon is divided in 3 periods of 2 hours
- In the first period all nodes must be served before 5.00 a.m..
- Total daily demand over all periods equals the total daily production of 240,000 newspapers
- Latest possible time for deliveries is 9 a.m.

Demand / period	132.000	82.000	26.000
Available	120.000	80.000	40.000

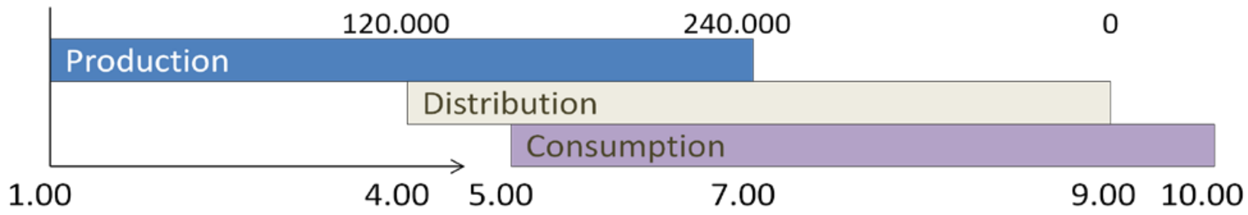

Figure 2: Production, distribution and consumption horizon

3.2. Solution Methods

To solve the newspaper delivery problem we use a decomposition approach that divides the problem into two phases: demand adjustment and routing. For both phases we use heuristics to find feasible solutions. A heuristic is “the art of finding the truth”, a “rule of thumb” used to come to a solution rapidly that is hoped to be close to the optimal solution. Heuristics provide solutions in cases where finding the exact solution would take too much time or simply is not possible.

3.2.1. Demand Adjustment

As there are not enough newspapers available at the beginning of the distribution cycle, we have to adjust the delivery volume to the available production. In the first period all stations must be visited. So it is important to visit those stations that can hold their total daily demand only in the first period to avoid visits in the other periods and save time and costs.

But this would lead to a total demand of 132,000 in the first period with only 120,000 available. So we have to move 12,000 newspapers to the second period without causing stock outs.

To cause only little additional costs we first look at those stations that have to be visited two or three times a day because they don’t have the capacity to hold their total daily demand.

Stations that are not served in the second period get less in the first period and are additionally served in second period. That leads to a total demand of 94,000 newspapers with only 80,000 available.

In a last step only those stations that are served in the second and in the third period get less in the second period.

After adjusting the demand to production capacity by moving delivery volume between periods in the last period demand equals the production at the depot.

With those simple decision rules we could adjust the demand to the limited production capacities without causing stock outs at the stations. At the end of the production horizon all newspapers produced are distributed to the stations and the inventory at the depot is 0.

3.2.2. Nearest Neighbor Heuristic

The Nearest Neighbor Heuristic is a well known heuristic for route construction. It builds its routes from the depot and always tries to go to the nearest located customer.

1. Start new tour at the depot
2. Find and mark nearest station
3. Repeat step 2 until vehicle runs out of newspapers or all stations are marked
4. Return to depot and repeat from step 1

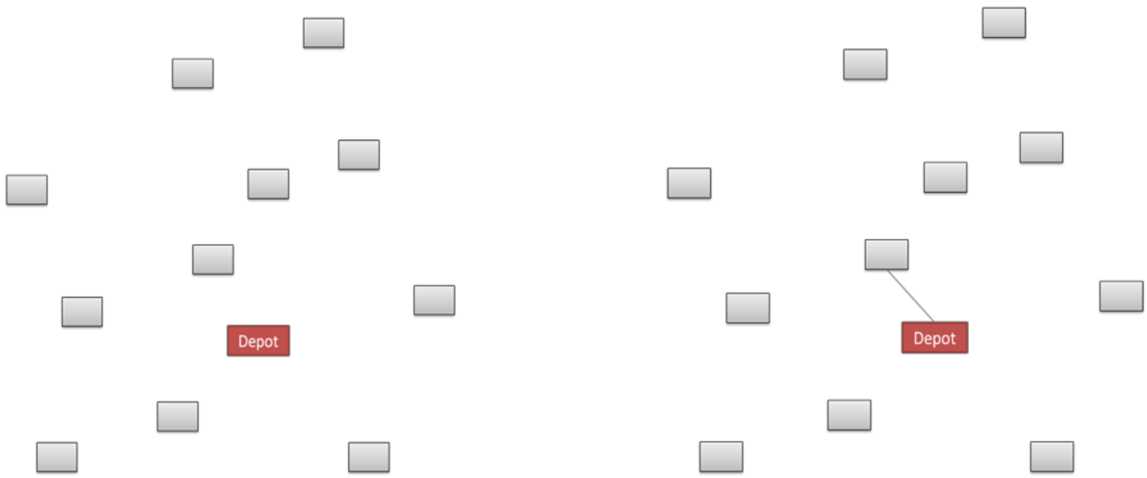

Figure 3: Nearest Neighbor Step 1 & 2

The Nearest Neighbor heuristic looks always for the closest unmarked station.[29]

[29] cs. Tyagi, (1968), p. 76 ff

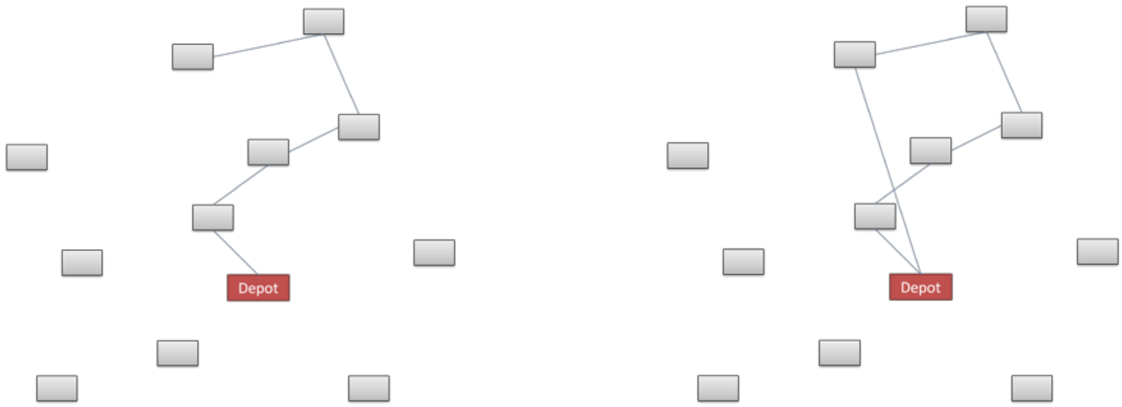

Figure 4: Nearest Neighbor Step 3 & 4

This is repeated as long as the vehicle runs out of newspapers or the maximum tour length is reached. The next tour starts at the depot followed by its closest unmarked neighbor.

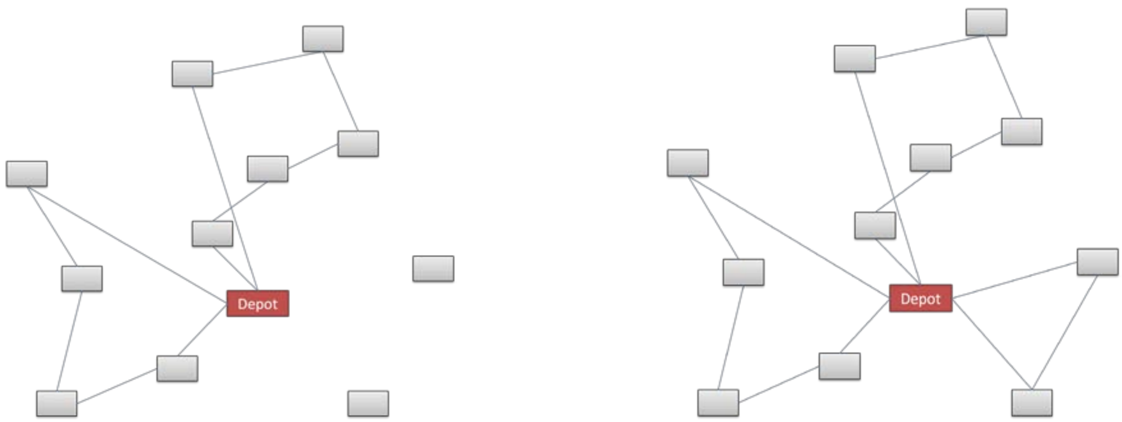

Figure 5: Nearest Neighbor Repeat from step 1

After all stations are marked the vehicle returns to the depot. The resulting delivery plan will be improved in the next step.

3.2.3. 2-Opt Heuristic

The 2-Opt heuristic, introduced by Croes (1958) tries to improve the tours by removing 2 edges and reconnect the stations the other way. If this move brings a better result than the original solution the change is saved. After trying all possible moves only the best is executed. The heuristic stops when no more improvement can be found.[30]

1. Remove two edges
2. Reconnect the other way
3. Find best move
4. Repeat until no more improvement can be found

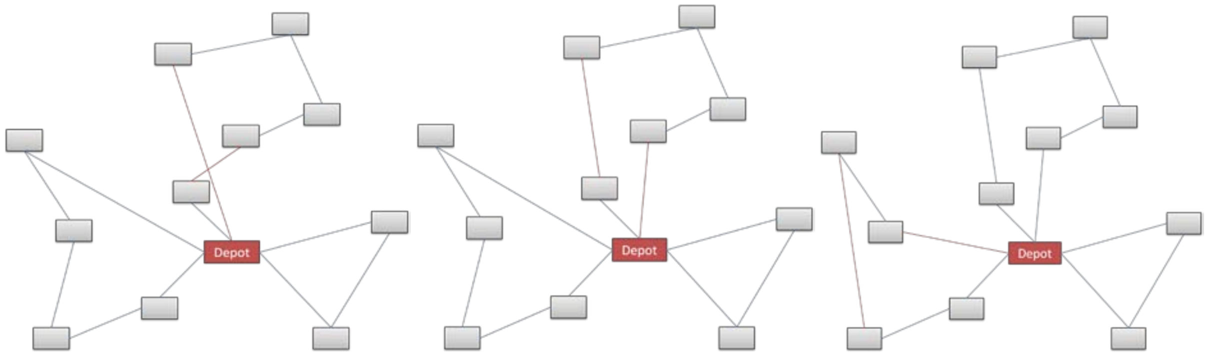

Figure 6: 2-Opt moves

[30] cs. Croes, (1958), p 791ff

4. Implementation

The solution methods are implemented in Microsoft Visual C++ 2008 Express Edition. The resulting program is executed on a Windows XP machine with an 2.2 GHz Intel Dual Core processor and 4 GB DDR3 RAM.

4.1. Input

There are 401 boxes all over Vienna plus the airport Wien - Schwechat. The data I build my work on is given by a delivery plan from November 21, 2007: 65 vehicle routes containing the boxes ID and category, the address and postal code of the station, the size and the color of the box and it’s demand. Possible categories for the boxes are public place, underground station, train station, bakery, retirement home and “Abwurfplatz”. The stations address is either the real address of the station if existing or the name of the underground or train station.

First I want to calculate the distances between all stations to get a distance matrix. This is done by WIGeoNetworks (Wirtschaftsgeografische Geoinformationssysteme) that calculates travel distance and travel time based on Tele Atlas street data, containing speed limits, one ways streets, red lights, speed limits, ban on turns, …
The software needs a list of X/Y coordinates, a so called shape file (*.shp).
At this point we need another software called JoinAdress Client to translate the list of the boxes addresses into X/Y coordinates.

But underground stations have no postal address. That’s why I had to search for the stations nearest existing address. There are more examples, like the airport or train stations, where I had to find the according address. Figure 7 shows two examples without a postal address, an underground station and a train station, and the real addresses used for the computation.

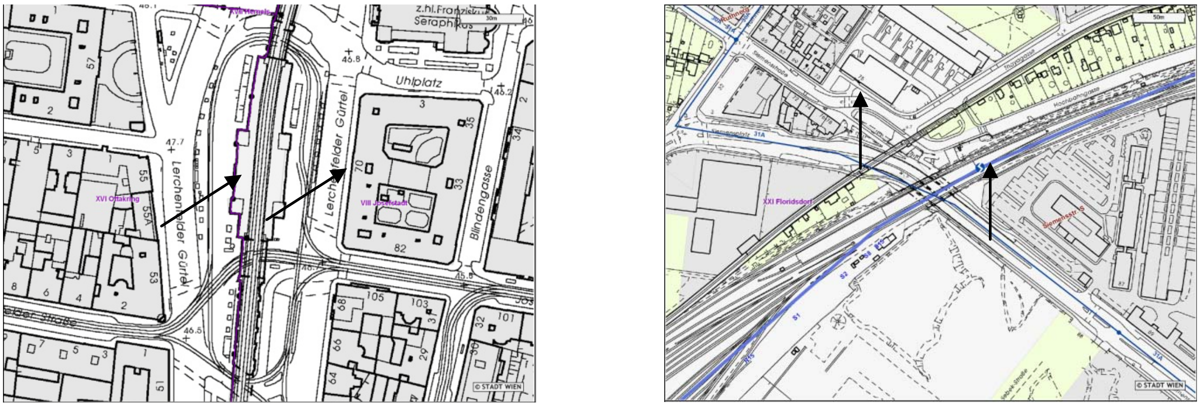

Figure 7: Station and nearest Address

4.2. Construction method

As a route construction method I used the Nearest Neighbor heuristic as described above. We perform the heuristic with every station as a start station to find a good start solution for our improvement heuristic.

For the calculation of the nearest station a combination of travel distance and travel time is used.

4.3. Improvement Method

To improve the calculated start solution I implemented the 2-Opt heuristic, also described above. In every iteration only the best move improvement is executed, as long as no more improvement can be achieved.

4.4. Output

The output should be a list of routes, containing the station ID, address and demand. We want to use Microsoft Excel, because of its plotting and data analysis capabilities. We can export the solution to Excel, that sets up a list of the computed vehicle routes for every period and also present the routes graphically.

A C++ program can communicate with Excel with the help of the Microsoft Component Object Model (COM – Interface). To use the interface we must download the Microsoft Platform SDK and include a number of Microsoft libraries into our C++ source code.

After writing all data into the sheets we can call a graph for every sheet to display the calculated solution graphically in an XY Scatter lines chart.
The result is a separate sheet for every period and a scatter lines chart depicting the solution graphically as we will see in the next chapter.

5. Computational Results

As the newspapers page number changes I want to show 3 different scenarios, thin, regular and thick newspaper, and compare them to our reference solution. The according page numbers are 26, 42 and 64. In these cases the vehicle capacity varies from 5,971 to 14,698 newspapers.

The resulting computational results are as follows

5.1. Reference Solution

First we show the results of the reference solution, given by the distribution plan from November 21, 2007.

The C++ program reads the reference solution from a list of the stations IDs and calculates the total solution duration and travel distance.

The vehicle capacity usage differs a lot from route to route, but also between the periods.

In the first period most of the stations are visited, providing them with as much newspapers as possible.

In order to avoid infeasibilities, the stations demands is also adjusted to the available production capacity of 120,000 newspapers.

The vehicle capacity usages varies from 3,450 to 8,200 newspapers. They also build a single tour for the airport with only 650 demanded units. The average capacity usage is 4,800.

This leads to 25 tours that take 663.73 km and 23.54 hours.

Figure 8 shows the results graphically, with the help of a scatter lines chart that is generated automatically by the C++ program.

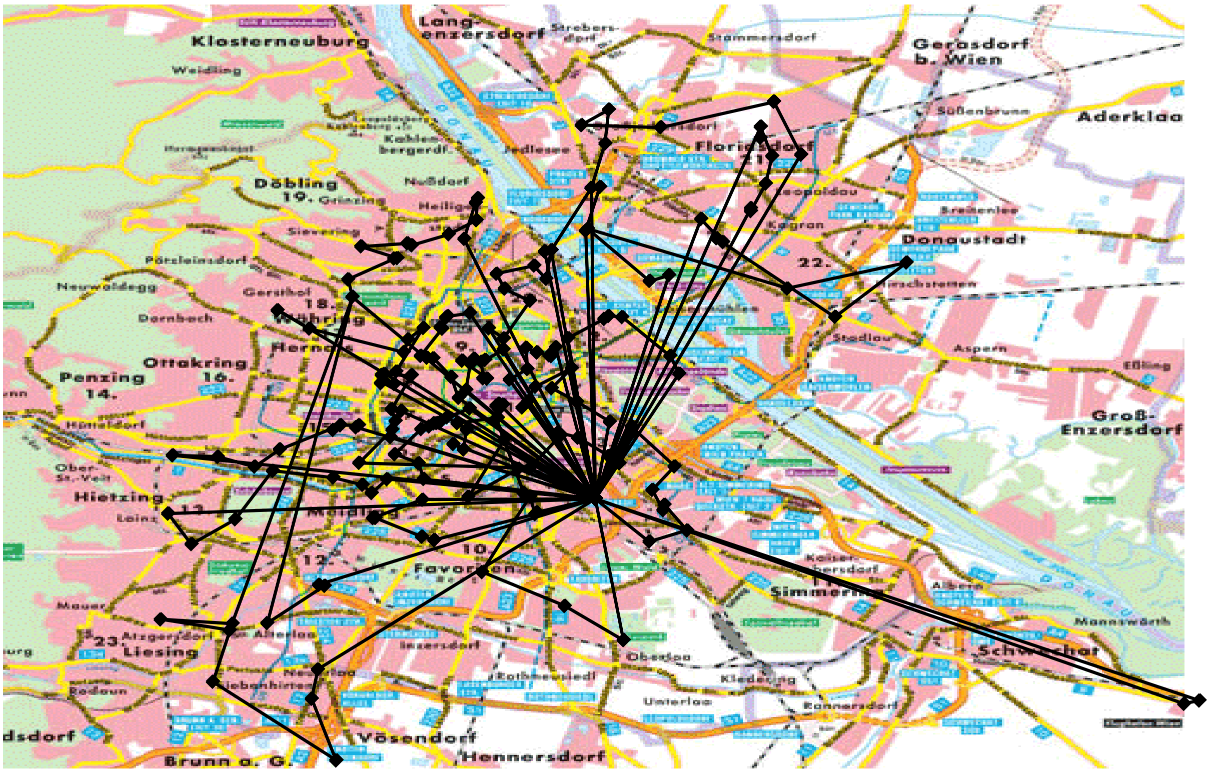

Figure 8: reference solution / period 1, graph

As the reference solution uses the same routes in the second period as in the first period, they need 27 routes to fulfill the demand of 80,000. The vehicle capacity usage varies from 600 to 7,350, with an average of 2,963. This is obviously a waste of resources, using the same number of vehicles to deliver only 2/3 of the volume and sending vehicles with a lot of free capacity back to the depot. Some vehicles only transport a fraction of their possible volume and the tours sometimes consist only of two or three stations. From the C++ route output we can also see that some routes are not delivered at all in period two, depicted by four following visits of the depot. The resulting routes need a total of 485.24 km and 15.62 hours.

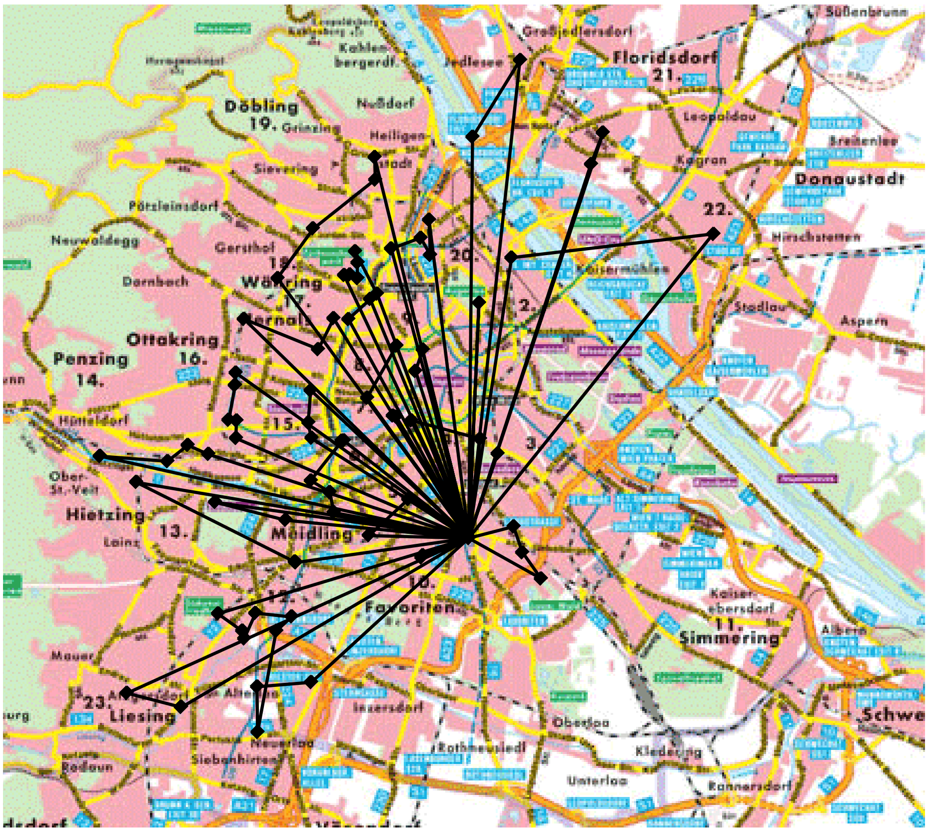

Figure 9: reference solution / period 2, graph

In the third period they use different routes, providing only the biggest stations with the highest demands with newspapers. The resources are better used than in the second period, vehicle loads vary from 3,400 to 7,200 newspapers, leading to 8 tours that need 188.45 km and 6.62 hours to deliver the last 40,000 newspapers.

Figure 10: reference solution / period 3, graph

The reference solution uses the same routes every day, no matter how thick the newspaper is at that day. It also uses the same routes in the first and in the second period, providing sometimes only some stations with newspapers, and return to the depot with unused capacity. In the last period only big underground stations and public places with high demand rates are served.

The resulting solution needs 60 routes with a total distance of 1,337.42 km and a total time of 45.78 hours.

The average vehicle capacity usage over the planning horizon is 4,000 newspapers.

5.2. Thick Newspaper

We start with a thick newspaper, 64 pages, which leads to results similar to the original proposed distribution plan. In that case the vehicles can deliver a maximum of 5,971 newspapers at each tour.

In the first period we need 23 routes with a travel distance of 631.9 kilometers and a total travel time of 23.26 hours compared to 25 routes, 663.73 kilometers and 23.54 hours of the reference solution. The vehicle capacity usage varies from 2,000 to 5,950 newspapers with an average of 5,217.4.

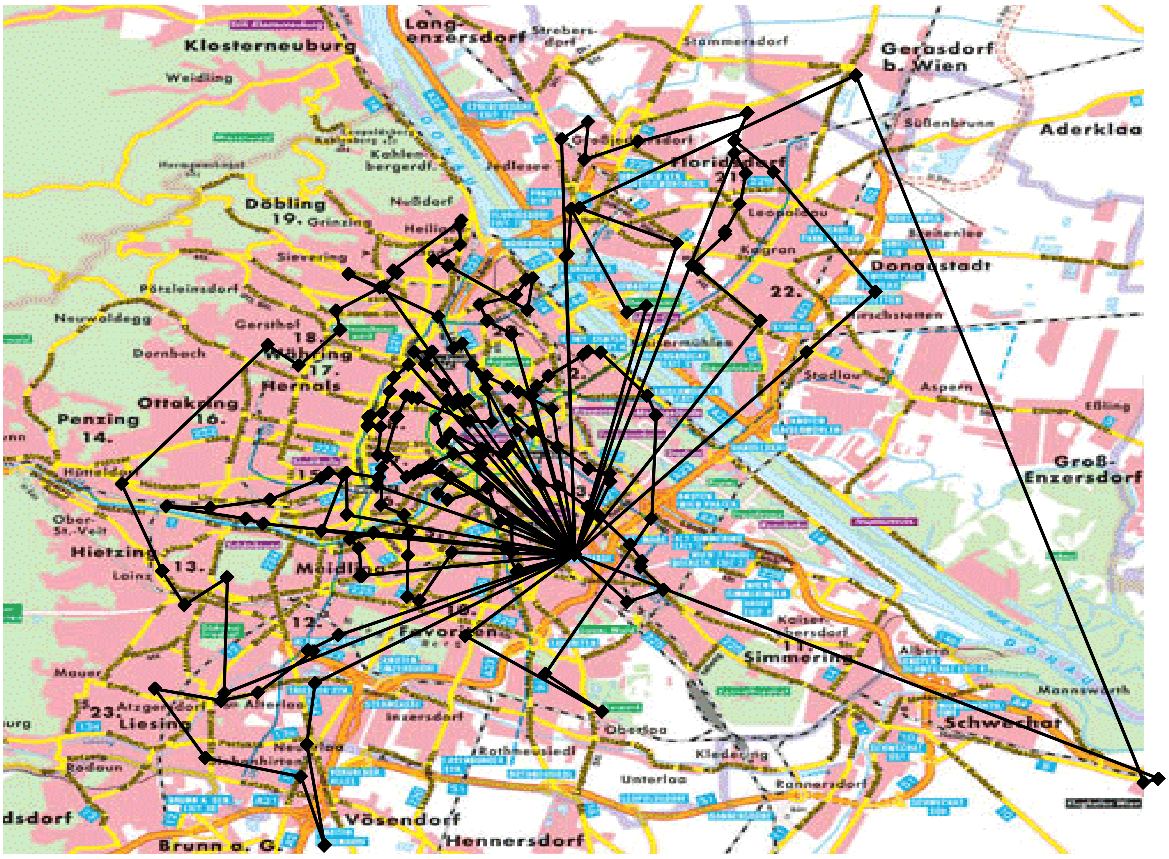

Figure 11: 64 pages / period 1, graph

In the second period our calculated distribution plan needs only 16 routes and 384.09 km compared to the 27 routes that take 485.24 km from the reference solution.

The total travel time is 14.34 hours, the vehicles load vary from 2,000 to 5,950 with an average of 5,000 newspapers.

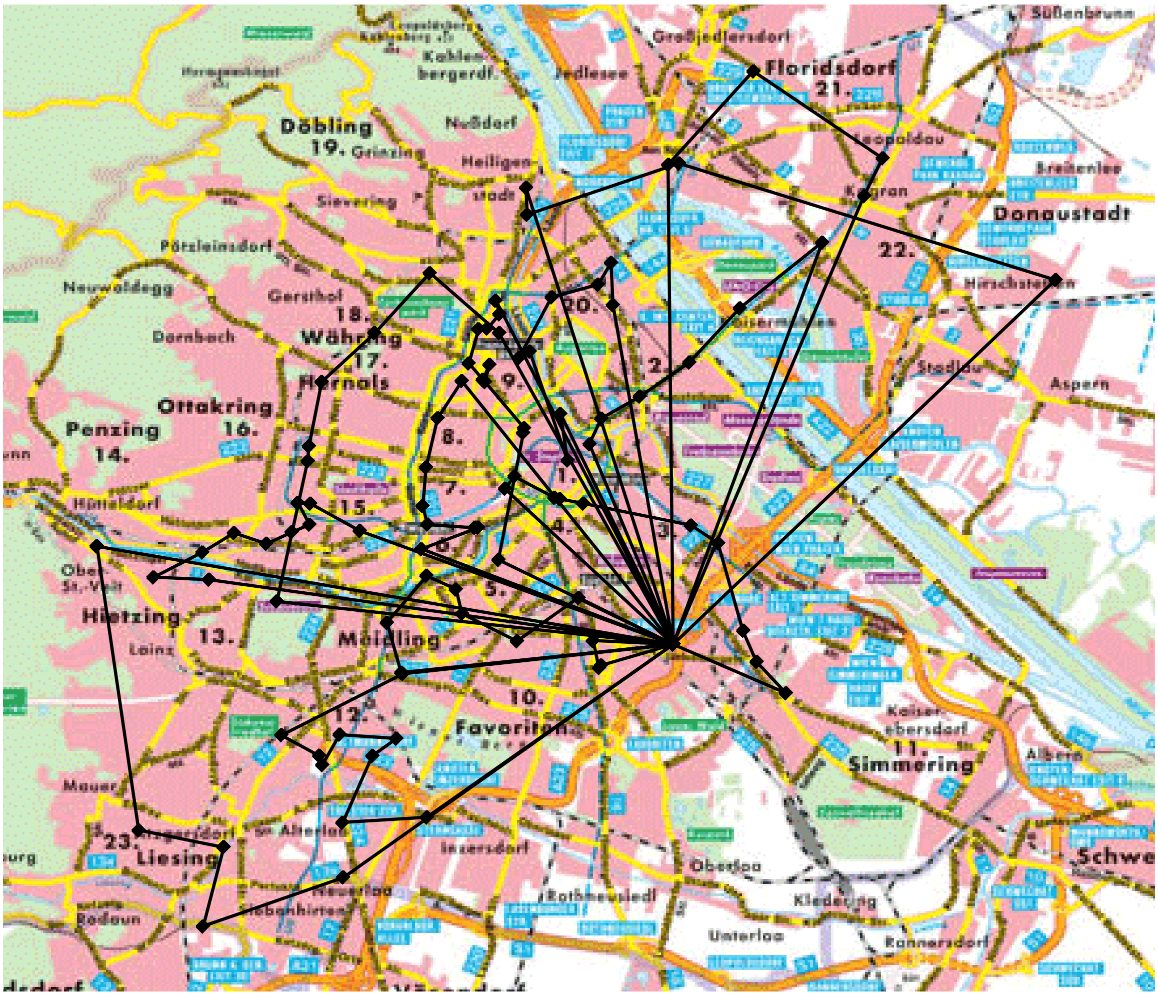

Figure 12: 64 pages / period 2, graph

In the third period both distribution plans need 8 routes, our solution needs 185.86 km, the original solution 188.45 km, with a capacity usage from 3,000 to 5,950 newspapers and an average of 4,862.5. The travel time is 6.53 hours.

Figure 13: 64 pages / period 3, graph

The total number of routes in the case of 64 pages is 47 with total travel distance of 1,201.89 km in opposite to the original plan that needs 60 routes and 1,337.42 km. The total travel time is 44.13 hours. The vehicles have an average capacity usage of 5,106 newspapers.

5.3. Regular Newspaper

Next we see what happens if the newspaper has an average page number. We suppose an often observed number of 42 pages. In that case every vehicle can load a maximum of 9,099 newspapers. The original distribution plan stays the same – our plan changes.

In the first period we can significantly reduce the number of vehicles. We only need 15 routes that take 506.5 km and 20.6 hours to deliver the newspapers. The average vehicle load is 8,000 with a single tour providing the airport with 650 and a maximum load of 9,050 newspapers.

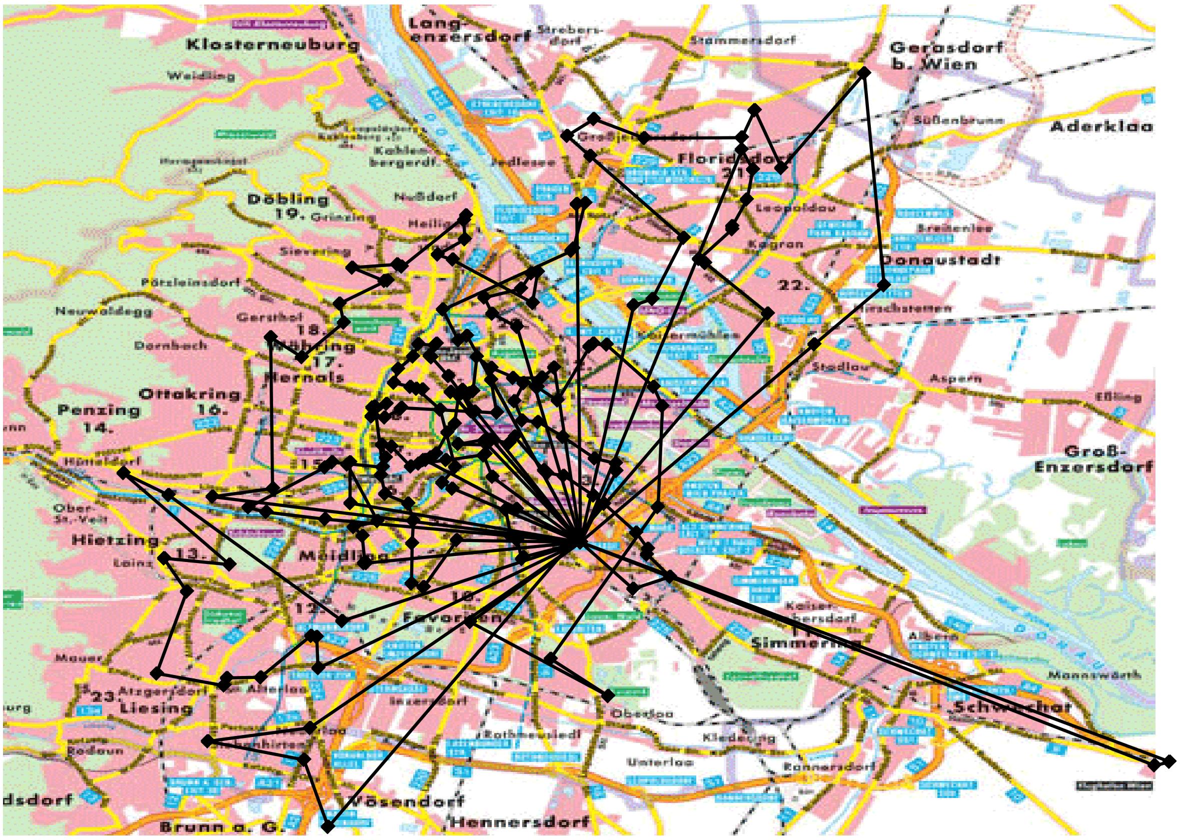

Figure 14: 42 pages / period 1, graph

In the second period we only need 10 routes and 289.88 km, 12.2 hours. The vehicle loads vary from 4,000 to 9,000 newspapers with an average of 8,000.

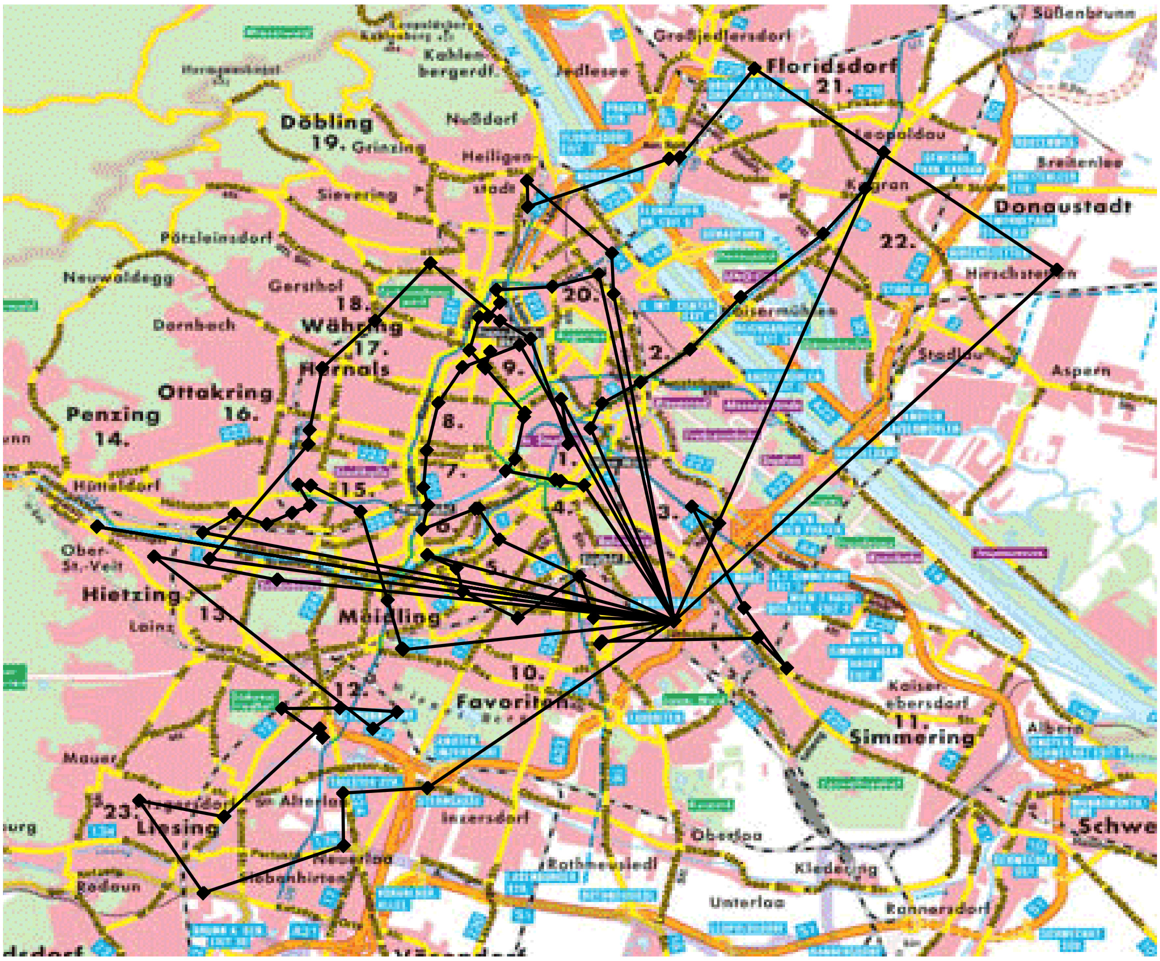

Figure 15: 42 pages / period 2, graph

In the third period we need 5 routes and 134.57 km that need a total time of 5.51 hours. The vehicle capacity usage goes from 5,450 to 8,700 with an average of 7,780.

Figure 16: 42 pages / period 3, graph

The total number of tours in our case is 30 with an average capacity usage of 8,000 newspapers compared to 60 tours. The total travel distance is only 930.95 km compared to 1,337.42 km. The travel time is reduced from 45.78 hours to 38.31 hours.

5.4. Thin Newspaper

In a last step we look at a thin newspaper with only 26 pages, and the results differ even more. The vehicles can load a maximum of 14,698 newspapers.

In the first period we only need 11 routes, 442.59 km and 19.02 hours. The minimum vehicle load is 650, which provides the airport, the other tours vary from 4,500 to 14,500 units. The average vehicle load is 10,909 newspapers.

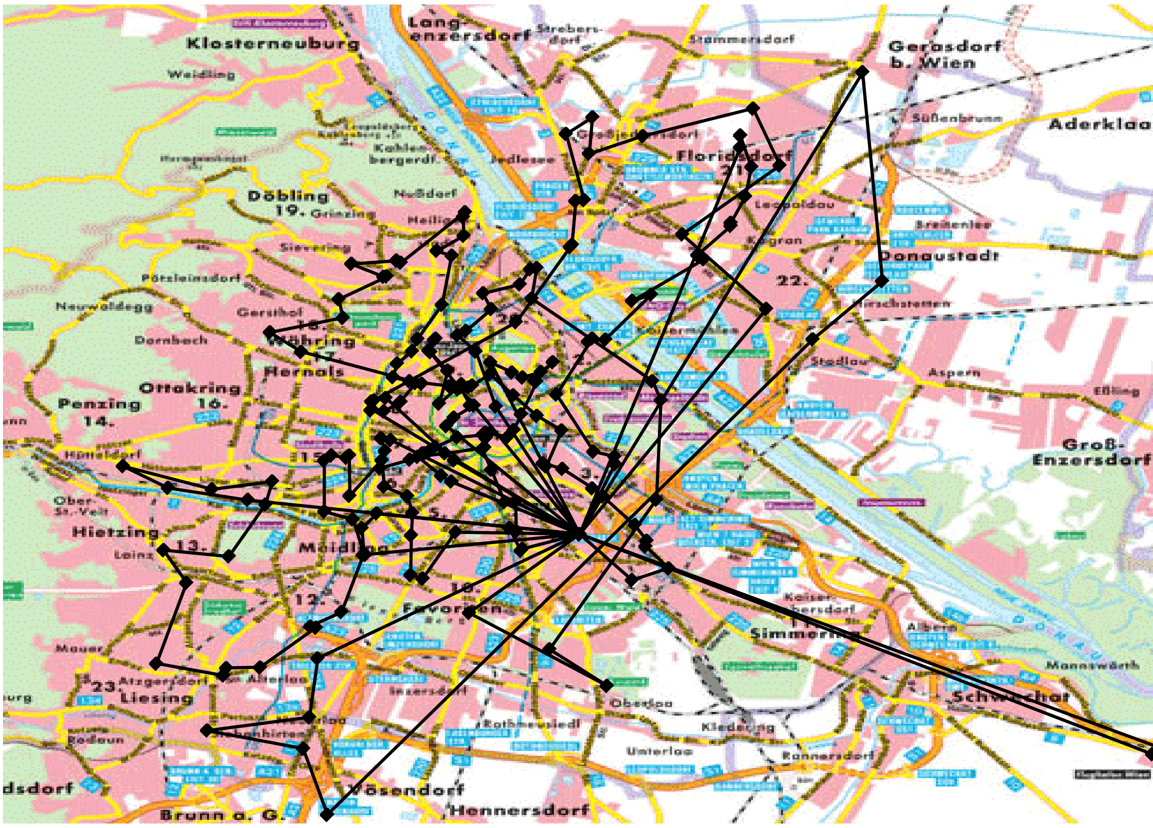

Figure 17: 26 pages / period 1, graph

To satisfy the demand of the total demand of 80,000 newspapers in the second period we need 6 routes that take 240.11 km and a total time of 10.74 hours. The vehicle loads vary from 9,450 to 14,400 with an average of 13,333 newspapers.

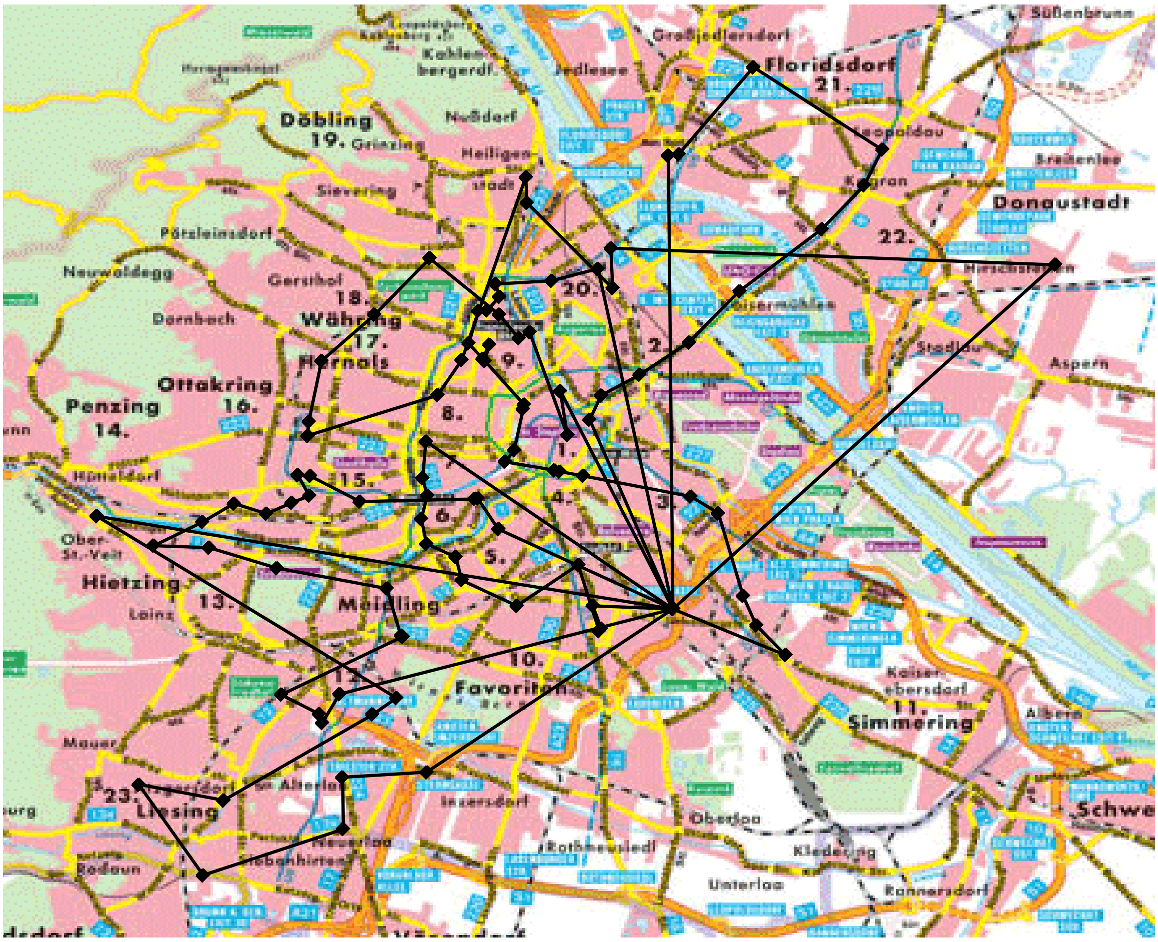

Figure 18: 26 pages / period 2, graph

In the third period 3 tours are built that take 114.73 km and 5.05 hours The average vehicle load is 12,966 newspapers varying from 12,200 to 13,500.

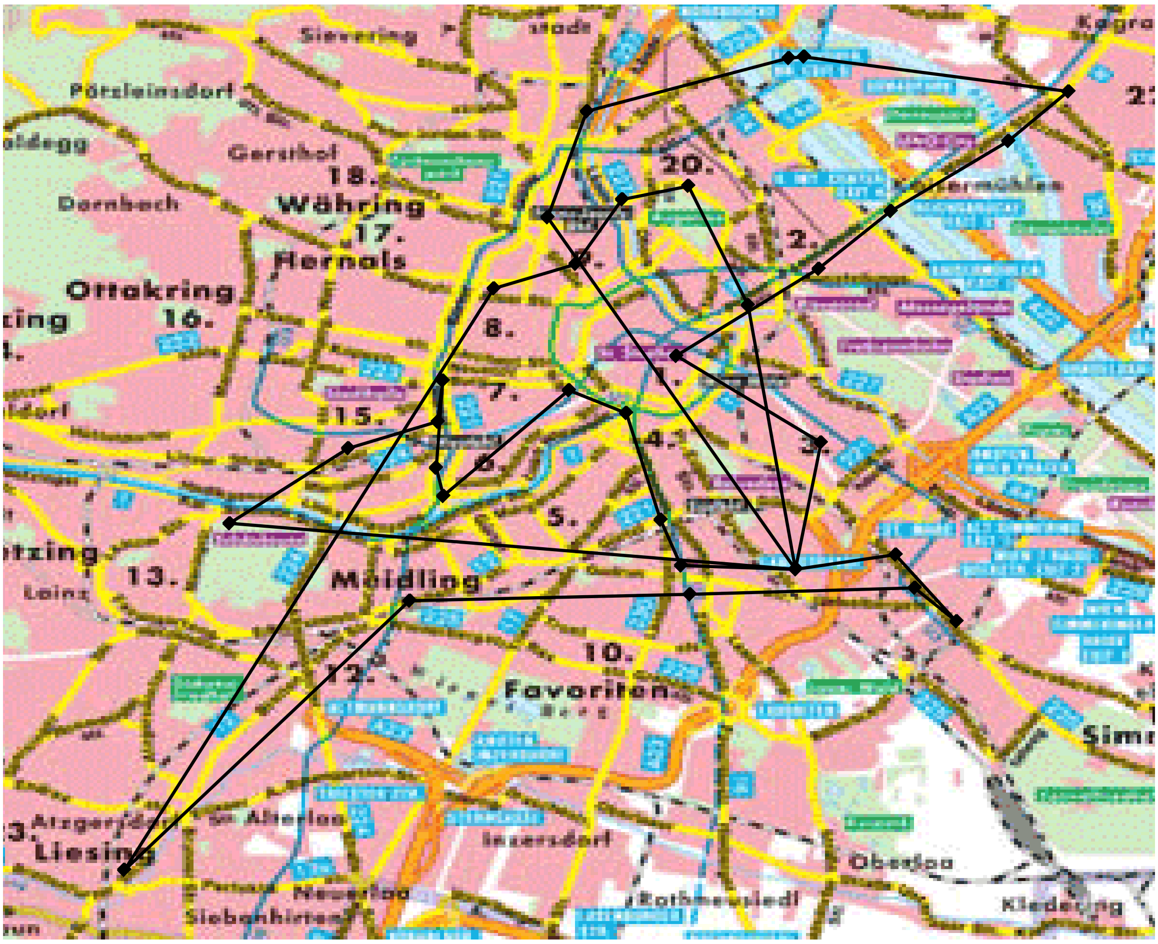

Figure 19: 26 pages / period 3, graph

In the last case presented, a thin newspaper with 26 pages, the total number of tours is 20. The travel distance is 797.43 km and the estimated total travel time is 34.81 hours, with an average vehicle capacity usage of 12,000.

If we compare this to the original distribution plan we can reduce the number of tours from 60 to 20, the travel time by more than 10 hours, with a travel distance nearly half of the proposed routes.

6. Conclusion

In this master thesis a real life inventory routing problem about delivering free daily newspapers was implemented and solved. It is a periodic problem about delivering newspapers from a depot to the newspaper-boxes that are placed in underground and tramway stations, public places, the airport, supermarkets, bakeries and retirement homes. The newspapers are produced at a single depot and distributed with a homogenous fleet within a certain time horizon. Depending on the page number of the newspapers the vehicles can load a different amount of newspapers. Therefore the vehicle routes should change with different newspaper thickness.

We try to minimize the total costs for distribution, which is a combination of travel distance and travel time, without causing stockouts at the stations. To do so we have to make decisions about when to serve a customer, how much to deliver and which delivery route to use.

The data this work is built on comes from an actual distribution plan. The distances between the stations is calculate by WIGeoNetworks software that uses Tele Atlas street data, containing speed limits, one way streets, red lights, ban on turns, …

The problem is decomposed into two phases: demand adjustment and routing. We use simple decision rules to adjust the demand to the available production to get a delivery schedule. For the route construction we use the Nearest Neighbor Heuristic and the 2-Opt Heuristic for further improvements. In all cases these simple methods provide results in reasonable CPU time. The solution is exported to Microsoft Excel to make the data available in every office. A list of the vehicle routes containing the boxes ID, the stations name, address and demand is automatically built and a graph is drawn to make the results visible.

We present the results of three different page numbers (64, 42 and 26 pages) and compare them to a reference solution.

The reference solution needs 60 vehicle routes that need 1,337.42 km and 45.78 hours to deliver all newspapers to the stations with an average vehicle capacity usage of 4,000 newspapers.

Compared with our solutions this is similar to a newspaper with 64 pages, which is the highest page number observed. In this case we can achieve a more effective usage of the vehicles capacity and therefore reduce the number of vehicle routes to 47, with according savings in the total travel distance and travel time. The average capacity usage in that case is 5,106 newspapers.

If the newspaper has less pages the number of vehicle routes needed to distribute the produced newspapers is also decreasing. In the average case of 42 pages the number of vehicle routes needed is 30 which is only half of the reference solution. The total travel distance can be reduced by 400 km and the total travel time by 7 hours with an average capacity usage of 8,000 newspapers.

In the case of a thin newspaper with only 26 pages the number of vehicle routes can be reduced to 20 and the average capacity usage rises to 12,000 newspapers. The total travel distance is 794.43 km and the total travel time is 34.81 hours.

The results show that a daily computation of the vehicle routes according to the newspaper thickness significantly reduces the number of vehicle routes and the total distribution costs.

Future work should focus on the implementation of more effective meta-heuristics because we only used simple route construction and improvement heuristics. It would also be interesting to put the focus on the number of vehicle routes instead of the total travel cost to keep the vehicle fleet small.

7. References

Al-Ameri T. A., Shah N., Papageorgiou L. G., (2008), Optimization of vendor-managed inventory systems in a rolling horizon framework, Computers & Industrial Engineering 54, pp. 1019 – 1047

Bard J. F., Huang L., Jaillet P., Dror M, (1998), A Decomposition Approach to the Inventory Routing Problem with Satellite Facilities, Transportation Science Vol. 32, No. 2, pp. 189-203

Campbell, A. M., & Savelbergh, M. W., (2004). A Decomposition Approach for the Inventory-Routing Problem. Transportation Science, Vol. 38, No. 4 , pp. 488-502.

Campbell A. M., Hardin J.R., (2005), Vehicle minimization for periodic deliveries, European Journal of Operational Research 165 pp. 668 -- 684

Chiou S.W., (2005), Integrating the Inventory Management and Vehicle Routing Problems for congested urban Logistics Network, Journal of the Eastern Asia Society for Transportation Studies, Vol. 6, pp.3038 – 3051,

Croes, G.A., (1958), A method for solving traveling salesman problems, Operations Research 6, pp. 791-812.

Gaur V., Fisher L.M., (2004), A Periodic Inventory Routing Problem at a Supermarket Chain, Operations Research; Vol. 52, No. 6, pp. 813-822

Jaillet P., Bard J.F., Huang L., Dror M., (2002), Delivery Cost Approximation for Inventory Routing Problems in a Rolling Horizon Framework, Transportation Science, Vol. 36, No. 3, pp. 292-300

Savelsbergh M, Song J.-H., (2007), Inventory Routing with continuous Moves, Computers & Operations Research, Volume 34, Issue 6, pp. 1744-1764

Tyagi, M., (1968), A practical method for the truck dispatching problem, Journal of Operations Research, Society of Japan, pp. 76-92

Internet

Bankhofer U., Wilhelm M., WIlliner G., (2006), Modelle und Methoden der Tourenplanung
http://www.db-thueringen.de/servlets/DerivateServlet/Derivate-10027/IBzWI_2006-05.pdf
call from 2010-06-09

Coene S., Arnout A., Spieksna F., (2008), The Periodic Vehicle Routing Problem: A Case Study
http://www.econ.kuleuven.ac.be/public/N05012/KBI_0828.pdf.
call from 2010-03-12

Cordeau, J.-F., Laporte G., Savelsbergh M., Vigo D., (2004), Short Haul Routing,
http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.122.9096&rep=rep1&type=pdf
call from 2010-03-12

Kleywegt A.J., Nori V. S., Savelsbergh M. W. P., (2000), The Stochastic Inventory Routing Problem with Direct Deliveries
http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.24.3273&rep=rep1&type=pdf
call from 2010-03-12

Kleywegt A.J., Nori V. S., Savelsbergh M. W. P., (2002), Dynamic Programming Approximations for a Stochastic Inventory Routing Problem,
http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.89.2866&rep=rep1&type=pdf
call from 2010-03-12

Österreichische Auflagenkontrolle, Auflagenliste 2.Halbjahr 2009
http://www.oeak.at/content/intern/Auflagenlisten/OEAK_2009_2HJ.pdf,
call from 2010-03-12

Ribeiro R., Laurenco H., (2003), Inventory Routing Model for a multi period problem with stochastic and deterministic demand
http://www.recercat.net/handle/2072/870
call from 2010-03-12

Scheurer S., (2004), Neue Tabusuche-Heuristiken für die logistische Tourenplanung bei restringierendem Anhängereinsatz, mehreren Depots und Planungsperioden
http://epub.uni-regensburg.de/10196/1/Scheuerer_Stephan_Dissertation_April_2004.pdf
call from 2010-06-09

Toriello A., Nemhauser G., Savelsbergh M., (2009), Decomposing Multi Period Fixed Charge Network Flows with Approximate Value Functions
http://www2.isye.gatech.edu/~atoriell/fix_charge_adp_decomp.pdf
call from 2010-03-12

Verband der Regionalmedien Österreichs, Regioprint 2009
http://www.themediaconsultants.at/uploads/media/Regioprint_2009_Web.pdf,
call from 2010-03-12

Wikipedia Gratiszeitung
http://de.wikipedia.org/wiki/Gratiszeitung
call from 2010-03-12

APPENDIX C ABSTRACT

Diese Diplomarbeit beschäftigt sich mit der Lösung eines real existierenden Inventory Routing Problems.

Für eine Österreichische Gratistageszeitung wird ein Programm zur Minimierung der Distributionskosten erstellt, das abhängig von der Seitenzahl Fahrzeugtouren erstellt.

Die Fahrzeuge beliefern ausgehend von einem Depot Zeitungsboxen, die in Straßen- und U-Bahn-Stationen aufgestellt sind mit Zeitungen.

Nach einer zeitlichen Anpassung des Bedarfs an das verfügbare Angebot werden mit einfachen Heuristiken Fahrzeugrouten gebildet.

Die Ergebnisse werden anhand von drei verschiedenen dicken Zeitungen dargestellt und mit einem Auslieferungsplan, der auch die Basis der Adress- und Bedarfsdaten bildet, verglichen und in Microsoft Excel ausgegeben.

APPENDIX D LEBENSLAUF

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Eidesstattliche Erklärung

Ich erkläre hiermit an Eides Statt, dass ich die vorliegende Arbeit selbständig und ohne Benutzung anderer als der gegebenen Hilfsmittel angefertigt habe.

Die aus fremden Quellen direkt oder indirekt übernommenen Gedanken sind als solche kenntlich gemacht.

Die Arbeit wurde bisher in gleicher oder ähnlicher Form keiner anderen Prüfungsbehörde vorgelegt und noch nicht veröffentlicht.

Wien, am 14.06.2010

(Thomas Krapf)