



Master's degree thesis

LOG950 Logistics

**Multi-period Vehicle Routing Problem with multiple
Time Windows**

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1.0 Introduction

In this thesis studied a Multi-period Vehicle Routing Problem with multiple Time Windows of a Russian Small Transportation Company (STC). STC uses own fleet of vehicles to delivery frozen and chilled goods for short and long distance in central part of Russia.

Company provides goods delivery with their warehouses denoted as depot to each customers directly. Delivery time and vehicle routes plans for two week in average. All customers is required to be visited once per week at certain day of the week and within opening hours. In the case of a visit to a customer at an inopportune time or date, the vehicle should wait until the nearest time opened for service. Delivery planning is of paramount importance as company's market competitiveness depends on it. Violation of the planning delivery date may lead to the penalty, loss of profit and even to the loss of a customer.

The problem is considered in the thesis is a variation of the Vehicle Routing Problem with Time Windows (VRPTW). The solution for VRPTW it's set of routes in which service at every customer should start and end in given time window. VRPTW is NP-hard combinatorial optimization problem, especially large real-life problem as in case described in this thesis. Normally problem can't be solved with exact methods in reason of the customers number and complexity of data. Multi-period Vehicle Routing Problem complicated with multiple Time Windows for every customer transfers the problem to a new level of complexity.

Thesis objective is to develop the tool or algorithm that could used by the company's to plane delivery process. It should provide a good quality solution to the daily problems of the company, with a reasonable computation time and use open-source or public available software.

The main part of the thesis is organized into 8 parts. Detailed company introduction and the vehicle routes planning with its disadvantages is presented in Chapter 2. Problem definition is given in Chapter 3. Chapter 4 covers literature review and some vehicle routing problem theoretical background. The two-phase solution methodology chosen to solve the problem described in Chapter 5. Chapter 6 provides distance and cluster matrix generation algorithm.

Chapter 7 covers computational experiment results and results analysis. Conclusion are made on work presented in Chapter 8.

References are listed in Chapter 9. Chapter 10 contents the Appendix with work detailed results and some additional information.

2.0 Problem description

This section covers company introduction and present the vehicle routes planning with its disadvantages.

2.1 Company general description

Small Transportation Company (STC) located in Moscow, Russia. The company main office based in Moscow, Krasnaya Sosna street, d. 2. STC provides perishable products delivery on short and long distance in the central part of Russia since 1998. Assortment of goods includes about 100 different items.

2.2 The vehicle fleet

Transportation of perishable products, certain medicines and chemicals requires a strict temperature control. Normal isothermal vehicle cannot meet these requirements. To solve this problem it is advisable to use isothermal vehicle equipped by refrigeration unit. This type of vehicle is called the refrigerator vehicle. Due to the special equipment, refrigerator vehicles maintain the set temperature at all times during the way.

On the ability to maintain a certain temperature, refrigerator vehicles are divided into classes:

- Class A: from 12 C to 0 C
- Class B: 12 C to - 10 C
- Class C: 12 C to - 20 ° C

The dimensions of the refrigerator truck:

- Carrying capacity - 20 tons.

Dimensions:

- The height of the camera - from 2.4 - 2.5m
- The length of the camera - from 13.2 - 13.6 m
- The width of the camera - from 2.43 - 2.45 m
- Body type - closed

- Method of loading - back.

The STC works with perishable products and own the fleet of 10 class C refrigerator vehicles. The own fleet is able to cover the demand, but if necessary the outsource vehicles hiring is possible. Cost of hiring outscores refrigerator vehicle is 5 NOK per kilometer.

2.3 Customers

Locations of the STC clients are distributed intracity of the central part of Russia. The Russian Traffic Network organized next way: all perishable product cargos first arrived to St. Petersburg and Moscow, and second distributed to the other cities. This terms based on warehouses location and Russia geographical position with respect to exporting countries. STC served different supermarkets required goods transportations from Moscow to its door. Lead time may reach 2 weeks approximately. In some cities goods delivery with big tonnage vehicle allowed only during the night.

In the first week of July 2014, SLC was required to serve 39 points located in Ivanovo, Kazan, Kostroma, Naberezhnye Chelny, Nizhny Novgorod, Perm, Pyshma Verhnaya, Tver, Ufa,

Yekaterinburg, Yaroslavl. All customers have time windows during the working day and time windows for available delivery day during the week. The number of requested pallets and the time windows within which service was allowed are reported in Table 1.

City	Sales Point	Number of box	Number of pallets	Time windows	Available Delivery Day
Ivanovo					
	Ashan	38	3	7:00 a.m. - 4:00 p.m.	Mon,Wed,Fri
	7 Continent	21	1	7:00 a.m. - 4:00 p.m.	Mon-Fri
	Magnit	65	2	7:00 a.m. - 4:00 p.m.	Mon-Fri
	Okey	7	2	7:00 a.m. - 4:00 p.m.	Mon-Fri
Kazan					
	Ashan	105	4	1:00 a.m. - 8:00 p.m.	Mon-Fri
	Zelgros	14	3	1:00 a.m. - 8:00 p.m.	Mon-Fri
	Ashan	143	4	1:00 a.m. - 8:00 p.m.	Mon-Fri

Kostroma					
	Ashan	59	3	7:00 a.m. - 4:00 p.m.	Mon-Fri
	7 Continent	25	1	7:00 a.m. - 4:00 p.m.	Mon-Fri
Naberezhnye					
Chelny					
	Lenta	107	2	7:00 a.m. - 4:00 p.m.	Mon-Fri
Nizhny					
Novgorod					
	Metro	29	1	7:00 a.m. - 4:00 p.m.	Mon,Wed,Fri
	Metro	25	1	7:00 a.m. - 4:00 p.m.	Mon,Wed,Fri
	Ashan	24	2	7:00 a.m. - 4:00 p.m.	Mon-Fri
	Lenta	101	2	7:00 a.m. - 4:00 p.m.	Mon-Fri
	Ashan	14	3	7:00 a.m. - 4:00 p.m.	Mon-Fri
	Okey	115	3	7:00 a.m. - 1:00 p.m.	Tue-Thu
	Magnit	450	11	7:00 a.m. - 4:00 p.m.	Tue-Thu
Pyshma					
Verhnaya					
	Perekrestok	78	1	7:00 a.m. - 4:00 p.m.	Mon-Fri
Perm					
	Lenta	150	2	10:00 a.m. - 7:00 p.m.	Mon-Fri
Tver					
	Atak	5	1	7:00 a.m. - 4:00 p.m.	Mon,Wed,Fr
	Atak	11	2	7:00 a.m. - 4:00 p.m.	Mon,Wed,Fr
	Magnit	579	6	7:00 a.m. - 2:00 p.m.	Mon-Fri
	Lenta	229	6	7:00 a.m. - 4:00 p.m.	Mon-Fri
Ufa					
	Lenta	171	3	5:00 p.m. - 8:00 p.m.	Mon-Fri
	Ashan	8	8	10:00 a.m. - 7:00 p.m.	Tue-Thu
	Okey	11	2	10:00 a.m. - 7:00 p.m.	Tue-Thu
	Okey	3	12	10:00 a.m. - 7:00 p.m.	Tue-Thu
	Okey	12	12	7:00 a.m. - 4:00 p.m.	Mon-Fri
	Magnit	1	1	1:00 a.m. - 8:00 p.m.	Mon-Fri
Yekaterinburg					
	Ashan	10	1	7:00 a.m. - 4:00 p.m.	Mon,Wed,Fri
	Ashan	62		7:00 a.m. - 4:00 p.m.	Mon,Wed,Fri
Yaroslavl					
	Lenta	109	3	7:00 a.m. - 4:00 p.m.	Mon,Wed,Fri
	7 Continent	13	1	8:00 a.m. - 5:00 p.m.	Wed
	Atak	3	1	7:00 a.m. - 4:00 p.m.	Wed, Fri
	Ashan	21	4	9:00 a.m. - 11:00 a.m.	Wed

Ashan	11	2	9:00 a.m. - 11:00 a.m.	Wed
Lenta	24	1	7:00 a.m. - 4:00 p.m.	Mon,Wed,Fri
Giperglobus	176	7	7:00 a.m. - 4:00 p.m.	Wed, Thu
Magnit	174	5	7:00 a.m. - 4:00 p.m.	Wed, Fri

Table 1. Number of box and pallets, time windows and delivery dates for customers

2.4 Cargos

STC provides perishables (refrigerated) cargo delivery. As special cargo it's requiring the special temperature, air and time mode, as well as moisture regime during transportation and storage in order to preserve its fitness.

By the method of heat treatment perishable goods are divided into five groups:

- Fresh. Such goods are not treated that could change their natural state;
- Chilled. Loads with a temperature of about -6 to 4 C;
- Frozen. Loads with temperature of -7 to -17 C;
- Deep Frozen. Loads cooled to -18 ° C and below;
- Heated. Loads with a temperature above the ambient air.

The bulk of perishable goods, offered for transport, are food, which include: meat and meat products, fish and seafood, canned goods, dairy products, bakery products (cakes), pastries, fruits, vegetables, etc.

Specificity of refrigerated transport of perishable goods and "thermos" (isothermal vehicle) is strict adherence to delivery dates and temperature. Observe the temperature in the refrigerator compartment at a rate of delivery is particularly important in the transport of such loads over long distances (1000 km or more) as for the bulk of perishable goods (transport of food and medical supplies) sanitary norms and set rules of retention periods, calculated from the time of their manufacture.

2.5 Current Planning

Processing of supermarkets incoming orders and vehicle route planning performed in the end of every week and show in Fig.1. Every customer has a minimal possible lead time starting from depot based on Distance Matrix.



Figure 1. Delivery schedule horizon

Location of the clients distributed through central part of Russia, lead time may reach of 10 days horizon. All clients have to type of the time windows: TW for available delivery time during the working day and TW for available delivery day during the working week.

For solving such type of problems and vehicle routes building SLC use public available site www.ATI.su. AutoTransInfo system is a convenient way of information exchange between participants of vehicle cargo transportation market: carriers, freight forwarders, shippers. AutoTransInfo database is completely free to place orders for the carriage of goods, report the presence of trucks in any direction and routes building. Fig. 2 shows how route request window looks. It simply consist of route start and end point.

Расчет расстояний

Москва, Москва (регион), Россия

Нижний Новгород, Нижегородская

Показывать карту


 Рассчитать

Figure 2. AutoTransInfo database route request window

Fig. 3 introduce the result of route request from Moscow, SLC location point, to Nizhny Novgorod, one of the destination towns. It's included Google maps routes parameters: start point, end point and allows to add intermediate points, contains total route duration and total travel time.

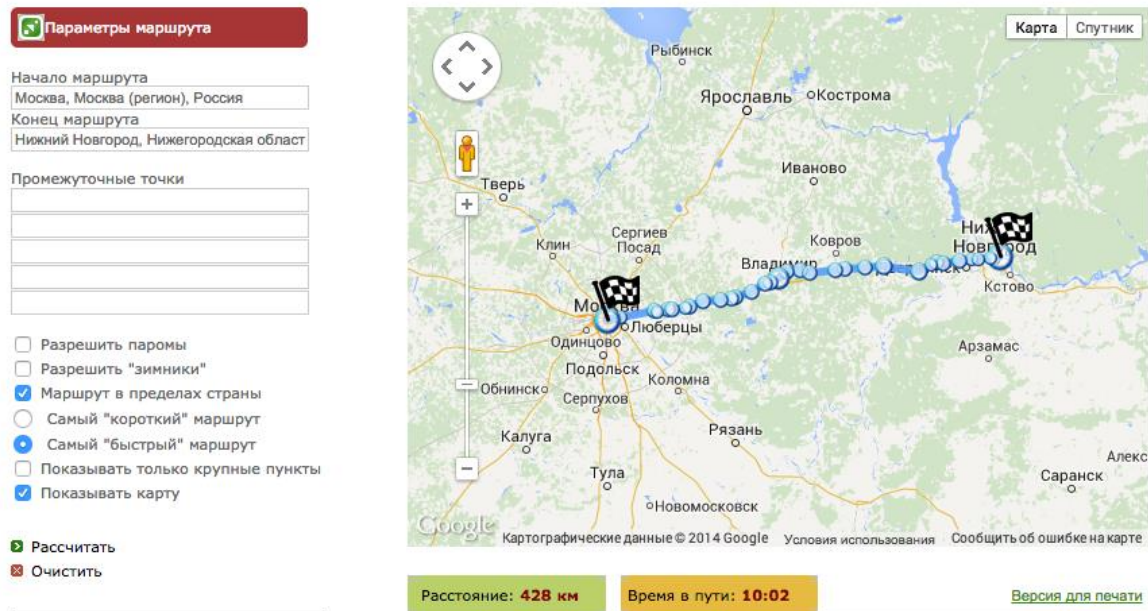


Figure 3. The result of route request

AutoTransInfo doesn't include a lot of restriction: speed limit, allowed time on route per day and other route constraints. Specific intracity supermarkets can't be chosen as intermediate route points. AutoTransInfo provides expensive simplified solution, which often does not reflect reality.

2.6 Disadvantages

Current planning routes isn't tied by days of the week. Its looks like a set of points on the map, with approximate time frames. The system is not allowing to build a route of more than 10 points, which during the construction greatly simplified the route. The route is built only between cities, as the main points and travel time between the customers inside the city is not considered, as the roughly aggregated by the operator without regard to the both customers TW. Time windows and available delivery day are added in the route manually by the operator, which leads to errors and, as a consequence, to delay, damage of the goods

and the dissatisfaction of the customers. Service time is not considered or included in the route also.

When route are planning, the customers are divided into groups manually by an operator and movement from group to group is time-consuming work, because the operator will need to recalculate all routes and accommodate the scheduling time windows.

In case of a new customer appearance, it just added to one of the groups manually on the operator's decision, focusing on the most convenient geographical location of the group, available space for the new customers demand in the vehicle. That may not be optimal solution in terms of the overall plan routes.

Available solution doesn't satisfying STC since as provides long travel distance and high cost. Methods using by AutoTransInfo are unknown. Customers delivery date often deviate from planning term, what leads to profits and orders loses. Deviation from travel time leads to non-compliance with goods retention periods. Restriction of route duration and rotation of work/rest per day doesn't take into account.

Since, as available solution is weak and doesn't produce requirement service level, optimization based decision support tool development is necessary. Problem can be classified as Multi-period Vehicle Routing Problem with multiple Time Windows.

3.0 Problem definition

The goal of the thesis is to develop decision support tool, which will provide good solutions to a real-life size problems. The resulted toll should provide the answers to the following questions: On what route which customers to appoint? Which customers an which days per week should be served? What should be the sequence of customers on the route? How many vehicles company need per week?

As mentioned above, the STC was required to serve 39 customers in 11 cities. The problem size is impressive, because this involves routes building between and inside cities. In similar studies customer nodes aggregation is sometimes employed (Sivaram Kumar, et al. 2014). The idea is to reduce the size of the problem by replacing some nodes – the ones that are situated arbitrary close to each other – by single node for each such aggregation. It is reasonably assumed that customers within such aggregations should be visited by the same vehicle in the same tour anyway. The reduced problem size may lead to reduced computational work necessary for obtaining optimal solution.

However, in this study such an aggregation is not considered. Variability of time windows requires that every customer node has to be treated as a separate vertex during schedule generation. It would be unreasonable to aggregate, for instance, two nodes with different service time windows, even if they are within arbitrary proximity of each other, since it's unclear how to manage the time window difference then.

Either way, the methodology described in this paper could be applied to a dataset with aggregated customer nodes as long as aggregation is done in a separate step during data preparation.

Below problem characteristics are provided:

- Travel distances and tariffs;
- The planning horizon of 14 days (in case of long distance, vehicle are able to start route at weekend);
- The customers number in each city;
- Time windows and available delivery day for each customer;

- Average customers service time;
- Demand for each customer;
- Fleet of vehicles;
- Vehicle cost.

Average vehicle speed is approximated to 70 km per hour. Thus, cost of vehicle on the move equals to 75 NOK per hour, cost of waiting vehicle is 31 NOK per hour, cost of fuel is 44 NOK per hour. Company interested in cost reducing strategy.

Objective of the problem:

- Build the routes containing delivery days and time intervals for each customer in each cluster with respect to TW and available delivery day for all nodes;
- Find departure time for each vehicle on each route;
- Minimize the cost of the total travel time, the cost of the total waiting time and the sum of the fixed cost of vehicles used, during the whole planning horizon.

Constraints on solution:

- Customers time windows.

TW represents the time interval for customers servicing during the day. The upper time limit equals to 7 am. The lower – 7 pm. All limits may vary from customer to customer and 3 hours are the smallest gap. All routes must be constructed with respect to given time available intervals.

- Customers available delivery day.

All customers have strictly specified days for delivery. It's vary from one to five days during the week. The rules are the same as for the TW. The customers can be served only in the stated days and the routes construction should take them into account.

- Route duration.

In present terms with respect to customers geographical position, maximum route length is 14 days. As soon as drivers working day are limited, company decides to place two drivers on each route that replace each other. It is assumed that driver has a workday of 8 hours, but does not necessary have a lunch break in the middle of a working day. Necessary lunch breaks during long trips can be included in travel times during data assembly for input.

- Vehicle capacity.

All vehicles have the same volume of 20 tons and customers demand represented in tons as well. Physical volume of customer orders is not available and isn't have of vital importance as the ordered goods size is rather small in compare with vehicle volume and the average vehicle load not more than two third of its capacity. But as the overload isn't allowed, this parameter should be taken into account.

4.0 Literature and theory review

This section covers prior publications and theory relevant to problem at hand.

4.1 *Problem classification and related work*

Solving VRPTW exactly is very difficult, even for pretty small problems. The time required for the solution grows exponentially in relation to the size of the problem.

Modern technology allows exact solving VRP with soft Time Windows and stochastic travel time with column generation and branch-and-price solution for 100 customers, see (Taş, et al. 2014). For another example of exact solution for VRP with semi-hard resource constraints for 50 customers, see (Abdallah and Jang 2014).

For capacitated clustering problem algorithms for vehicles shipments see (Koskosidis and Powell 1992), article include mathematical model of the capacitated vehicle routing problem, iterative heuristic algorithm for the CCP, relaxation and bounds for the CCP, the seed initialization procedure and computational study.

Some articles describe VRPTW with flexible customers time windows, solving with linear programming model (see Taş, Jabali, and Van Woensel 2014). As example of useful exact, heuristic and metaheuristic methods (El-Sherbeny 2010) and (Chiang, et al. 2009), or (Mingozzi, Baldacci and Giorgi 1999). For another good illustrations of some ILP see (Calvete, et al. 2007) – in this article authors considers applying goal-programming for solving VRP with soft time windows.

At present days exist a big range of VRP types. Approaches for solving were described by (Toth and Vigo 2002), see Figure 4.

- Capacitated VRP (CVRP). Normally the VRP defined under route and length constraints. Problem can be denoted as CVRP when only capacity constraints are present, another words, when customers are served by vehicles with some capacity restriction (Laporte 1992).

- Duration-Constrained VRP (DVTP). When only length constraints are present, problem can be denoted as DVTP.
- VRP with Time Windows (VRPTW). When time interval with in customer should be served are present. Problem can be denoted as VRPTW (El-Sherbeny 2010).
- VRP with Pickup and Delivery (VRPPD). When delivery and pickup service are requested, problem can be denoted as VRPPD.
- Heterogeneous Fleet VRP (HFVRP). When capacity constraints and vehicles with different bulk are present, problem can be denoted as HFVRP.
- Inventory Routing Problem (IRP). Important extension of the VRP. Problem can be denoted as IRP, when inventory control restriction are present (Cordeau, et al. 2004).
- Stochastic VRP (SVRPs). When some components are random and deterministic space are lived, problem can be denoted as SVRPs.
- Others.

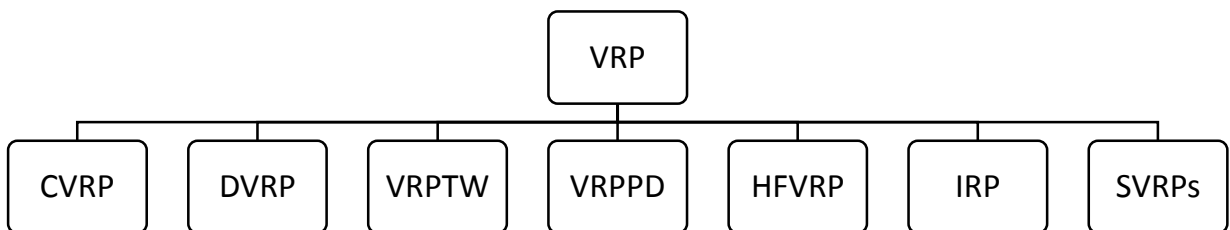


Figure 4.VRP classification

4.2 Vehicle Routing Problem with Time Windows

Time windows can be split in two groups: hard and soft time windows. If delivery time can be violated, customer agree to move time frame, sometimes with some penalty, it is soft time windows. In case, when moving time windows are prohibited – it is hard time windows.

There are some main expansions of the VRPTW:

- Multi-depot VRPTW (MDVRPTW). If several depot are present and customers can be served from any of them (Cordeau, et al. 2004).
- Site-dependent VRPTW (SDVRPTW). If present variety of different vehicles type and customers can be served from any of them.
- Periodic VRPTW (PVRPTW). If time windows are determinate and time horizon in several days or weeks, for example, when customers are far away from each other and from depot. Problem of such type was first introduced by (Beltrami and Bodin 1974).
- VRP with multiple time windows (VRPmTW). If customers can have several and different type time windows. For example, when customer have opening working hours during the week and same specific days for delivery (Toth and Vigo 2002).

The STC problem is classified as Multi Period Vehicle Routing Problem with multiple Time Windows. Since methodology used in this paper employs two phases – clustering and routing – theory mentioned in this chapter covers both these subjects.

4.2.1 Notation of VRPTW

The notation based on the VRPwTW by (Cordeau, et al. 2004).

Let $N = \{1, \dots, n\}$ be the set of nodes and K , indexed by k , be set of available vehicles, $|K| = m$. C indexed by c , be set of supermarkets. Direct graphs $G^k = (V^k, A^k)$, for all $k \in K$. V^k - set of nodes, A^k - set of arcs. The set of V^k consist of $N \cup \{s, \bar{s}\}$, where s and \bar{s} represent respectively the origin-depot node and destination-depot node of vehicle k . Start of time horizon denotes by E , end of time horizon denotes by L .

For each $i \in N$, there is a demand d_i and time window $[a_i, b_i]$ within which the supermarket permits the start of service. For each vehicle $k \in K$, assume a capacity of vehicle b .

For each arc $(i, j) \in A$, there is a travel time t_{ij} , travel distance c_{ij} and service time s_i .

The mathematical programming formulation to be introduced next two types of binary variables: flow variables $X_{ij}^k, (i, j) \in A, k \in K, i \neq j$, equal to 1 if arc (i, j) is used by vehicle k , 0 otherwise; time variable $W_i^k, i \in V, k \in K$ specifying the arrival at node i .

4.2.2 Mathematical model of VRPTW

The formulation based on the VRPwTW by (Cordeau, et al. 2004). For different VRP formulation (Yeun, et al. 2008).

The problem of finding the minimal travel distance (cost) set of routes satisfying the VRPTW constraints can be formulated as follows:

$$\text{Minimize } \sum_{k \in K} \sum_{(i,j) \in A} c_{ij} X_{ij}^k \quad (2.3.1)$$

subject to

$$\sum_{k \in K} \sum_{(i,j) \in A} X_{ij}^k = 1, \quad \forall i \in C \quad (2.3.2)$$

$$\sum_{(s,j) \in A} X_{sj}^k = 1, \quad \forall k \in K \quad (2.3.3)$$

$$\sum_{(i,\bar{s}) \in A} X_{i\bar{s}}^k = 1, \quad \forall k \in K \quad (2.3.4)$$

$$\sum_{(i,j) \in A} X_{ij}^k = \sum_{(j,i) \in A} X_{ji}^k, \quad \forall i \in C, k \in K \quad (2.3.5)$$

$$\sum_{i \in C} \sum_{(i,j) \in A} d_i X_{ij}^k \leq b, \quad \forall k \in K \quad (2.3.6)$$

$$W_s^k = 0, \quad \forall k \in K \quad (2.3.7)$$

$$W_i^k + s_i + t_{i,j} - W_j^k \leq (1 - X_{ij}^k) M_{ij}, \quad \forall (i,j) \in A, \forall k \in K \quad (2.3.8)$$

$$a_i \sum_{(i,j) \in A} X_{ij}^k \leq W_i^k \leq b_i \sum_{(i,j) \in A} X_{ij}^k, \quad \forall k \in K, i \in C \quad (2.3.9)$$

$$E \leq W_i^k \leq L, \quad \forall i \in \{s, \bar{s}\}, k \in K \quad (2.3.10)$$

$$X_{ij}^k \text{ binary}, \quad \forall (i,j) \in A, \forall k \in K \quad (2.3.11)$$

This is nonlinear formulation where the objective function (2.3.1) represent the total distance (cost). Constraint (2.3.2) describe that each customer be assigned exactly once to a vehicle route. Constraint (2.3.3 – 2.3.5) describe the flow on the path that vehicle k will use. Constraint (2.3.6) guarantee feasibility of routes. Constraint (2.3.7) assign for each vehicle start time from depot equal 1. Constraints (2.3.8-2.3.10) ensure feasibility of the time schedule, where M_{ij} are large constants, that can be replace by the value $\max\{b_i + s_i + t_{ij} - a_i, 0\}, \forall (i,j) \in C$. Binary conditions on the flow variables are given in (2.3.11).

4.3 Solution methods for Vehicle Routing Problem with Time Windows

VRPTW is NP-hard combinatorial optimization problem according to (Lenstra and Rinnooy 1981). Existing solution methods:

- Exact methods and algorithms;
- Heuristics algorithms.

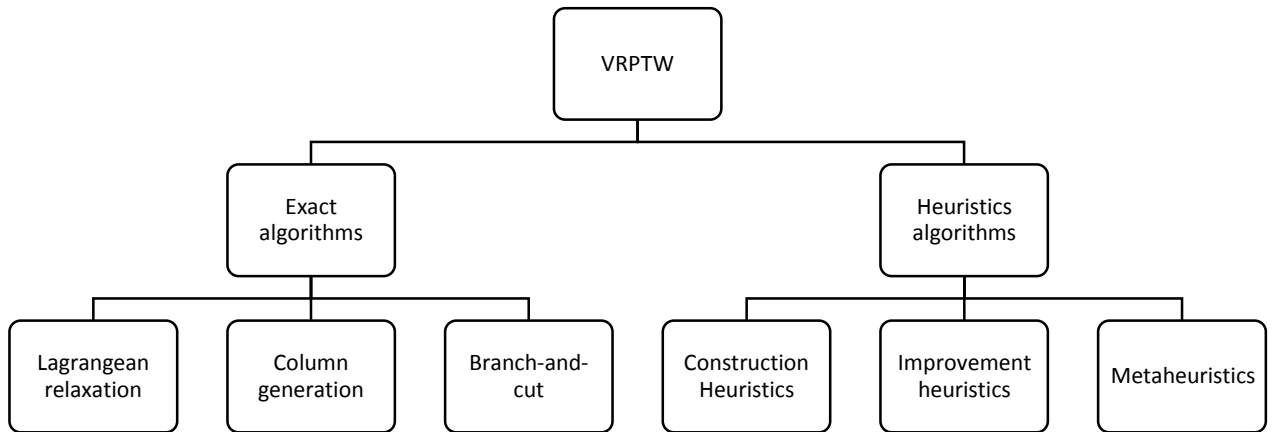


Figure 5. VRPwTW solutions methods

Exact algorithms:

- Lagrangean relaxation.

In case of VRPTW Lagrangean relaxation can be applied in several ways. For a Lagrangean relaxation based on k -trees, where k denotes the number of available vehicle see (M. Fisher 1994).

- Colum generation.

According to (Cordeau, et al. 2004), Colum generation can be present as a way to update the multipliers associated with the relaxed constraints.

- Branch-and-cut.

Was developed by (Bard, Kontoravdis and Yu 2002).

Heuristics algorithms:

- Construction heuristics.

Algorithm work by inserting into partial routes one customer at a time until a feasible solution is found.

- Improvement heuristics.

Trough exchange performing, Improvement heuristics step by step improving initial feasible solution while maintaining feasibility. See (Russell 1977) for the first improvement heuristics for the vehicle routing problem with time windows.

- Metaheuristics.

Metaheuristics continue the search into the search space after a local minimum explored. Including a lot of different methods, such as Tabu search, Genetic algorithm, GRASP and others.

After literature and theory review starting with heuristics implements was decide and Fisher and Jaikumar heuristic first phase was chosen to reduce complexity of the problem. After initial clustering is complete, presented problem will consist of a set of MPVRPmTW. Solving these is final part of proposed method. After the complexity of problem will be reduce, it will be possible to solve mathematical model of the MPVRPmTW with exact method.

4.3.1 Fisher and Jaikumar heuristic

Sometimes the customers grouping can be convenient. It's good tactical decision make the detailed planning work with complicated MPVRPmTW easy. In this case assigning customer to region must be done with care and caution.

Start with clustering in STC problem will be good approach. It means, that group or cluster of the customer geographically close to each other and with the same time windows will serve by the same vehicle. Narrow time windows should be taken into account, because such time windows always will lead to cost increasing. As based of clustering process first of two the Fisher & Jaikumar heuristic decompose planning problems can be used. After this clustering will done, such customer cluster aggregation will reduce the complexity of the problem.

Step 1. Clustering.

MPVRPmTW can be present as two decompose planning problems that can be solved in simultaneously. First problem is sequential, that is in which sequence vehicle should visit a customers, and the relative position and time windows of the customers are taken into account. Second problem can be classified as an allocation or assignment problem: which customers should be assigning to which vehicles. Customers demand should not exceed the capacity of the vehicle.

Assignment problem is performed first and can be solved with the help of clustering algorithm as it formulate in (Fisher and Jaikumar 1981), whose objective is to minimize customer clustering adding cost. Then to solve second planning problem, in which sequence customers should be visited in.

For each of the vehicle k , for all $k \in K$ assigned a specific customer node that must be visited by vehicle k . This customer will called the seed-node. Number of seed-nodes will be equal to the number of vehicles. Seed-node will be chosen geographically far from each other. It will add the following decision variables:

$$Y_{ik} = \begin{cases} 1 & \text{if vehicle } k \text{ is used for serving customer } i \\ 0 & \text{otherwise} \end{cases}$$

Let i_k^* denote the seed-node.

$$\sum_{k \in K} Y_{i_k^* k} = 1 \quad \forall i, i = 1 \dots n \quad (3.1.1)$$

Constraint (3.1.1) represent, that vehicle k is assigned to its seed-node i_k^* .

Now we travel with vehicle k from the depot s to the seed-node i_k^* and back without visiting any other node. In symmetric case travel distance (cost) t_{ij} will be multiple by two. This case then compare with the case where we visit one other customer on the way from or to the visit to the seed-node, it leads to an added cost. The added cost (travel distance) can be calculated as next:

$$m_{i,k} = c_{s,i_k^*} + c_{i_k^*,i} + c_{i,s} - c_{s,i_k^*} - c_{i_k^*,s} = c_{i_k^*,i} + c_{i,d} - c_{i_k^*,s}$$

Added cost are calculated for each vehicle and all the customers. Then the model will be as follows:

$$\text{Minimize } \sum_{i=1}^n \sum_{k=1}^K m_{ik} Y_{ik} \quad (3.1.2)$$

subject to

$$\sum_{k=1}^K Y_{ik} = 1, \quad \forall i, i = 1 \dots n \quad (3.1.3)$$

$$\sum_{i=1}^n d_i Y_{ik} \leq C_k, \quad \forall k \in K \quad (3.1.4)$$

Constraint (3.1.2) represent the added cost sum minimization. (3.1.3) represent that all customer nodes are visited once and (3.1.4) observes the capacities of vehicles.

The solution of the model will be that each vehicle k is assigned to its seed-node and the set of the other customers such that the capacity of vehicles is observed. Then for each vehicle TSP should be solving. The suggested model will be solved by solver software. Exact programming formulation will be presented in Section 6.3.

5.0 Two-phase solution approach

In this chapter developed solution approach presented. Problem is formulated in precise algebraic notation. The solution methodology is described. Both phases of methodology are modelled and formulated in algebraic notation.

5.1 Problem description

The mathematical model based on mathematical formulation for VRPMTW by (Belhaiza, Hansen and Laporte 2014) and extended by adding multiple time windows with all related constraints.

The MPVRPmTW is defined on a directed graph $G = (V, A)$, where V is the vertex set and A is the arc set. The vertex set is partitioned into $V = \{N, D\}$, where $N = \{1, \dots, n\}$ is a set of customers and D is the depot. Set R describes vehicles and the number of vehicles denote by m . Q_k is the capacity of vehicle k , where $k \in R$. Every customer $i \in N$ has a non-negative demand q_i , a non-negative service time s_i , a set $W_i = \{[l_i^p, u_i^p], p = 1, \dots, H\}$ of p_i time windows, where H is the time horizon in days. The travel time associated with arc $(i, j) \in A$ is denoted by t_{ij} . By D_k denote the maximum duration of the route of vehicle k .

The aim of MPVRPmTW is to generate a schedule for vehicles, minimizing travel costs while complying with the following requirements:

1. Every customer node is served once by single vehicle;
2. Service of every customer takes place during one of the multiple time windows given for him;
3. Capacity of a vehicle should be enough to satisfy customers' demand along the route;
4. Maximal duration of a given route is not exceeded;
5. Routes start and end at the Depot;

5.2 First phase mathematical formulation

Since a given data set includes as much as 40 nodes across multiple time-window horizon, and VRP problems with Time Windows are NP-hard problems, employing exact methods will introduce unacceptably long computational times (Lenstra and Rinnooy Kan 1981).

To reduce computation times to reasonable amounts, applying of a heuristical algorithms in various ways is deemed necessary. In this paper, Fisher & Jaikumar heuristic (Fisher and Jaikumar 1981) is used to generate clusters of 5-15 nodes, which, in turn, are instances of small enough size to be solved by exact methods. Then for every instance exact solution approach is applied. For that a mathematical model for the MPVRPmTW problem is formulated, and an available solver software is utilized to calculate solutions that satisfy necessary constraints.

It is meaningful to note that during cluster generation step of solving the problem the algorithm ignores time window constraints. Clustering is done solely based on distance matrix and capacity constraints.

Parameter	Type	Description
t_{ij}	Real	Travel time associated with the arc (i,j)
Q_k	Real	Vehicle k capacity
q_i	Real	Demand at node i
d_i^k	Real	Travel distance associated with the arc (k,j)
m_i^k	Real	Costs of adding customer i to cluster k

Table 2. Definition of the parameters for first phase

Variable	Type	Description
Y_i^k	Binary	Equal 1 if customer i in assigned to cluster k, 0 otherwise

Table 3. Definition of the variables for first phase

Added cost are calculated for each vehicle and all the customers:

$$d_i^k = t_{0j} + t_{kj} - t_{kn}, \quad \forall k \in V, \quad \forall j \in N$$

The model will be as follows:

$$\text{Minimize } \sum_{i=1}^n \sum_{k=1}^V Y_i^k d_i^k$$

subject to

(1)

$$\sum_{k=1}^V Y_i^k = 1, \quad j \in N$$

$$\sum_{j \in N} q_j Y_j^k \leq Q_k, \quad k \in V \quad (2)$$

(3)

The objective is to minimize total added cost.

Constraints (1) insure, that all customer i are visited by vehicle k and no one is missing.

Constraints (2) ensure, that capacity of vehicle will not be exceed.

5.3 Second phase mathematical formulation

The MPVRPmTW can be formulated as a mixes integer linear program. The variables and the parameters used in formulation are defined in Table 4 and Table 5.

Parameter	Type	Description
L	Real	Equal 1 for time window p lower bound, equal 2 for time window p upper bound
tw_{il}^p	Real	Time window p lower and upper TW for every customer i in every day per route
q_i	Real	Demand at node i
Q_k	Real	Vehicle k capacity

f^k	Real	Fixed cost of vehicle k using
TC^k	Real	Cost of moving vehicle per hour
WC^k	Real	Cost of waiting vehicle per hour
mh	Real	Maximum number of hours driver can drive/work per day
t_{ij}	Real	Travel time associated with the arc (i,j)
sa_i^p	Real	Start of serving period at node i
s_i	Real	Service time at node i
M	Real	Arbitrary large constant
d_k	Real	Max route duration

Table 4. Definition of the parameters for MPVRPmTW

Variable	Type	Description
X_{ij}^k	Binary	Equal to 1 if arc (i,j) is used by vehicle k, 0 otherwise
R_k	Binary	Equal to 1 if vehicle k is used, 0 otherwise
Z_i^k	Binary	Equal 1 if customer i is assigned to vehicle k, 0 otherwise
V_i^p	Binary	1 if customer i is served within time window p
A_i^k	Real	Arrival time for vehicle k at node i
B_i^k	Real	Departure time for vehicle k at node i
D_k	Real	Route duration for vehicle k
W_i^k	Real	Waiting time of vehicle k at customer i

Table 5. Definition of the variables MPVRPmTW

Objective function:

$$\text{Minimize } \sum_{\substack{k \in R \\ i, l \in A}} t_{ij} X_{ij}^k TC^k + \sum_{\substack{k \in R \\ i \text{ in } N}} W_i^k WC^k + \sum_{k \in R} f_i^k R^k$$

subject to

$$\sum_{k \in R} Z_i^k = 1, \quad i \in N, \quad (1)$$

$$\sum_{\substack{(i,j) \in A \\ k \in R}} X_{ij}^k = 1, \quad j \in V, \quad (2)$$

$$\sum_{\substack{(i,j) \in A \\ i \neq j}} X_{ij}^k = \sum_{\substack{(j,i) \in A \\ i \neq j}} X_{ji}^k, \quad i \in V \text{ and } k \in R, \quad (3)$$

$$2X_{ij}^k \leq Z_i^k Z_j^k, \quad i, j \in A, \quad (4)$$

$$\sum_{\substack{k \in R \\ (i,j) \in A \\ i \neq j}} X_{ij}^k \leq 1, \quad i \in N, \quad (5)$$

$$\sum_{\substack{i \in N \\ (i,j) \in A}} q_i X_{ij}^k \leq Q_k, \quad k \in R, \quad (6)$$

$$A_s^k - B_s^k \leq d_k + M(1 - Z_s^k), \quad k \in R, \quad (7)$$

$$B_i^k \geq A_i^k + W_i^k + s_i - M(1 - Z_i^k), \quad i \in N \text{ and } k \in R, \quad (8)$$

$$B_i^k \leq A_i^k + W_i^k + s_i + M(1 - Z_i^k), \quad i \in N \text{ and } k \in R, \quad (9)$$

$$A_j^k \geq B_i^k + t_{ij} - M(1 - X_{ji}^k), \quad i, j \in A \text{ and } k \in R, \quad (10)$$

$$A_j^k \leq B_i^k + t_{ij} + M(1 - X_{ji}^k), \quad i, j \in A \text{ and } k \in R, \quad (11)$$

$$A_i^k + W_i^k \geq tw_{i1}^p - M(1 - Z_i^k) - M * (1 - V_i^p), \quad i \in V \text{ and } p \in Y \text{ and } k \in R, \quad (12)$$

$$A_i^k + W_i^k + s_i \leq tw_{i2}^p + M(1 - Z_i^k) - M * (1 - V_i^p), \quad i \in V \text{ and } p \in Y \text{ and } k \in R, \quad (13)$$

$$\sum_{p=1}^H V_i^p Z_i^k = 1, \quad i \in N, \quad (14)$$

$$\sum_{p=1}^H V_s^p Z_s^k \leq 2, \quad i \in N, \quad (15)$$

$$V_i^p \leq sa_i^p, \quad i \in V \text{ and } p \in Y, \quad (16)$$

$$(17)$$

$$R_k \geq Z_i^k, \quad i \in V \text{ and } k \in R, \quad (18)$$

$$W_s^k = 0, \quad k \in R, \quad (19)$$

$$B_s^k = 0, \quad k \in R, \quad (20)$$

$$\sum_{(i,j) \in A} t_{ij} X_{ij}^k = D_k, \quad k \in R, \quad (21)$$

$$W_i^k, D_k, A_i^k, B_i^k \geq 0, \quad (22)$$

$$R_k, X_{ij}^k, V_i^p, Z_l^k \text{ binary}. \quad (23)$$

The objective is to minimize the cost of the total travel time, plus the cost of the total waiting time, plus the sum of the fixed cost of vehicles used.

Constraints (1) state that each customer is assigned exactly to one vehicle k . Constraints (2) state that any arc (i,j) is traversed exactly one vehicle k . Constraints (3) insure that no vehicles get stuck in nodes. Constraints (4) mean, that any arc (i,j) can be pass through by vehicle k only if Z_i^k and Z_j^k are both equal to 1. Constraints (5) complementary conditions that every customer i to be visited by one vehicle k . Constraints (6) insure, that capacity of vehicle k will not be exceeded. Constraints (7) insure, that the maximal route duration d_k for vehicle k will not be exceeded.

Constraints (8) show that the departure time from customer i at least equal to the arrival time at customer i , plus waiting time W_i^k and service time s_i at customer i , only if this customer i is assigned to vehicle k . Constraint (9) enforce leaving of vehicle k from customer i right after service is done. Constraints (10) and (11) show that the arrival time at customer j is equal to the departure time from customer i , plus the $travel_time_{ij}$ of arc (i,j) only if this arc is assigned to vehicle k . Constraints (12) and (13) mean that the arrival time A_i^k plus the waiting time W_i^k of vehicle k at customer i is within the time window tw_{il}^p lower and upper bound only if customer i is assigned to vehicle k and time window p is chosen. Constraints (14) show that exactly one time windows tw_{il}^p chosen for every customer i , (15) complements situation with depot, as so as departure and arrival time for vehicles k may be in different day p . Constraints (16) ensure, that every customer I will be visited only if it's allowed. Constraints (18) mean that customer i will be serve by vehicle k only if this vehicle is chosen. Constraints (19) ensure that waiting time for vehicle k at the depot is equal to 0. Similarly, constraints (20) ensure that the departure time from the depot for vehicle k is 0. Constraints (21) help to compute total route duration time. Finally, constraints (22) and (23) provision the feasibility intervals for the decision variables.

6.0 Matrix generation

This chapter describes the work that was done in order to digitalize raw data acquired from company.

Solvers need very specific data representation to perform calculations. The job of converting real world data in such a format is a daunting task, this study is no exception.

With a given number of 40 customer nodes, the amount of work needed to manually input the relevant data is unreasonable, so employing various automatization techniques was deemed necessary.

Following steps were performed in process:

- Input customer addresses
- Using Google API to obtain distance matrix for all customers (described in detail in Section 6.1)
- Employing custom-developed scripts to obtain distance matrices for specific customers (described in detail in Section 6.2)
- Input time windows data, capacity data and all other relevant constraint data

The savings resulting from automatization in terms of researcher time are estimated to weeks, as suggests the comparison with similar studies, where these steps were performed manually. Thus, it is concluded that these techniques are quite a meaningful contribution and deserve a highlight.

6.1 Complete distance matrix generation

In order to build the routes for cargos delivery for SLC using the mathematical model is necessary provide data in matrices of two types: travel time matrix and travel distance matrix. In this two matrix represented minimal necessary time and distance value between any two customers. In such situation to calculate this date manually are very time

consuming. The matrix size depends on the number n of customers and hosted $n \times n$ for both travel distance and travel time case. Both matrixes are asymmetric.

For solving this matrix generation task a custom application was developed. That application uses Google Maps API (application programming interface) and tools Geocoder and Distance Matrix.

Geocoder is Google utility that converts addresses to coordinates. Distance Matrix is Google utility that provides travel distance and time for a matrix of origins and destinations. Then, any available office software can be used to convert Distance Matrix output into form that is comprehensible for solver.

Google does not disclose what sort of algorithms Distance Matrix utility uses behind the scenes to calculate route distances. The initial versions were run on Dijkstra's algorithm (Chang 2009).

Customers addresses in English or Russian languages can be used as input data. An example of input data is represented in Table 6.

	City, Street, Building
1	Ярославль, Тутаевское шоссе, д.1
2	Иваново, Куконковых ул., д.141
3	Нижний Новгород, Речное шоссе, д.50
4	Тверь, Орджонекидзе ул, д.51
5	Казань, Мамадышский тракт,32

Table 6. Input data sample for the matrix generation

Application starts from options parsing: location of input and output data, measurement units (kilometers, hours). Data from the input file is used to get coordinates from the Geocoder. Geocoder converts address to maps coordinates. Each pair of coordinates, latitude and longitude for start and end point are sent to API Distance Matrix and saves in list as distance or time.

Matrix generation procedure can be realized in requests. The request numbers are n for Geocoder and n^2 for Distance Matrix, where n – the number of customers (addresses). All requests generate automatically based on addresses list.

Application output data is in .csv file. The application code with comments can be found in the Appendix 10.2

6.2 Cluster matrix generation

Before it is possible to use a solver for calculating exact solution of MPVRPmTW for individual clusters, cluster distance matrices need to be generated. This section describes how these matrices were obtained from a large complete distance matrix in this study.

Due to size of the problem – 40 nodes in complete graph, between 3 to 5 customer clusters – certain degree of automatization was utilized. Custom script on Ruby programming language was designed. Full listing of the script may be found in Appendix 10.3.

First, the list of customers in the cluster is injected in script body, e.g.:

```
cs = %w[
  MoscowDepot    Yaroslavl_LENTA1    Yaroslavl_7Continent    Yaroslavl_ATAK
  Yaroslavl_ASHANn Yaroslavl_ASHANp Yaroslavl_LENTA
  Yaroslavl_Giperglobus Yaroslavl_Magnit Kostroma_ASHAN Kostroma_7Continent
  MoscowDepotEND
]
```

It is important for customer names to be the same as they are in Complete Distance Matrix (see Section 6.1).

Then the script should be launched. It takes the names injected, looks for these names in Complete Distance Matrix table (which was transformed in readable format in previous step,

see Section 6.1), and assembles a Cluster Distance Matrix for customers with these names in a separate .cv file. This file should be then imported into CSV format as “Delimited” with Text Qualifier “,”. The result will be a .csv table containing Cluster Distance Matrix.

The next step is to use available office software – in this study Excel and TextPAD – to convert this table in format readable by solver.

7.0 Experiment setup

In this chapter two-phase methodology presented in Section 5 will be used to generate routes. The model formulation can be found in Sections 5.2 and 5.3. The results will be described and analyzed in Section 7.3 of this chapter.

Computational experiments was implemented on IMac with Intel® Core™ i7-3770 CPU @ 3.40 GHz, 32 GB Memory with IBM ILOG CPLEX large-scale solver, version: 12.6.1.

The following scenarios were developed:

- Scenario 1 – three clusters, seeds set Variant 1;

The scenario 1 consists of three seeds, seeds Variant 1: Yaroslavl_Magnit, NNovgorod_ASHANm, Ufa_OKEYk. Each seed forms a cluster of customers linked to it. For each cluster separately held computing calculation. Aggregating the results of all three clusters calculation are the results of the scenario 1.

- Scenario 2 – three clusters, seeds set Variant 2;

Same with scenario 1, seeds Variant 2: Tver_ATAKo, Yekaterinburg_ASHANh, Kazan_Zelgros.

- Scenario 3 – four clusters, seeds set Variant 1;

The scenario 3 consists of four seeds, seeds Variant 1: Yaroslavl_LENTA1, NaberezhnyeChelny_LENTA, NNovgorod_Okey, Perm_LENTA. Each seed forms a cluster of customers linked to it. For each cluster separately held computing calculation. Aggregating the results of all three clusters are the results calculation of the scenario 3.

- Scenario 4 – four clusters, seeds set Variant 2;

Same with scenario 3, seeds Variant 2: Tver_ATAKo, Kostroma_ASHAN, Yekaterinburg_ASHANh, Kazan_Zelgros.

- Scenario 5 – five clusters, seeds set Variant 1;

The scenario 5 consists of five seeds, seeds Variant 1: Yaroslavl_ATAK, NNovgorod_LENTA, Kazan_ASHANp, Ufa_OKEYe, Yekaterinburg_ASHANh. Each

seed forms a cluster of customers linked to it. For each cluster separately held computing calculation. Aggregating the results of all three clusters are the results calculation of the scenario 5.

- Scenario 6 – five clusters, seeds set Variant 2;

Same with scenario 5, seeds Variant 2; Tver_ATAKo, Kostroma_7Continent, Kazan_ASHANy, Perm_LENTA, Yekaterinburg_ASHANm.

- Scenario 7 – six clusters, seeds set Variant 1

The scenario 7 consists of six seeds, seeds Variant 1: Tver_LENTA, Yaroslavl_Giperglobus, NNovgorod_METRON, NaberezhnyeChelny_LENTA, Kazan_Zelgros, Yekaterinburg_ASHANh. Each seed forms a cluster of customers linked to it. For each cluster separately held computing calculation. Aggregating the results of all three clusters calculation are the results of the scenario 7.

- Scenario 8 – six clusters, seeds set Variant 2

Same with scenario 7, seeds Variant 2: Tver_ATAKo, Ivanovo_Okey, NNovgorod_Magnit, NaberezhnyeChelny_LENTA, Ufa_OKEYk, Perm_LENTA.

Each cluster is associated with a separate vehicle. In case, if we choose a smaller number of clusters, for example two, the complexity of the problem grows strongly, the computation time becomes unacceptable. Furthermore, there is a problem with both time windows and available delivery day appeared. With a large number of customers in the cluster to take into account all of them hard TW is impossible since they are mutually exclusive. Computational experiments presented in two steps, separately for the first and the second phases.

7.1 Computational results of cluster construction heuristics

The first phase algorithm applying doesn't require of any specific preparation. It starts with complete distance matrix as input file. Complete distance matrix creation described in detailed in Section 6.1. Then first phase algorithm is running.

Scenario seeds chosen by operator manually based on geographical position and customers demand. At the result of first phase algorithm run there is a set of clusters with selected seed and a list of customers with required demand. First phase computational time is small for each cluster and wasn't take into account.

Result for scenario 1 are presented in this chapter in Table 7. Detailed description of the other first phase scenario solution is presented in Appendix 10.4 – 10.10.

Seed:	Customers in cluster	Demand
Yaroslavl_Magnit		
	Yaroslavl_LENTA1	1857.0
	Yaroslavl_7Continent	59.0
	Yaroslavl_ATAK	32.0
	Yaroslavl_ASHANn	197.0
	Yaroslavl_ASHANp	112.0
	Yaroslavl_LENTA	133.0
	Yaroslavl_Giperglobus	1600.0
	Yaroslavl_Magnit	2240.0
	Kostroma_ASHAN	510.0
	Kostroma_7Continent	78.0
	Tver_ATAKo	35.0
	Tver_ATAKmk	125.0
	Tver_Magnit	3500.0
	Tver_LENTA	1847.0
	Total Demand:	12325.0
NNovgorod_ASHANm;		
	Ivanovo_ASHAN	279.0
	Ivanovo_7Continent	68.0
	Ivanovo_Magnit	650.0
	Ivanovo_Okey	28.0
	NNovgorod_METROn	65.0
	NNovgorod_METROm	54.0

	NNovgorod_ASHANb	238.0
	NNovgorod_LENTA	898.0
	NNovgorod_ASHANm	152.0
	NNovgorod_Magnit	4657.0
	Total Demand:	7089.0
Ufa_OKEYk;		
	NNovgorod_Okey	672.0
	Kazan_ASHANy	439.0
	Kazan_Zelgros	123.0
	Kazan_ASHANp	754.0
	NaberezhnyeChelny_LENTA	878.0
	Ufa_LENTA	1014.0
	Ufa_ASHAN	80.0
	Ufa_OKEYe	37.0
	Ufa_OKEYk	15.0
	Ufa_OKEYmj	43.0
	Ufa_Magnit	9.0
	Pyshma_Perekrestok	221.0
	Yekaterinburg_ASHANh	52.0
	Yekaterinburg_ASHANm	525.0
	Perm_LENTA	757.0
	Total Demand:	5619.0

Table 7. First phase result for scenario 1

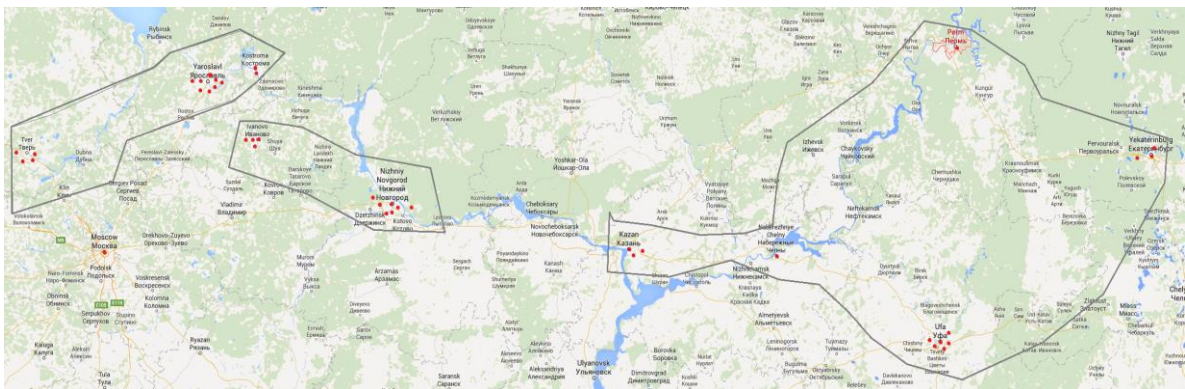


Figure 6. Clusters received with scenario 1 first phase

7.2 Computational results of MPVRPmTW

The second phase algorithm starts with creating cluster matrix as input files, based on the first phase results. Cluster matrix generation is described in details in Section 6.2. Each new cluster required complete changes in the second phase algorithm data file. Then algorithm is run.

Result for the third cluster of scenario 1 is presented in this chapter. Other second phase scenario solutions detailed description is presented in Appendix 10.11 – 10.18. Customers in the tables are listed in order of location on the route.

	Arrival Time	Departure Time	Visit Day	Waiting time
MoscowDepot	13.86	13.23	Sat-Wed	0
Yekaterinburg_ASHANh	12.5	12.7	Mon	0
Yekaterinburg_ASHANm	12.93	13.13	Mon	0
Pyshma_Perekrestok	15.8	16	Mon	0
Perm_LENTA	23.34	11.53	Tue	11.99
Ufa_OKEYmj	18.09	18.29	Tue	0
Ufa_OKEYe	18.41	18.61	Tue	0
Ufa_ASHAN	18.8	19	Tue	0
Ufa_LENTA	19.21	19.41	Tue	0
Ufa_OKEYk	19.62	10.2	Wed	14.38
Ufa_Magnit	10.53	10.73	Wed	0
NaberezhnyeChelny_LENTA	14.57	14.77	Wed	0
Kazan_ASHANy	17.95	18.15	Wed	0
Kazan_ASHANp	18.44	18.64	Wed	0
Kazan_Zelgros	18.81	19.01	Wed	0
NNovgorod_Okey	0.52	8.2	Thu	7.48
Computational time (sec):	3256.08			
Total Trevel Cost (NOK):	1102			

Rout Duration (Hours):	93.64
------------------------	-------

Table 8. MPVRPmTW results for scenario 1 third cluster

Routes maps are presented for the results visualization.



Figure 7. MPVRPmTW route for scenario 1 third cluster

7.3 Results analysis

In this chapter we analyze results of the conducted experiments. Detailed description of the each scenario result can be found in Appendix 10.4. Data is presented in Table 9 and collected into four groups according to the seeds number. Row Duration is sum of all clusters route duration in hours for each scenario. Row Cost is sum of all clusters route total cost in NOK for each scenario. Waiting Time row contains the total vehicle waiting time for each scenario. And the row Computational Time represent total computational time in seconds for each scenario.

	Scenarios							
	3 seeds		4 seeds		5 seeds		6 seeds	
	V1	V2	V1	V2	V1	V2	V 1	V 2
Duration	145.9	171.8	140.6	142.1	167.6	136	150.5	152.6

Cost	3949.8	5219.9	4604.3	7574.8	11207.4	10050.7	11013.3	11904.8
Waiting time	48.11	66.96	51.79	41.48	31.54	30.44	6.52	12.48
Computational Time	8399.7	8219.9	7492.8	7280.1	4933.1	4320.4	1594	2696.2

Table 9. Scenarios result

Data for visual comparisons were divided into four parts: Scenarios cost results, scenarios route durational results, scenarios waiting time and scenarios computational time. All scenarios were grouped by number of seeds and variant type.

Fig. 8 shows that the total cost scenario increasing trend to the number of seeds. This is not surprising, since each cluster in the scenario visited by separate vehicle. The total cost includes the total travel time cost, cost of the total waiting time and fixed cost of each vehicle used. The spread between the cheapest and the most expensive result are 7 000 NOK.

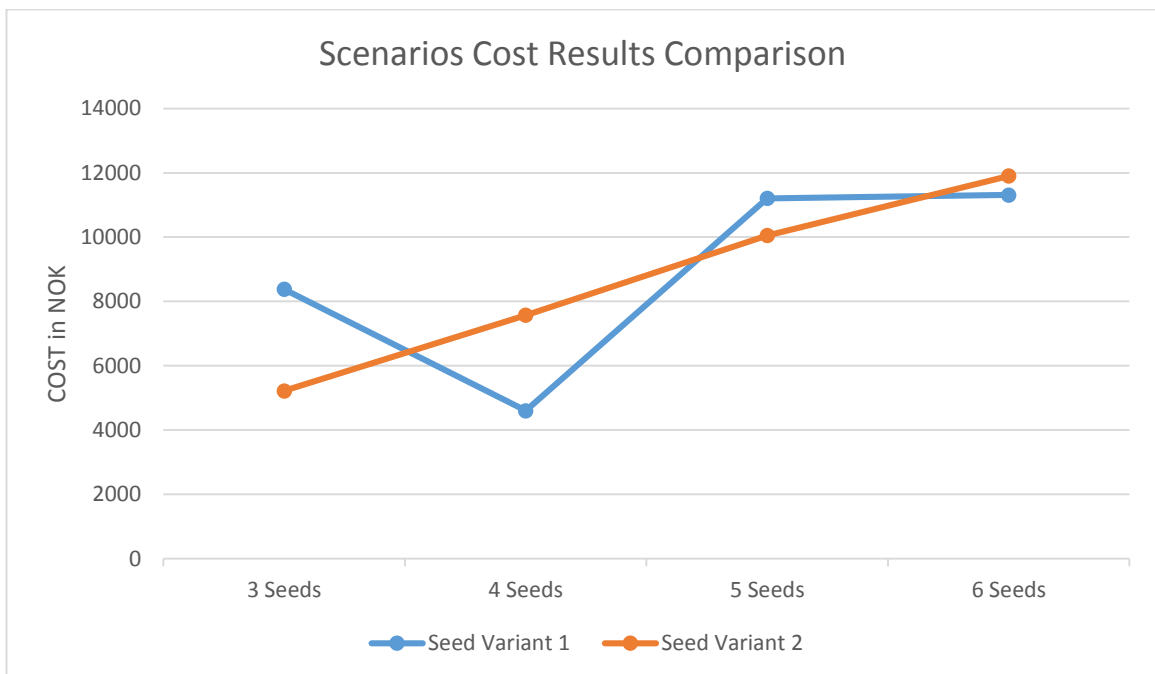


Figure 8. Scenarios Cost Result Comparison

The waiting time is reduced as seeds number increase as Fig.9 shows. Increasing the number of seeds helps to build routes more accurately according to the waiting time because it lessens the number of clients in the cluster. The spread between the longest and the shortest waiting time is one hour.

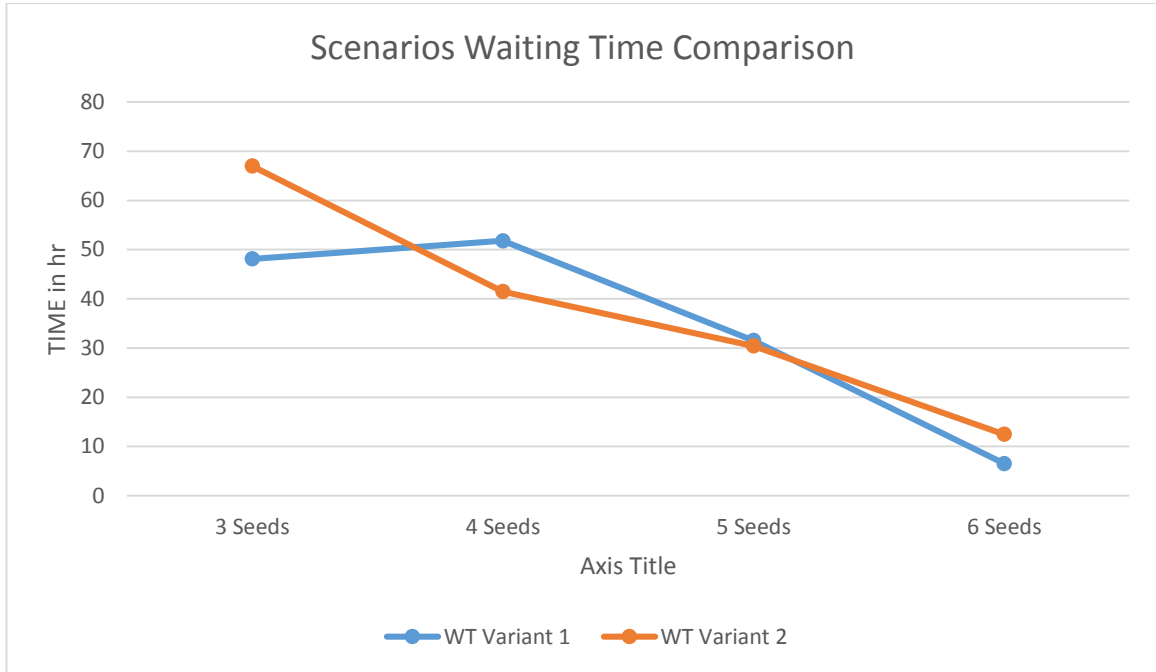


Figure 9. Scenarios Waiting Time Comparison.

Considering the total route duration shown in Fig.9. The spread between the longest and the fastest route duration time is 30 hours. The best result presented by scenarios with four seeds and the second variant of five seeds scenario.

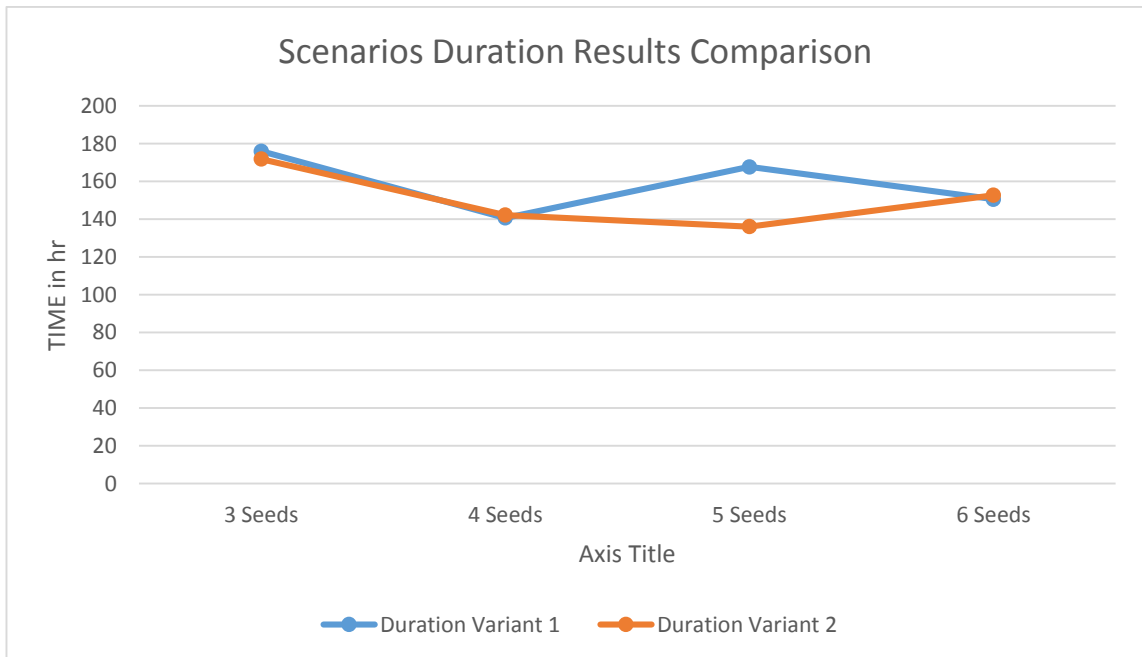


Figure 10. Scenarios Duration Result Comparison.

In terms of computational time presented on Fig.10, the preferable result shows scenarios with six seed. It should be noted that the calculation time can be significantly reduced by increasing computing power.

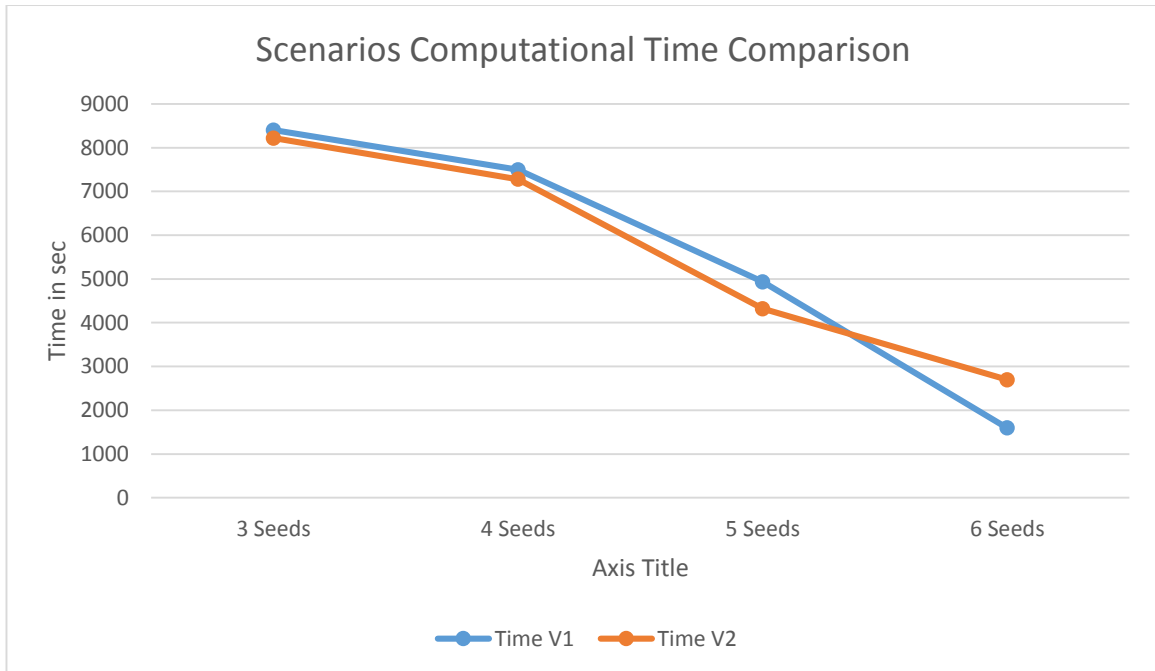


Figure 11. Scenarios Computational Time Comparison

Based on achieved results the 4 seeds scenarios are the best. It's the fastest by the means of route duration time and also the third between the cheapest result and the cheapest one, as there are only four vehicles in use and the waiting time short. On the other hand computation time result is one of the highest, but it's acceptable in case of computing power increasing. MPVRPmTW has a limitations in it's application such as large computational time and software required. Using powerful computer to reduce computation time will be god tactical decision.

It's obvious that the route with largest vehicle number is the most expensive one, but with the shortest waiting time results. For three clusters preparation time will be reduced on the MPVRPmTW data file preparation stage as its required only three tables generation (in comparison to 4,5 and 6 on the other variants accordingly). In average the cluster data file preparation time takes 20 minutes to half an hour.

So, the total cost will increase with the vehicles number. Total route duration slightly depends on the number of vehicles used and customers' TW - more time on route and on waiting, more expensive it becomes. Recommend to use the scenario solution that meets more than one priority requirement: total travel time; route duration time; total waiting time; computational time.

Comparing our results to the Company's current plan, we can note the following. To meet the demand in this problem, the Company used five vehicles, duration of the route was 157 hours and the total cost was 8750 NOK. We recommend the solution obtained for the third scenario: 4 vehicles, 140.6 hours the duration of the route and the total cost of 4604.3 NOK. This will reduce the number of used vehicles by 25%, the routed duration to 10.5% and the total cost by 47.4%. To summarize, we developed a decision support tool that provide a good solution to the Company's problem

8.0 Conclusion

The goal of this master thesis was to design a decision support tools and use it to efficiently solve a Multi-Period Vehicle Routing Problem with Multiple Time windows of relatively large size. A particular case is presented: Small Transportation Company is providing delivery services to a set of 40 customers located in 11 cities from a single depot. Delivery quantities are given by customers, as well as the time horizon for a delivery, while exact schedule is left for Company to figure out. The task is further complicated because customers have limited time windows for service during the day as soon as limited available delivery day, and are not able to service vehicles on certain days at all. The task is challenging and is fairly common in business, so an efficient and flexible solution is a relevant contribution.

In this study a solution method for a large-sized MPVRPmTW is suggested, and a set of tools supporting the data handling is developed. The design was being developed and validated while solving a Small Transportation Company case.

Heuristical two phase solution approach involving decompose system and mathematical model formulated to solve the Company real-life problem. Different number of seeds to generate different scenarios to find the best one with decompose system was made. The results show that several scenarios always should use with different clusters/seeds set in practice. Mixed integer programming model for MPVRPmTW was implemented in AMPL. Feasible solutions has been received. Possibility of infeasibility due to Time Windows and available delivery day was taken into account for future work.

Result solutions derived are compared to each other, the best one is highlighted and recommendations on the use of the decision support tools have been formulated.

For future research we recommend to review soft Time Windows potential with violated delivery time taken into consideration.

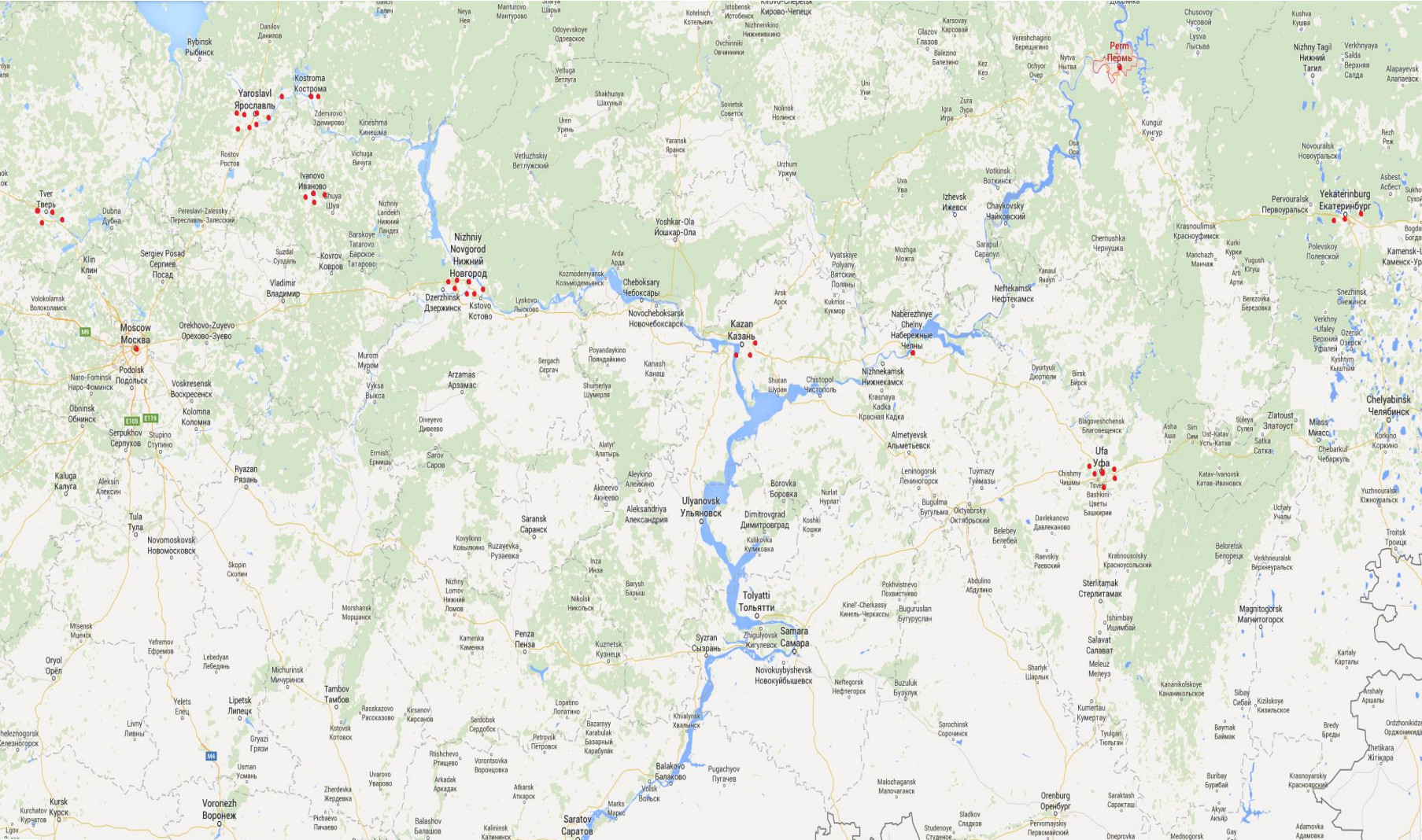
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10.0 Appendix

10.1 Map of the operation area with customer nodes marked



10.2 Complete distance matrix generation application code

```
#!/usr/bin/env ruby
require 'httparty'
require 'open-uri'
#require 'google_distance_matrix'
require 'csv'
require 'optparse'

options = {}
optparse = OptionParser.new do|opts|
  opts.banner = "Usage: #{$0} [-i ./addresses ] [-t textall|texttime|textdist|km|minutes|hours]
[-o ./output.csv] "
  options[:input] = "addresses"
  opts.on('-i FILE', '--input FILE', "Addresses FILE") do |file|
    options[:input] = file
  end
  options[:output] = 'output.csv'
  opts.on('-o FILE', '--output FILE', "Write data to FILE") do |file|
    options[:output] = file
  end
  options[:outdata] = 'textall'
  puts options[:outdata]
  opts.on('-t FILE', '--type FILE', "Output data type") do |type|
    options[:outdata] = type
    puts options[:outdata]
    if ['textall', 'texttime', 'textdist', 'km', 'minutes', 'hours'].include? options[:outdata]
then
      puts "format ok"
    else
      puts "available formats are - textall, texttime, textdist, km, minutes, hours"
      exit 1
    end
  end
end
```

```

    opts.on( '-h', '--help', 'Display this screen' ) do
      puts opts
      exit
    end
  if ARGV.length < 2 then
    puts opts
    exit
  end
end
optparse.parse!
GEOCODER_ENDPOINT_URL="https://maps.googleapis.com/maps/api/geocode/json?address="
DISTANCE_MATRIX_URL="https://maps.googleapis.com/maps/api/distancematrix/json"
filename = ARGV[0]
points = open(File.expand_path(options[:input])).read.split("\n") # читаем адреса
geocoder_url = GEOCODER_ENDPOINT_URL
coordinates = {}
points.each do |point|
  # для каждого адреса идем в гугл
  response = HTTParty.get(geocoder_url+URI::encode(point))
  sleep(1.0/4.0)
  adr = JSON.parse(response.body)
  coordinates[adr['results'][0]['formatted_address']] =
  adr['results'][0]['geometry']['location']['lat'].to_s+", "+adr['results'][0]['geometry']['location']['lng'].to_s
end
dm_url = DISTANCE_MATRIX_URL
matrix = []
destinations = ["origins/destinations"]
coordinates.each_pair {|k,v| destinations << k}
matrix << destinations
coordinates.each_pair do |o_address, o_coord|
  row = [o_address]
  coordinates.each_pair do |d_address, d_coord|

```

```

    response = HTTParty.get(DISTANCE_MATRIX_URL, :query => {:origins =>
o_coord, :destinations => d_coord})
    sleep(1.0/5.0)
    json = JSON.parse(response.body)
    puts json
    case options[:outdata]
    when "textall"
        row << json['rows'][0]['elements'][0]['distance']['text']+" "+
json['rows'][0]['elements'][0]['duration']['text'] # texts
        when 'minutes'
            row << (json['rows'][0]['elements'][0]['duration']['value'].to_f/60.0).round().to_s #
value travel time in min
        when 'hours'
            row <<
(json['rows'][0]['elements'][0]['duration']['value'].to_f/60.0/60.0).round(2).to_s # value
travel time in hours
        when 'km'
            row <<
(json['rows'][0]['elements'][0]['distance']['value'].to_f/1000.0).round(1).to_s # value
distance in km
        when 'texttime'
            row << json['rows'][0]['elements'][0]['duration']['text'] # text travel time
        when 'textdist'
            row << json['rows'][0]['elements'][0]['distance']['text'] # text distance
        end
    end
    matrix << row
end
CSV.open(File.expand_path(options[:output]), 'w', :col_sep => "\t") do |csvfile|
matrix.each do |row|
    csvfile << row # пишем матрицу в файл
    end
end
end

```


10.3 Cluster matrix generation custom script

```
cs = %w[
    MoscowDepot    Kostroma_ASHAN    Kostroma_7Continent    Ivanovo_ASHAN
    Ivanovo_7Continent    Ivanovo_Magnit    Ivanovo_Okey    NNovgorod_METROn
    NNovgorod_METROm    NNovgorod_ASHANb
    NNovgorod_LENTA    NNovgorod_ASHANm    NNovgorod_Okey    NNovgorod_Magnit
    Kazan_ASHANy    Kazan_Zelgros    Kazan_ASHANp    NaberezhnyeChelny_LENTA
    Ufa_LENTA    Ufa_ASHAN    Ufa_OKEYe
    Ufa_OKEYk    Ufa_OKEYmj    Ufa_Magnit    Pyshma_Perekrestok    Yekaterinburg_ASHANh
    Yekaterinburg_ASHANm    Perm_LENTA    MoscowDepotEND
]
f = File.read('traveldistance-hours.csv').chomp
parsed = CSV.parse(f).map {|i| i.reject(&:nil?)}
headers = parsed[1][1..-1]
data = parsed[2..-1].map {|i| i[1..-1]}
def build_body(street_name, all_streets, headers, data)
  row = [street_name]
  first_idx = headers.index(street_name)
  all_streets.map do |street|
    idx = headers.index(street)
    row << data[first_idx][idx]
  end
  row
end
new_csv = CSV.generate() do |csv|
  csv << ["\\"] + cs
  cs.map do |str|
    csv << build_body(str, cs, headers, data)
  end
end
File.open('new.csv', 'w').write(new_csv)
```

10.4 Detailed Scenarios Results

3 Seeds						
	Variant 1			Variant2		
	Cluster 1	Cluster 2	Cluster 3	Cluster 1	Cluster 2	Cluster 3
# customers in cluster	14	10	15	15	10	14
Total Route Waiting Time	14.26	0	33.85	15.73	37.56	13.67
Total Route Duration	56.5	25.83	93.64	28.57	75.5	67.78
Total Route Cost	1745.81	1102	1102	1506.38	4005.61	4483.02
Computational time	3122.81	40.8438	5256.08	4737.56	3243.14	2239.281

Table 10. Computational results for scenario 1 and 2

4 Seeds								
	Variant 1				Variant 2			
	C1	C 2	C 3	C 4	C 1	C 2	C 3	C 4
# customers in cluster	12	7	4	16	4	10	15	10
Total Route Waiting Time	15.73	5.83	0	30.23	0	12.2	11.14	8.14
Total Route Duration	11.97	28.84	11.63	88.18	5.58	9.94	57.3	69.32
Total Route Cost	1386.38	2344.73	873.25	5284.38	419.5	746.5	4654.38	1754.5
Computational time	5804.34	14.9062	1664.7	8.85938	5604.34	2.26562	1664.7	8.85938

Table 11. Computational results for scenario 3 and 4

5 Seeds										
Variant 1						Variant2				
	C 1	C 2	C 3	C 4	C 5	C 1	C 2	C 3	C 4	C 5
# customers in cluster	12	6	3	8	10	4	9	10	6	10
Total Route Waiting Time	15.73	0	0	2.14	13.67	0	7.2	20.1	0	3.04
Total Route Duration	27.7	12.09	22.16	38.14	67.78	5.58	9.79	23.38	39.47	57.85
Total Route Cost	1386.38	907.75	1663	2767.34	4483.02	419.5	735.25	1754.5	2961.25	4180.24
Computational time	3086.94	0.234375	0.046875	73.4375	1772.45	0.0625	0.984375	8.78125	100.3125	4210.281

Table 12. Computational results for scenario 5 and 6

6 Seeds											
Variant 1						Variant2					
	C 1	C 2	C 3	C 4	C 5	C6	C 1	C 2	C 3	C 4	C 5
# customers in cluster	4	4	5	6	8	14	4	3	6	17	9
Total Route Waiting Time	0	0	0	6.17	0.35	0	0	0	7.71	0	4.77
Total Route Duration	5.58	8.99	11.84	34.65	36.01	53.52	5.58	8.17	12.09	35.36	21.98
Total Route Cost	419.5	675.25	889	2328.27	2686.35	4015	419.5	613.75	1907.75	2313.76	1649.5
Computational time	5.58	8.99	11.84	28.48	1035.66	503.52	0.046875	1.29688	0.28125	0.140625	0.015625

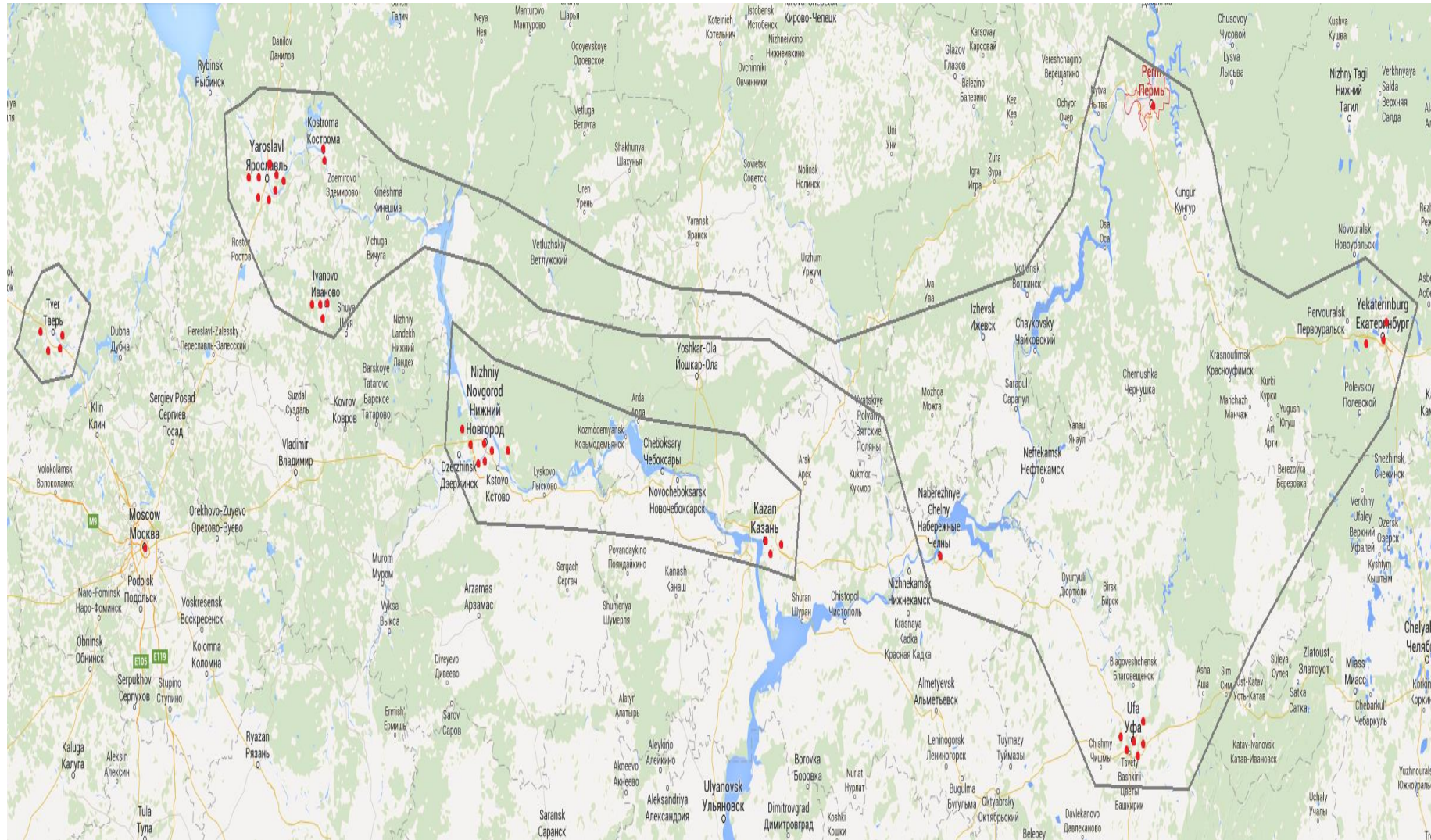
Table 13. Computational results for scenario 7 and 8

10.5 First phase result for Scenario 2

Seed:	Customers in cluster	Demand
Tver_ATAKo	Tver_ATAKo	35.0
	Tver_ATAKmk	125.0
	Tver_Magnit	3500.0
	Tver_LENTA	1847.0
	Total Demand:	5507.0
Yekaterinburg_ASHANh	Yaroslavl_LENTA1	1857.0
	Yaroslavl_7Continent	59.0
	Yaroslavl_ATAK	32.0
	Yaroslavl_ASHANn	197.0
	Yaroslavl_ASHANp	112.0
	Yaroslavl_LENTA	133.0
	Yaroslavl_Giperglobus	1600.0
	Yaroslavl_Magnit	2240.0
	Kostroma_ASHAN	510.0
	Kostroma_7Continent	78.0
	Ivanovo_ASHAN	279.0
	Ivanovo_7Continent	68.0
	Ivanovo_Magnit	650.0
	Ivanovo_Okey	28.0
	NaberezhnyeChelny_LENTA	878.0
	Ufa_LENTA	1014.0
	Ufa_ASHAN	80.0
	Ufa_OKEYe	37.0
	Ufa_OKEYk	15.0
	Ufa_OKEYmj	43.0
	Ufa_Magnit	9.0
	Pyshma_Perekrestok	221.0
	Yekaterinburg_ASHANh	52.0
	Yekaterinburg_ASHANm	525.0
	Perm_LENTA	757.0

	Total Demand:	11474.0
Kazan_Zelgros	NNovgorod_METROn	65.0
	NNovgorod_METROm	54.0
	NNovgorod_ASHANb	238.0
	NNovgorod_LENTA	898.0
	NNovgorod_ASHANm	152.0
	NNovgorod_Okey	672.0
	NNovgorod_Magnit	4657.0
	Kazan_ASHANy	439.0
	Kazan_Zelgros	123.0
	Kazan_ASHANp	754.0
	Total Demand:	8052.0

10.5.1 Clusters received with Scenario 2 first phase

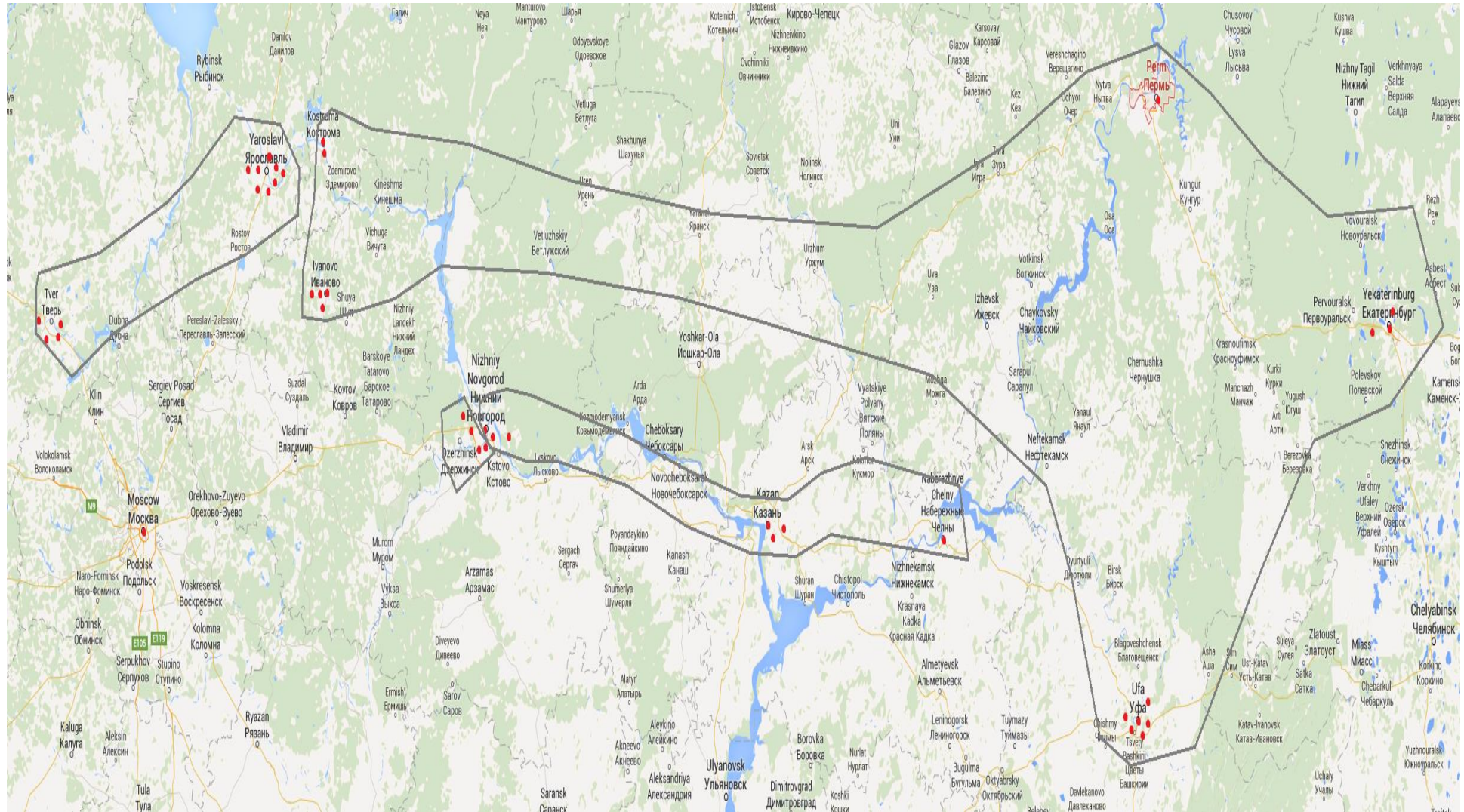


10.6 First phase result for Scenario 3

Seed:	Customers in cluster	Demand
Yaroslavl_LENTA1		
	Yaroslavl_LENTA1	1857.0
	Yaroslavl_7Continent	59.0
	Yaroslavl_ATAK	32.0
	Yaroslavl_ASHANn	197.0
	Yaroslavl_ASHANp	112.0
	Yaroslavl_LENTA	133.0
	Yaroslavl_Giperglobus	1600.0
	Yaroslavl_Magnit	2240.0
	Tver_ATAKo	35.0
	Tver_ATAKmk	125.0
	Tver_Magnit	3500.0
	Tver_LENTA	1847.0
	Total Demand:	11737.0
NaberezhnyeChelny_LENTA		
	NNovgorod_METROn	65.0
	NNovgorod_METROm	54.0
	NNovgorod_ASHANb	238.0
	Kazan_ASHANy	439.0
	Kazan_Zelgros	123.0
	Kazan_ASHANp	754.0
	NaberezhnyeChelny_LENTA	878.0
	Total Demand:	2551.0
NNovgorod_Okey		
	NNovgorod_LENTA	898.0
	NNovgorod_ASHANm	152.0
	NNovgorod_Okey	672.0
	NNovgorod_Magnit	4657.0
	Total Demand:	6379.0

Perm_LENTA		
	Kostroma_ASHAN	510.0
	Kostroma_7Continent	78.0
	Ivanovo_ASHAN	279.0
	Ivanovo_7Continent	68.0
	Ivanovo_Magnit	650.0
	Ivanovo_Okey	28.0
	Ufa_LENTA	1014.0
	Ufa_ASHAN	80.0
	Ufa_OKEYe	37.0
	Ufa_OKEYk	15.0
	Ufa_OKEYmj	43.0
	Ufa_Magnit	9.0
	Pyshma_Perekrestok	221.0
	Yekaterinburg_ASHANh	52.0
	Yekaterinburg_ASHANm	525.0
	Perm_LENTA	757.0
	Total Demand:	4366.0

10.6.1 Clusters received with Scenario 3 first phase

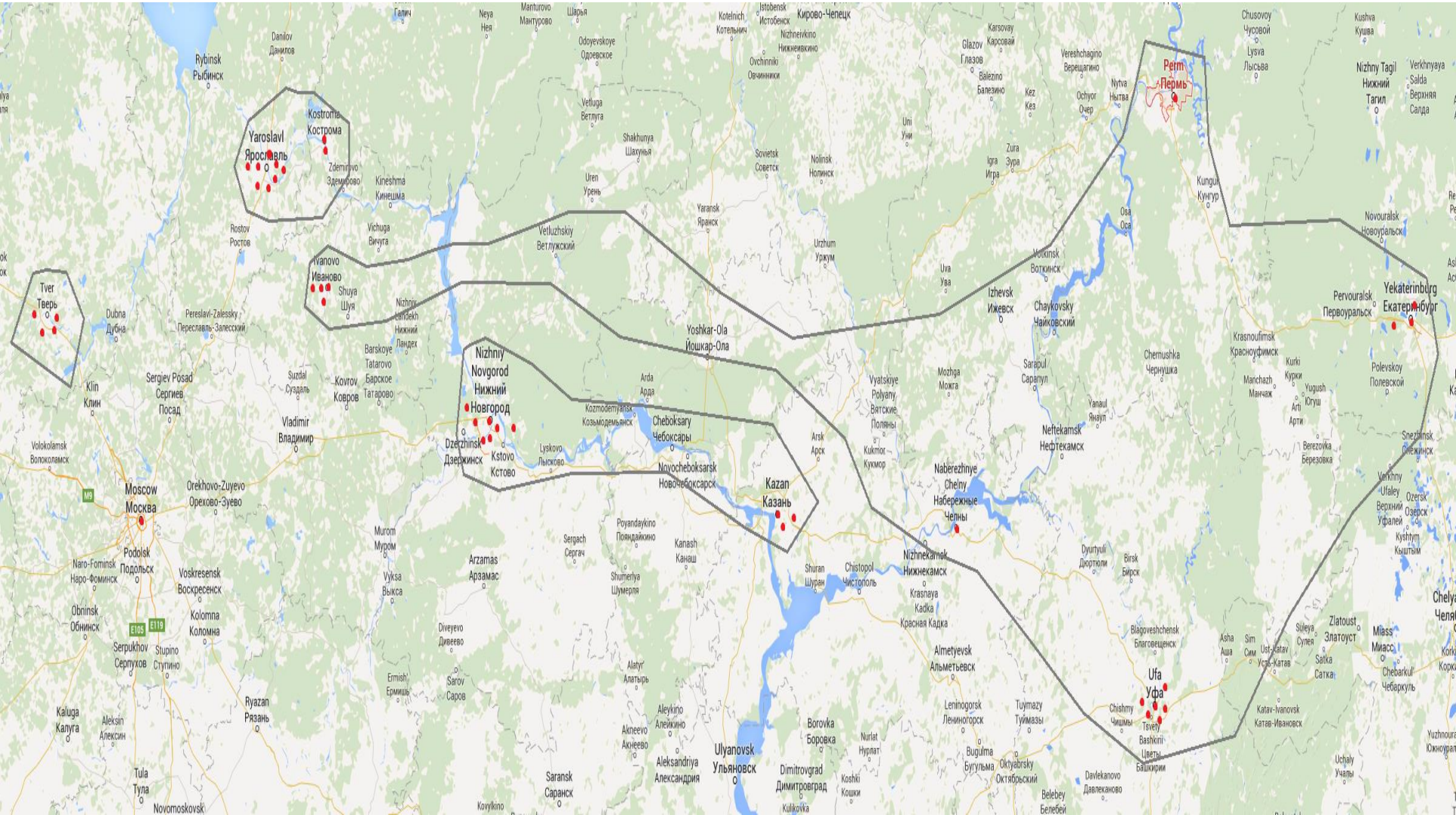


10.7 First phase result for Scenario 4

Seed:	Customers in cluster	Demand
Tver_ATAKo		
	Tver_ATAKo	35.0
	Tver_ATAKmk	125.0
	Tver_Magnit	3500.0
	Tver_LENTA	1847.0
	Total Demand:	5507.0
Kostroma_ASHAN		
	Yaroslavl_LENTA1	1857.0
	Yaroslavl_7Continent	59.0
	Yaroslavl_ATAK	32.0
	Yaroslavl_ASHANn	197.0
	Yaroslavl_ASHANp	112.0
	Yaroslavl_LENTA	133.0
	Yaroslavl_Giperglobus	1600.0
	Yaroslavl_Magnit	2240.0
	Kostroma_ASHAN	510.0
	Kostroma_7Continent	78.0
	Total Demand:	6818.0
Yekaterinburg_ASHANh		
	Ivanovo_ASHAN	279.0
	Ivanovo_7Continent	68.0
	Ivanovo_Magnit	650.0
	Ivanovo_Okey	28.0
	NaberezhnyeChelny_LENTA	878.0
	Ufa_LENTA	1014.0
	Ufa_ASHAN	80.0
	Ufa_OKEYe	37.0
	Ufa_OKEYk	15.0

	Ufa_OKEYmj	43.0
	Ufa_Magnit	9.0
	Pyshma_Perekrestok	221.0
	Yekaterinburg_ASHANh	52.0
	Yekaterinburg_ASHANm	525.0
	Perm_LENTA	757.0
	Total Demand:	4656.0
Kazan_Zelgros		
	NNovgorod_METROn	65.0
	NNovgorod_METROm	54.0
	NNovgorod_ASHANb	238.0
	NNovgorod_LENTA	898.0
	NNovgorod_ASHANm	152.0
	NNovgorod_Okey	672.0
	NNovgorod_Magnit	4657.0
	Kazan_ASHANy	439.0
	Kazan_Zelgros	123.0
	Kazan_ASHANp	754.0
	Total Demand:	8052.0

10.7.1 Clusters received with Scenario 4 first phase

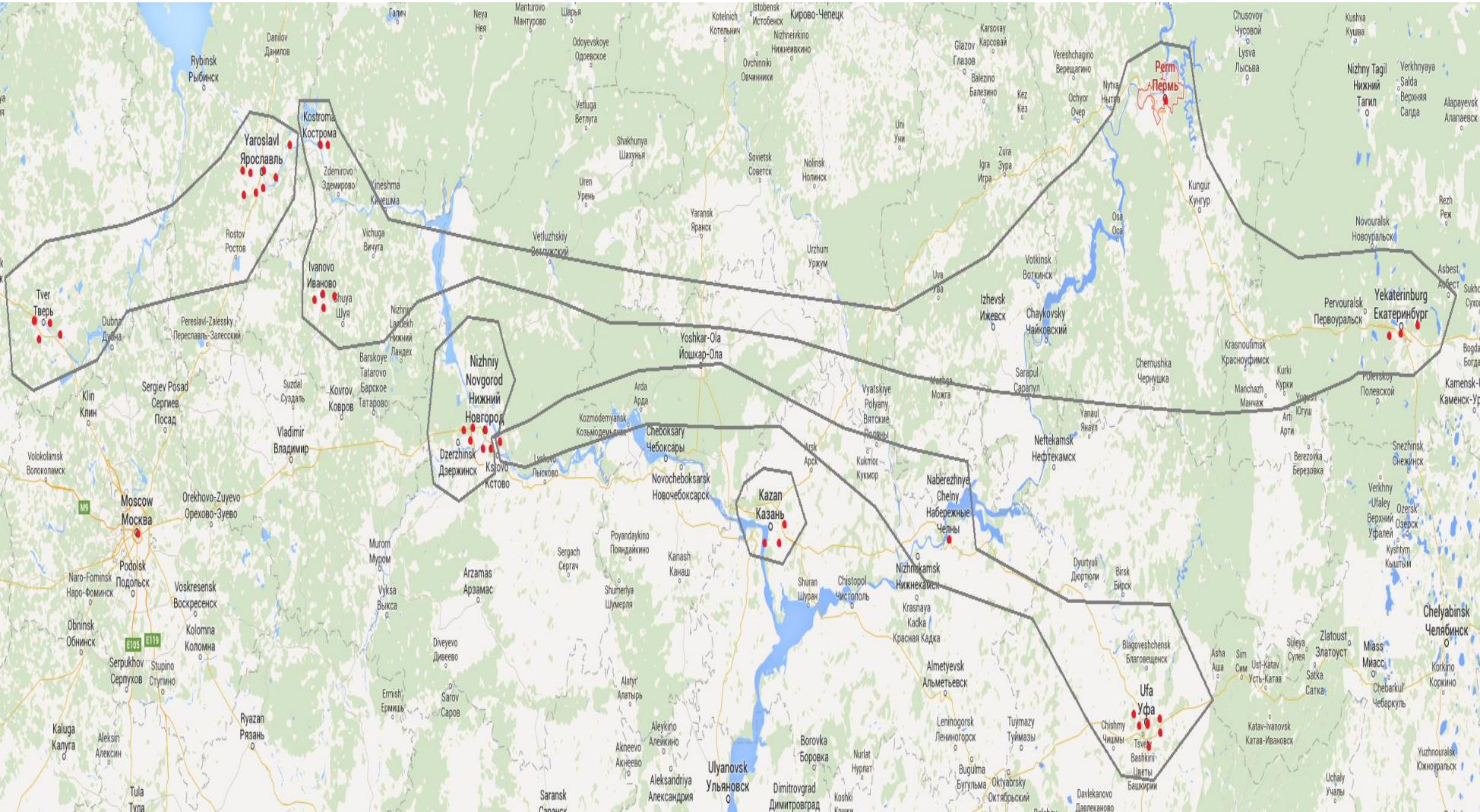


10.8 First phase result for Scenario 5

Seed:	Customers in cluster	Demand
Yaroslavl_ATAK		
	Yaroslavl_LENTA1	1857.0
	Yaroslavl_7Continent	59.0
	Yaroslavl_ATAK	32.0
	Yaroslavl_ASHANn	197.0
	Yaroslavl_ASHANp	112.0
	Yaroslavl_LENTA	133.0
	Yaroslavl_Giperglobus	1600.0
	Yaroslavl_Magnit	2240.0
	Tver_ATAKo	35.0
	Tver_ATAKmk	125.0
	Tver_Magnit	3500.0
	Tver_LENTA	1847.0
	Total Demand:	11737.0
NNovgorod_LENTA		
	NNovgorod_METROn	65.0
	NNovgorod_METROm	54.0
	NNovgorod_ASHANb	238.0
	NNovgorod_LENTA	898.0
	NNovgorod_ASHANm	152.0
	NNovgorod_Magnit	4657.0
	Total Demand:	6064.0
Kazan_ASHANp		
	Kazan_ASHANy	439.0
	Kazan_Zelgros	123.0
	Kazan_ASHANp	754.0
	Total Demand:	1316.0
Ufa_OKEYe		
	NNovgorod_Okey	672.0

	NaberezhnyeChelny_LENTA	878.0
	Ufa_LENTA	1014.0
	Ufa_ASHAN	80.0
	Ufa_OKEYe	37.0
	Ufa_OKEYk	15.0
	Ufa_OKEYmj	43.0
	Ufa_Magnit	9.0
	Total Demand:	2748.0
Yekaterinburg_ASHANh		
	Kostroma_ASHAN	510.0
	Kostroma_7Continent	78.0
	Ivanovo_ASHAN	279.0
	Ivanovo_7Continent	68.0
	Ivanovo_Magnit	650.0
	Ivanovo_Okey	28.0
	Pyshma_Perekrestok	221.0
	Yekaterinburg_ASHANh	52.0
	Yekaterinburg_ASHANm	525.0
	Perm_LENTA	757.0
	Total Demand:	3168.0

10.8.1 Clusters received with Scenario 5 first phase

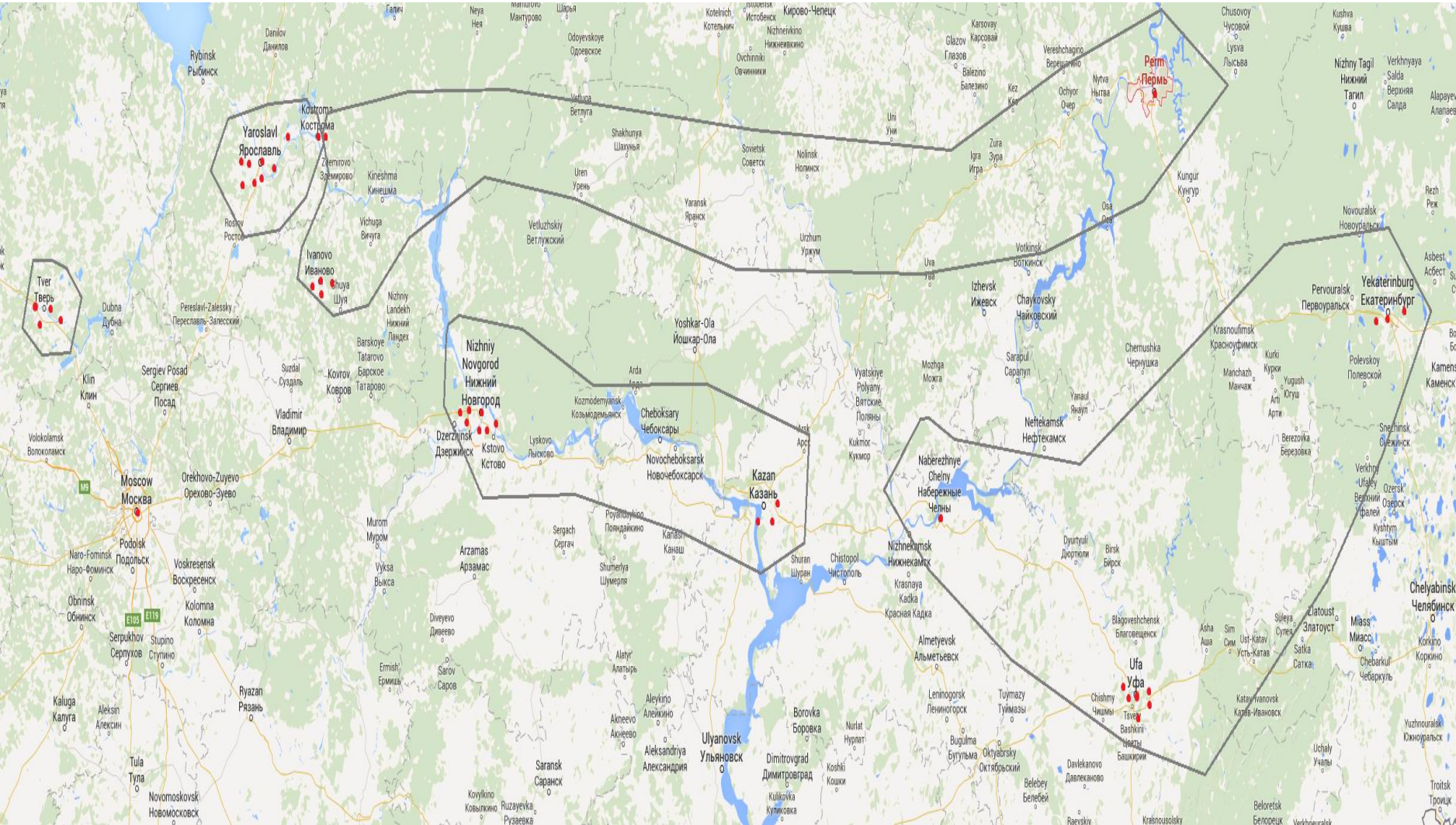


10.9 First phase result for Scenario 6

Seed:	Customers in cluster	Demand
Tver_ATAKo		
	Tver_ATAKo	35.0
	Tver_ATAKmk	125.0
	Tver_Magnit	3500.0
	Tver_LENTA	1847.0
	Total Demand:	5507.0
Kostroma_7Continent		
	Yaroslavl_LENTA1	1857.0
	Yaroslavl_7Continent	59.0
	Yaroslavl_ATAK	32.0
	Yaroslavl_ASHANn	197.0
	Yaroslavl_ASHANp	112.0
	Yaroslavl_LENTA	133.0
	Yaroslavl_Giperglobus	1600.0
	Yaroslavl_Magnit	2240.0
	Kostroma_7Continent	78.0
	Total Demand:	6308.0
Kazan_ASHANy		
	NNovgorod_METROn	65.0
	NNovgorod_METROm	54.0
	NNovgorod_ASHANb	238.0
	NNovgorod_LENTA	898.0
	NNovgorod_ASHANm	152.0
	NNovgorod_Okey	672.0
	NNovgorod_Magnit	4657.0
	Kazan_ASHANy	439.0
	Kazan_Zelgros	123.0
	Kazan_ASHANp	754.0
	Total Demand:	8052.0
Perm_LENTA		

	Kostroma_ASHAN	510.0
	Ivanovo_ASHAN	279.0
	Ivanovo_7Continent	68.0
	Ivanovo_Magnit	650.0
	Ivanovo_Okey	28.0
	Perm_LENTA	757.0
	Total Demand:	2292.0
Yekaterinburg_ASHANm		
	NaberezhnyeChelny_LENTA	878.0
	Ufa_LENTA	1014.0
	Ufa_ASHAN	80.0
	Ufa_OKEYe	37.0
	Ufa_OKEYk	15.0
	Ufa_OKEYmj	43.0
	Ufa_Magnit	9.0
	Pyshma_Perekrestok	221.0
	Yekaterinburg_ASHANh	52.0
	Yekaterinburg_ASHANm	525.0
	Total Demand:	2874.0

10.9.1 Clusters received with Scenario 6 first phase

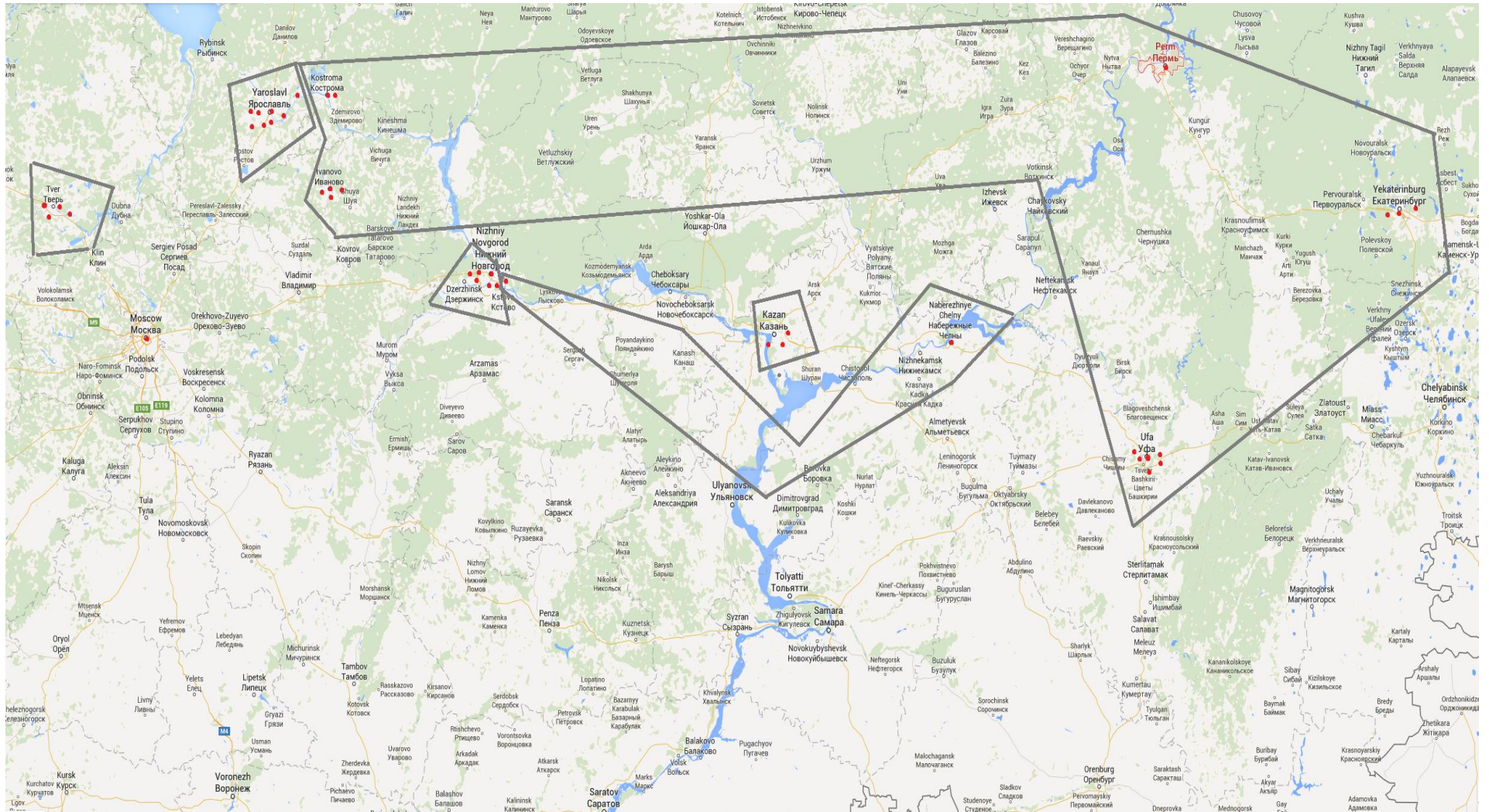


10.10 First phase result for Scenario 7

Seed:	Customers in cluster	Demand
Tver_LENTA		
	Tver_ATAKo	35
	Tver_ATAKmk	125
	Tver_Magnit	3500
	Tver_LENTA	1847
	Total Demand:	5507
Yaroslavl_Giperglobu		
	Yaroslavl_LENTA1	1857
	Yaroslavl_7Continent	59
	Yaroslavl_ATAK	32
	Yaroslavl_ASHANn	197
	Yaroslavl_ASHANp	112
	Yaroslavl_LENTA	133
	Yaroslavl_Giperglobus	1600
	Yaroslavl_Magnit	2240
	Total Demand:	6230
NNovgorod_METRON		
	NNovgorod_METRON	65
	NNovgorod_METROm	54
	NNovgorod_ASHANb	238
	NNovgorod_LENTA	898
	NNovgorod_ASHANm	152
	Total Demand:	1407
NaberezhnyeChelny_LENTA		
	NNovgorod_Okey	672
	NaberezhnyeChelny_LENTA	878
	Total Demand:	1550
Kazan_Zelgros		

	Kazan_ASHANy	439
	Kazan_Zelgros	123
	Kazan_ASHANp	754
	Total Demand:	1316
Yekaterinburg_ASHANh		
	Kostroma_ASHAN	510
	Kostroma_7Continent	78
	Ivanovo_ASHAN	279
	Ivanovo_7Continent	68
	Ivanovo_Magnit	650
	Ivanovo_Okey	28
	Ufa_LENTA	1014
	Ufa_ASHAN	80
	Ufa_OKEYe	37
	Ufa_OKEYk	15
	Ufa_OKEYmj	43
	Ufa_Magnit	9
	Pyshma_Perekrestok	221
	Yekaterinburg_ASHANh	52
	Yekaterinburg_ASHANm	525
	Perm_LENTA	757
	Total Demand:	4366

10.10.2 Clusters received with Scenario 7 first phase

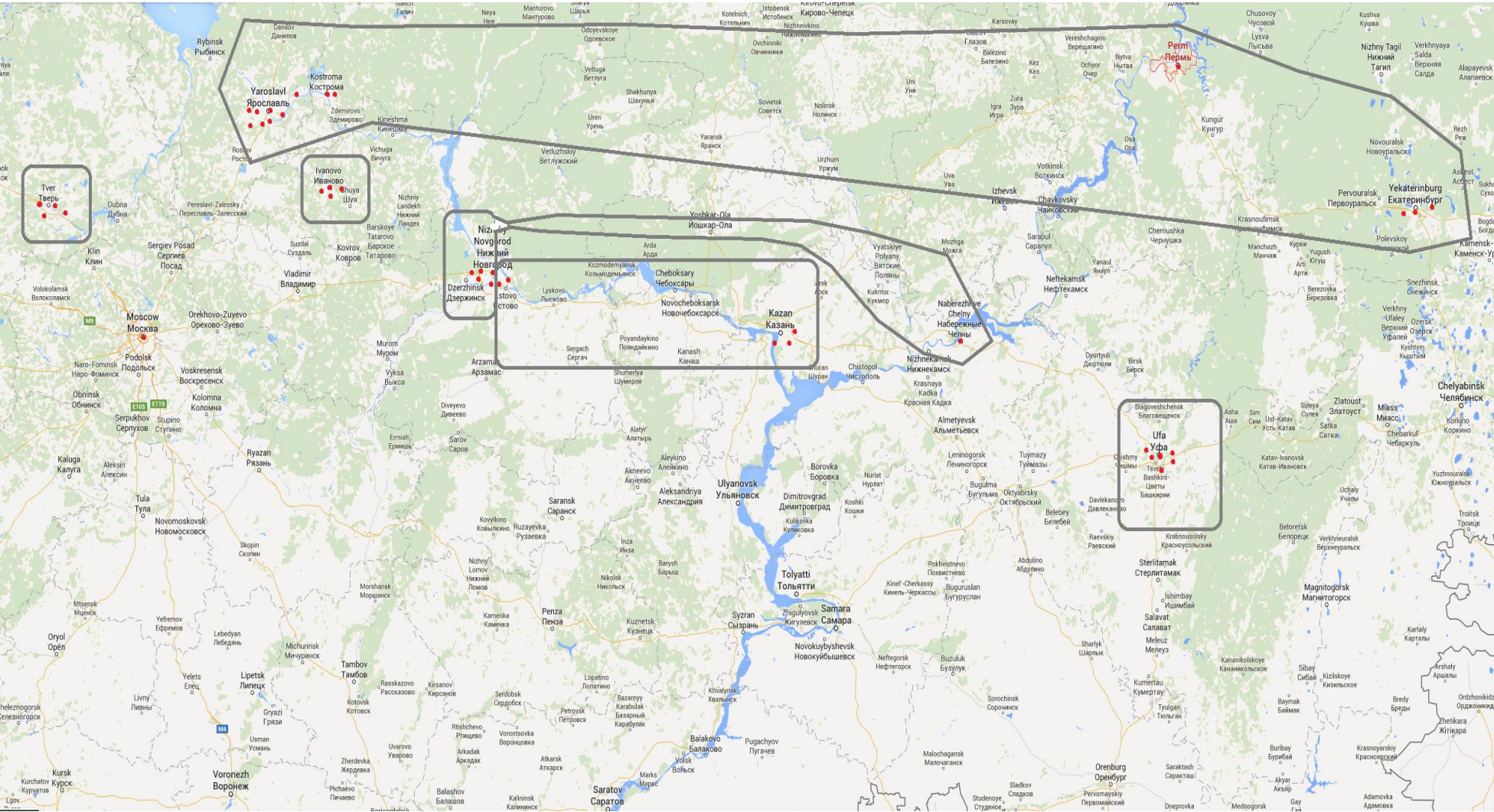


10.11 First phase result for Scenario 8

Seed:	Customers in cluster	Demand
Tver_ATAKo		
	Tver_ATAKo	35
	Tver_ATAKmk	125
	Tver_Magnit	3500
	Tver_LENTA	1847
	Total Demand:	5507
Ivanovo_Okey		
	Ivanovo_ASHAN	279
	Ivanovo_7Continen	68
	Ivanovo_Magnit	650
	Ivanovo_Okey	28
	Total Demand:	1025
NNovgorod_Magnit		
	NNovgorod_METROm	54
	NNovgorod_ASHANb	238
	NNovgorod_LENTA	898
	NNovgorod_ASHANm	152
	NNovgorod_Magnit	4657
	Total Demand:	5999
NaberezhnyeChelny_LENTA		
	NNovgorod_METROn	65
	NNovgorod_Okey	672
	Kazan_ASHANy	439
	Kazan_Zelgros	123
	Kazan_ASHANp	754
	NaberezhnyeChelny_LENTA	878
	Total Demand:	2931
Ufa_OKEYk		

	Ufa_LENTA	1014
	Ufa_ASHAN	80
	Ufa_OKEYe	37
	Ufa_OKEYk	15
	Ufa_OKEYmj	43
	Ufa_Magnit	9
	Total Demand:	1198
Perm_LENTA		
	Yaroslavl_LENTA1	1857
	Yaroslavl_7Continent	59
	Yaroslavl_ATAK	32
	Yaroslavl_ASHANn	197
	Yaroslavl_ASHANp	112
	Yaroslavl_LENTA	133
	Yaroslavl_Giperglobus	1600
	Yaroslavl_Magnit	2240
	Kostroma_ASHAN	510
	Kostroma_7Continent	78
	Pyshma_Perekrestok	221
	Yekaterinburg_ASHANh	52
	Yekaterinburg_ASHANm	525
	Perm_LENTA	757
	Total Demand:	8373

10.11.1 Clusters received with Scenario 8 first phase

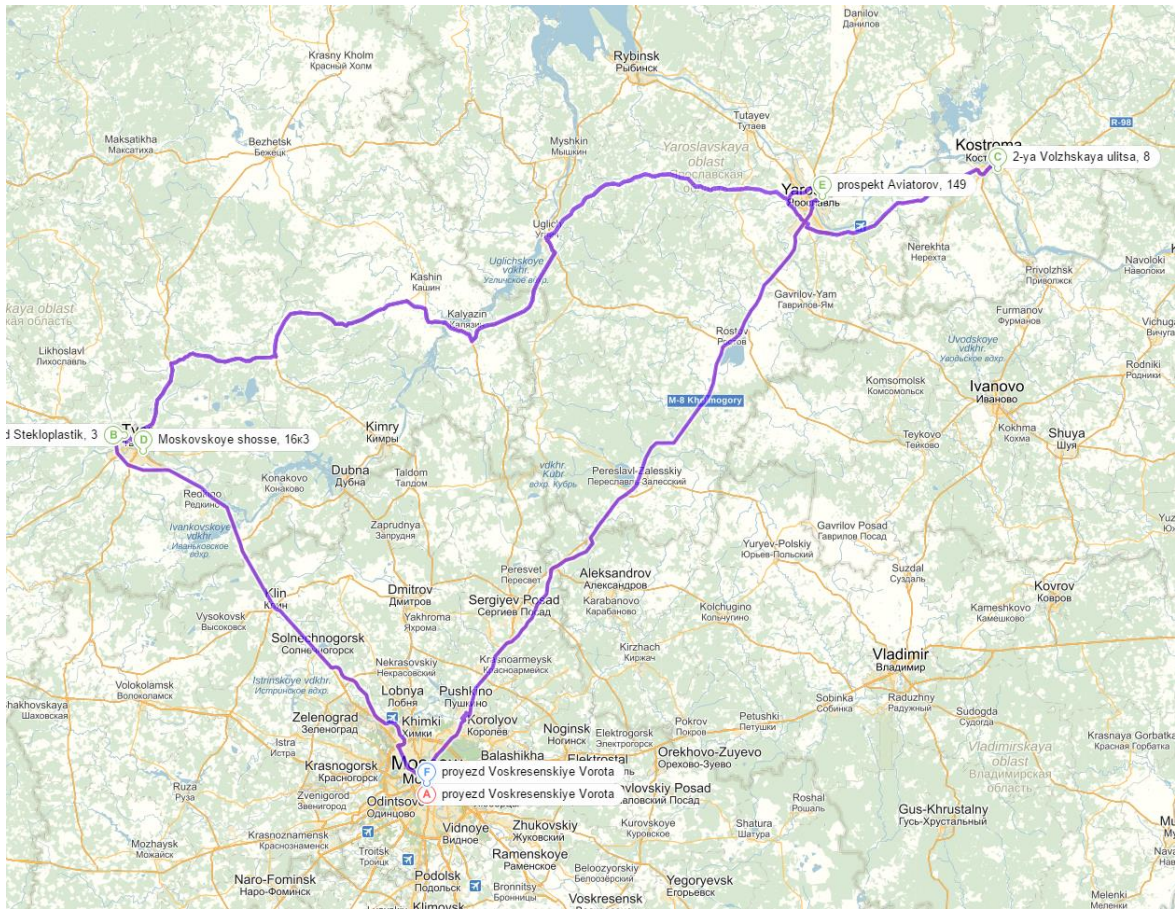


10.12 MPVRPmTW results for Scenario 1

10.12.1 MPVRPmTW results for Scenario 1 first cluster

	Arrival Time	Departure Time	Visit Day	Waiting time
MoscowDepot	17.96	7.53	Tue-Fr	0
Tver_Magnit	10.15	10.35	Tue	0
Kostroma_7Continent	15.48	15.68	Tue	0
Kostroma_ASHAN	15.8	16	Tue	0
Yaroslavl_Magnit	17.03	7.49	Fr	14.26
Yaroslavl_LENTA	7.85	8.05	Fr	0
Yaroslavl_Giperglobus	8.21	8.41	Fr	0
Yaroslavl_LENTA1	8.73	8.93	Fr	0
Yaroslavl_ASHANp	9	9.2	Fr	0
Yaroslavl_7Continent	9.42	9.62	Fr	0
Yaroslavl_ASHANn	9.66	9.86	Fr	0
Yaroslavl_ATAK	10.07	10.27	Fr	0
Tver_ATAKmk	14.64	14.84	Fr	0
Tver_ATAKo	15.06	15.26	Fr	0
Tver_LENTA	15.36	15.56	Fr	0
Computational time (sec):				3122.81
Total Travel Cost (NOK):				1745.81
Route Duration (Hours):				31.63

10.12.1.1 MPVRPmTW route for Scenario 1 first cluster

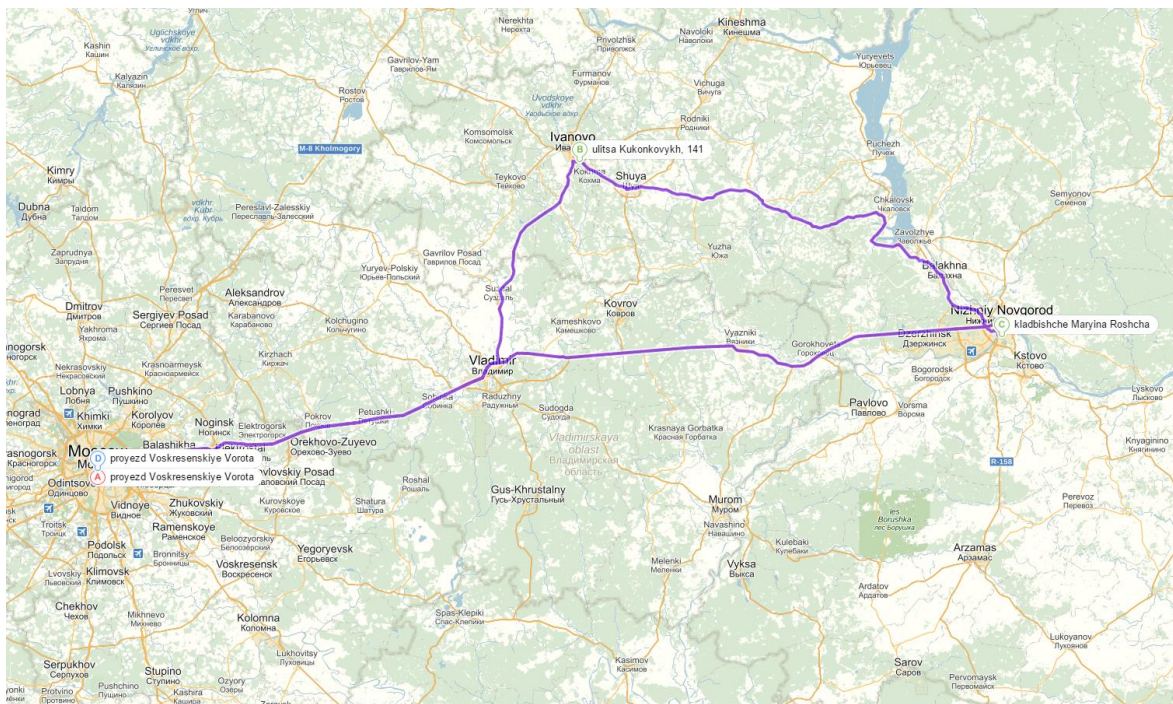


10.12.2 MPVRPmTW results for Scenario 1 second cluster

	Arrival Time	Departure Time	Visit Day	Waiting time
MoscowDepot	19.42	2.74	Tue-Wed	0
Ivanovo_Magnit	7	7.2	Tue	0
Ivanovo_Okey	7.29	7.49	Tue	0
Ivanovo_ASHAN	7.65	7.85	Tue	0
Ivanovo_7Continent	7.93	8.13	Tue	0
NNovgorod_METROm	11.68	11.88	Tue	0
NNovgorod_LENTA	11.94	12.14	Tue	0
NNovgorod_ASHANb	12.34	12.54	Tue	0
NNovgorod_ASHANm	12.82	13.02	Tue	0
NNovgorod_METROn	13.21	13.41	Tue	0

NNovgorod_Magnit	13.61	13.81	Tue	0
Computational time (sec):	2000.8438			
Total Travel Cost (NOK):	1102			
Route Duration (Hours):	14.68			

10.12.2.1 MPVRPmTW route for Scenario 1 second cluster

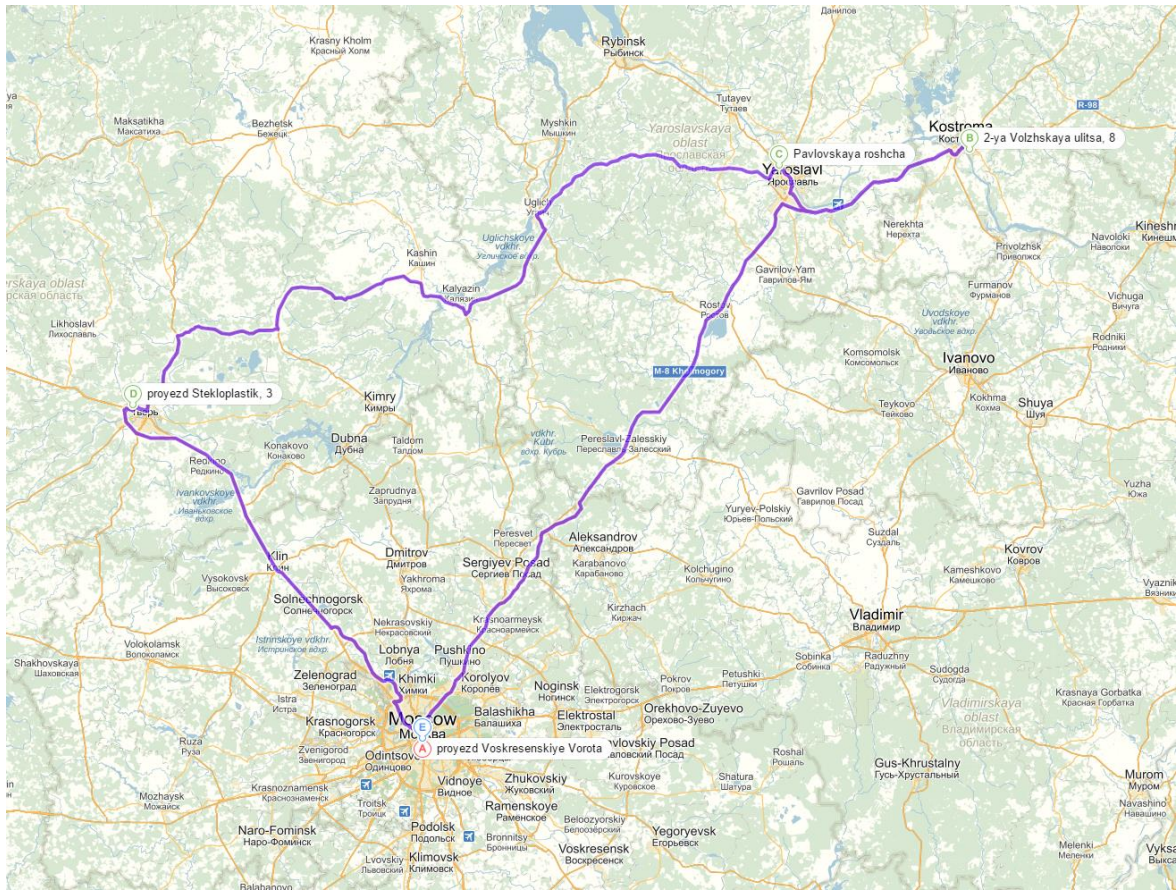


10.13 MPVRPmTW results for Scenario 2

10.13.1 MPVRPmTW results for Scenario 2 first cluster

	Arrival Time	Departure Time	Visit Day	Waiting time
MoscowDepot	11.43	3.53	Thu-Wed	0
Kostroma_7Continent	7.75	7.95	Wed	0
Yaroslavl_Magnit	8.85	9.05	Wed	0
Yaroslavl_ATAK	9.13	9.33	Wed	0
Yaroslavl_ASHANn	9.54	9.74	Wed	0
Yaroslavl_7Continent	9.78	9.98	Wed	0
Yaroslavl_ASHANp	10.22	10.42	Wed	0
Yaroslavl_LENTA	10.58	10.78	Wed	0
Yaroslavl_Giperglobus	10.94	11.14	Wed	0
Yaroslavl_LENTA1	11.66	11.86	Wed	0
Tver_ATAKmk	15.8	16	Wed	0
Tver_Magnit	16.27	8.2	Wed	15.73
Tver_ATAKo	8.53	8.73	Thu	0
Tver_LENTA	8.83	9.03	Thu	0
Computational time (sec):				40.8438
Total Travel Cost (NOK):				1506.38
Route Duration (Hours):				29.3

10.13.1.1 MPVRPmTW route for Scenario 2 first cluster

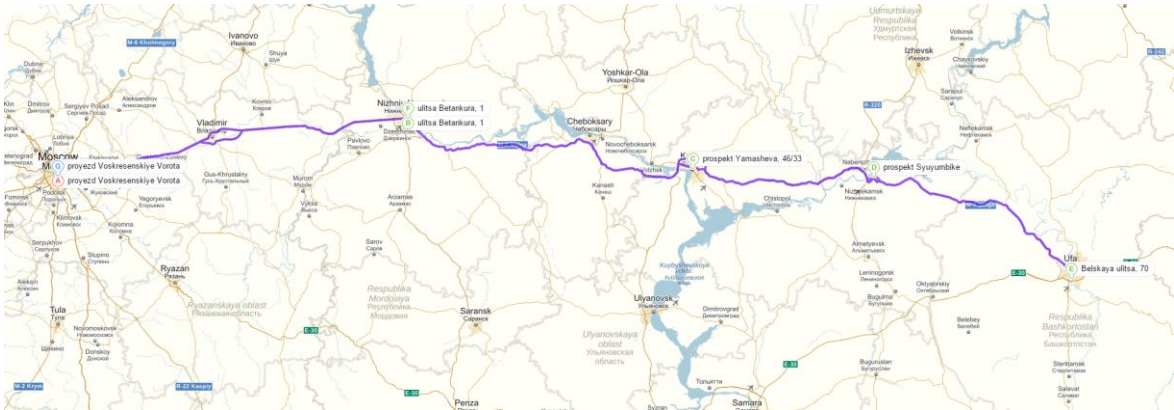


10.13.2 MPVRPmTW results for Scenario 2 second cluster

	Arrival Time	Departure Time	Visit Day	Waiting time
MoscowDepot	14.57	7.74	Mon-Thu	0
NNovgorod_METROn	13.43	13.63	Mon	0
Kazan_ASHANy	18.94	19.14	Mon	0
Kazan_ASHANp	19.43	19.63	Mon	0
Kazan_Zelgros	19.8	20	Mon	0
NaberezhnyeChelny_LENTA	22.97	12.02	Tue	12.85
Ufa_Magnit	15.8	16	Tue	0
Ufa_ASHAN	16.24	16.44	Tue	1.4

Ufa_OKEYmj	18.19	18.39	Tue	0
Ufa_OKEYk	18.54	18.74	Tue	0
Ufa_OKEYe	18.8	19	Tue	0
Ufa_LENTA	19.17	20	Tue	0.63
NNovgorod_LENTA	8.2	8.4	Wed	0
NNovgorod_ASHANb	8.6	8.8	Wed	0
NNovgorod_METROm	9.05	16	Wed	6.75
NNovgorod_ASHANm	16.07	8.2	Thu	15.93
NNovgorod_Magnit	8.36	8.56	Thu	0
NNovgorod_Okey	8.71	8.91	Thu	0
Computational time (sec):				3243.14
Total Travel Cost (NOK):				4005.61
Route Duration (Hours):				75.43

10.13.2.1 MPVRPmTW route for Scenario 2 second cluster

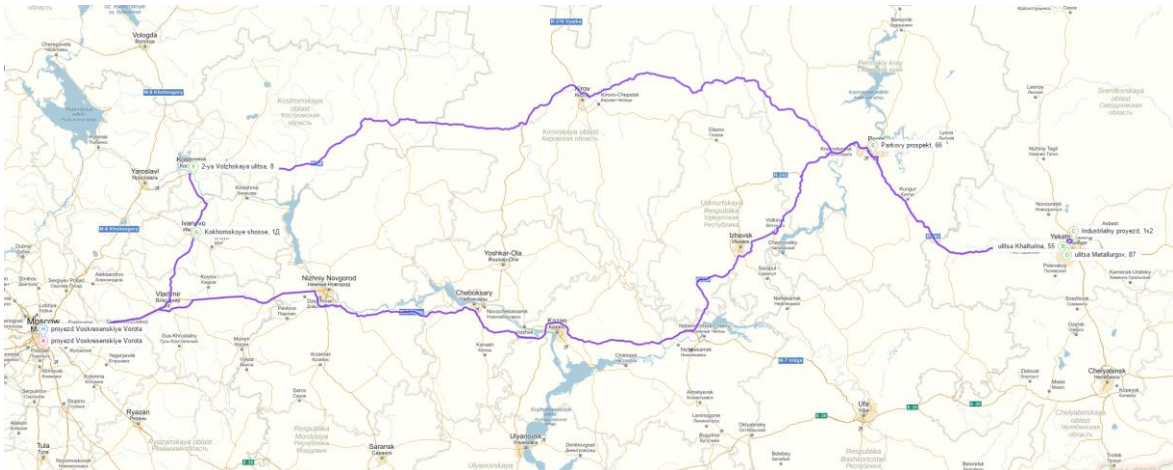


10.13.3 MPVRPmTW results for Scenario 2 third cluster

	Arrival Time	Departure Time	Visit Day	Waiting time
MoscowDepot	14.3	16.72	Tue-Fr	0
Yekaterinburg_ASHANm	15.8	16	Wed	0
Pyshma_Perekrestok	18.67	8.54	Thu	13.67

Yekaterinburg_ASHANh	11.29	11.49	Thu	0
Perm_LENTA	16.33	16.53	Thu	0
Kostroma_ASHAN	7	7.2	Fr	0
Ivanovo_Okey	8.77	8.97	Fr	0
Ivanovo_7Continent	9.15	9.35	Fr	0
Ivanovo_ASHAN	9.43	9.63	Fr	0
Ivanovo_Magnit	9.8	10	Fr	0
Computational time (sec):				2239.281
Total Travel Cost (NOK):				4483.02
Route Duration (Hours):				67.78

10.13.3.1 MPVRPmTW route for Scenario 2 third cluster

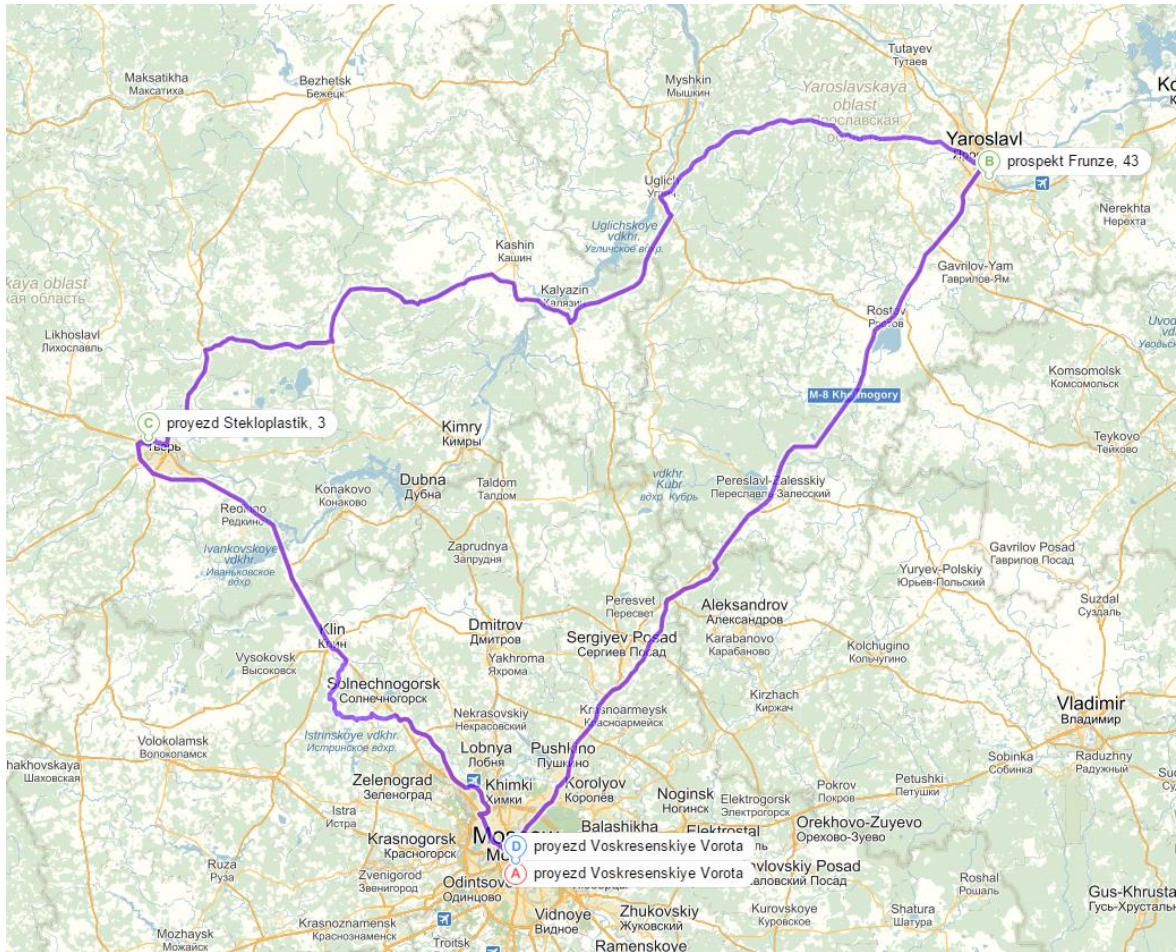


10.14 MPVRPmTW results for Scenario 3

10.14.1 MPVRPmTW results for Scenario 3 first cluster

	Arrival Time	Departure Time	Visit Day	Waiting time
MoscowDepot	11.11	5.01	Thu-Wed	0
Yaroslavl_7Continent	8.33	8.53	Wed	0
Yaroslavl_ATAK	8.72	8.92	Wed	0
Yaroslavl_Magnit	8.99	9.19	Wed	0
Yaroslavl_ASHANn	9.42	9.62	Wed	0
Yaroslavl_LENTA	9.96	10.16	Wed	0
Yaroslavl_Giperglobus	10.32	10.52	Wed	0
Yaroslavl_ASHANp	10.78	10.98	Wed	0
Yaroslavl_LENTA1	11.06	11.26	Wed	0
Tver_ATAKo	15.37	15.57	Wed	0
Tver_ATAKmk	15.8	16	Wed	0
Tver_Magnit	16.27	8.2	Thu	15.73
Tver_LENTA	8.51	8.71	Thu	0
Computational time (sec):				5804.34
Total Travel Cost (NOK):				1386.38
Rout Duration (Hours):				27.7

10.14.1.1 MPVRPmTW route for Scenario 3 first cluster

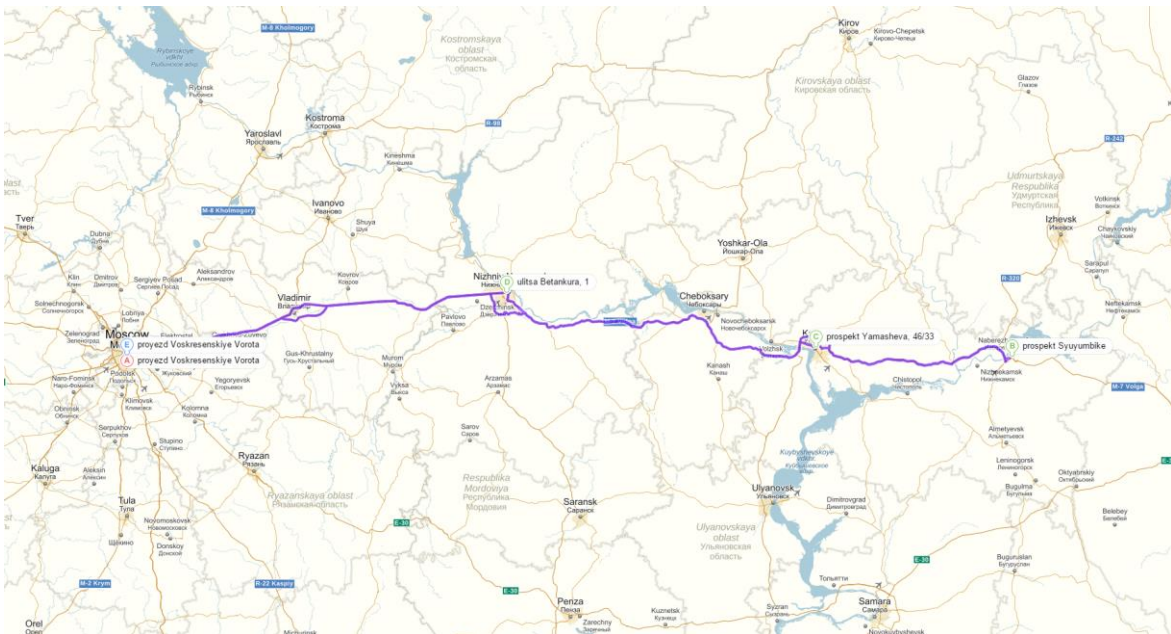


10.14.2 MPVRPmTW results for Scenario 3 second cluster

	Arrival Time	Departure Time	Visit Day	Waiting time
MoscowDepot	2.01	14.08	Tue-Wed	0
NaberezhnyeChelny_LENTA	15.71	15.91	Tue	0
Kazan_ASHANp	18.96	19.16	Tue	0
Kazan_Zelgros	19.33	19.53	Tue	0
Kazan_ASHANy	19.8	20	Tue	0
NNovgorod_METROn	1.31	7.34	Wed	5.83

NNovgorod_METROm	7.59	7.79	Wed	0
NNovgorod_ASHANb	8	8.2	Wed	0
Computational time (sec):				14.9062
Total Travel Cost (NOK):				2344.73
Rout Duration (Hours):				34.67

10.14.2.1 MPVRPmTW route for Scenario 3 second cluster

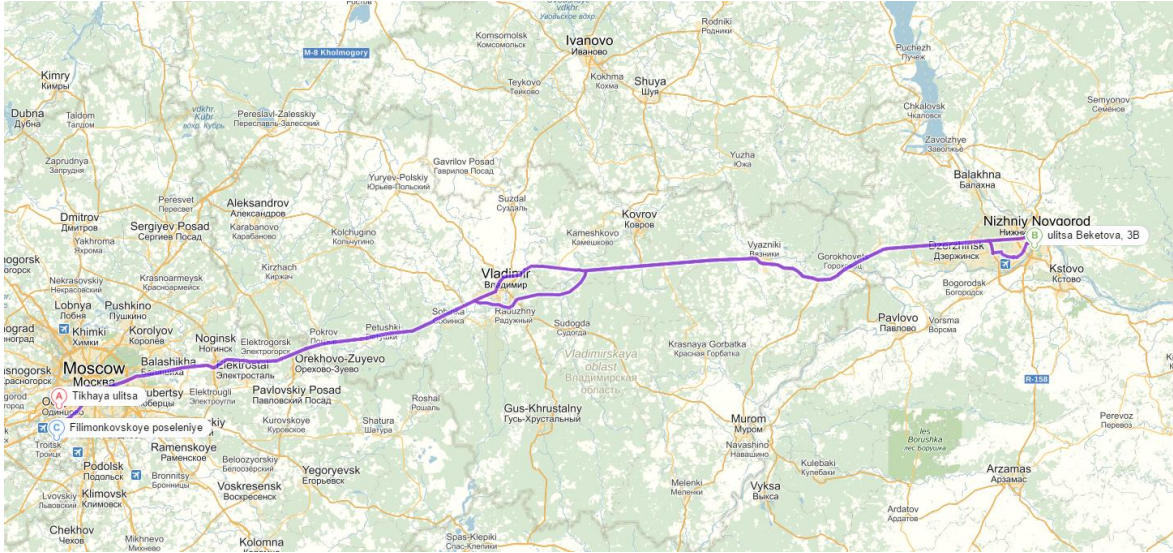


10.14.3 MPVRPmTW results for Scenario 3 third cluster

	Arrival Time	Departure Time	Visit Day	Waiting time
MoscowDepot	14.86	2.43	Tue	0
NNovgorod_Okey	8	8.2	Tue	0
NNovgorod_Magnit	8.39	8.59	Tue	0
NNovgorod_LENTA	8.78	8.98	Tue	0
NNovgorod_ASHANm	9.06	9.26	Tue	0
Computational time (sec):				0.015625

Total Travel Cost (NOK):	873.25
Rout Duration (Hours):	11.63

10.14.3.1 MPVRPmTW route for Scenario 3 third cluster

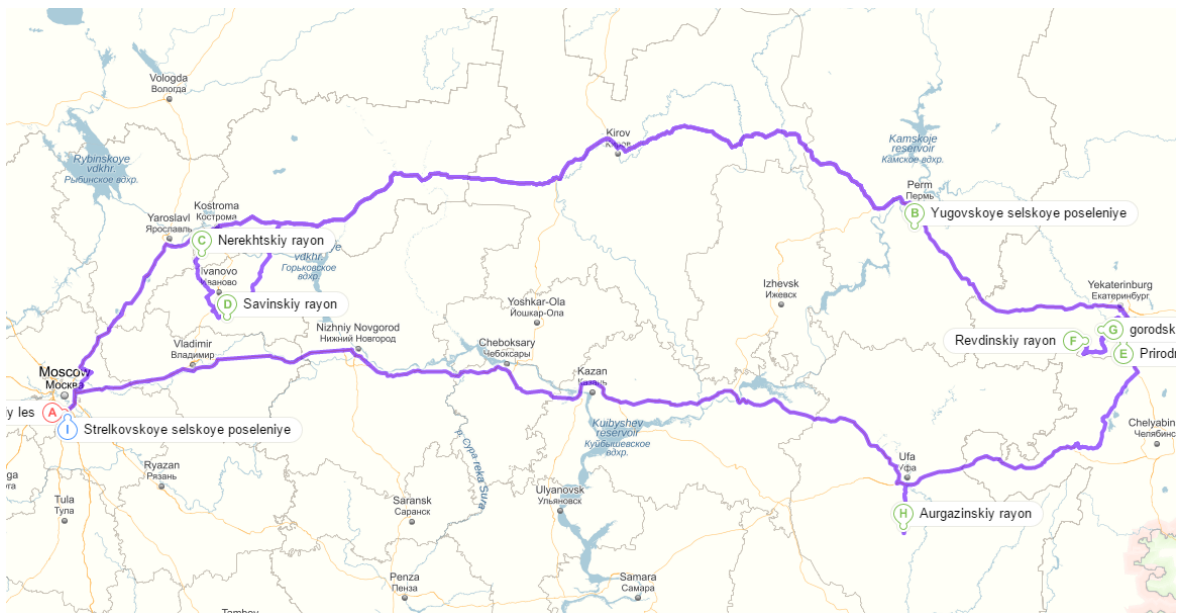


10.14.4 MPVRPmTW results for Scenario 3 forth cluster

	Arrival Time	Departure Time	Visit Day	Waiting time
MoscowDepot	3.94	8.56	Mon-Fr	
Perm_LENTA	7.2	10.2	Mon	2.8
Kostroma_7Continent	12.78	12.98	Mon	0
Kostroma_ASHAN	13.1	13.3	Mon	0
Ivanovo_Okey	14.87	15.07	Mon	0
Ivanovo_Magnit	15.16	15.36	Mon	0
Ivanovo_7Continent	15.52	15.72	Mon	0
Ivanovo_ASHAN	15.8	16	Mon	0
Yekaterinburg_ASHANh	15.03	15.23	Tue	0
Pyshma_Perekrestok	17.92	7.38	Wed	13.26
Yekaterinburg_ASHANm	10.11	10.31	Wed	0
Ufa_OKEYk	10.27	10.47	Wed	0

Ufa_OKEYmj	17.96	18.16	Wed	0
Ufa_ASHAN	18.8	19	Wed	0
Ufa_Magnit	19.29	9.66	Thu	14.17
Ufa_OKEYe	10	10.2	Thu	0
Computational time (sec):				2690.69
Total Travel Cost (NOK):				5284.38
Rout Duration (Hours):				88.18

10.14.4.1 MPVRPmTW route for Scenario 3 forth cluster

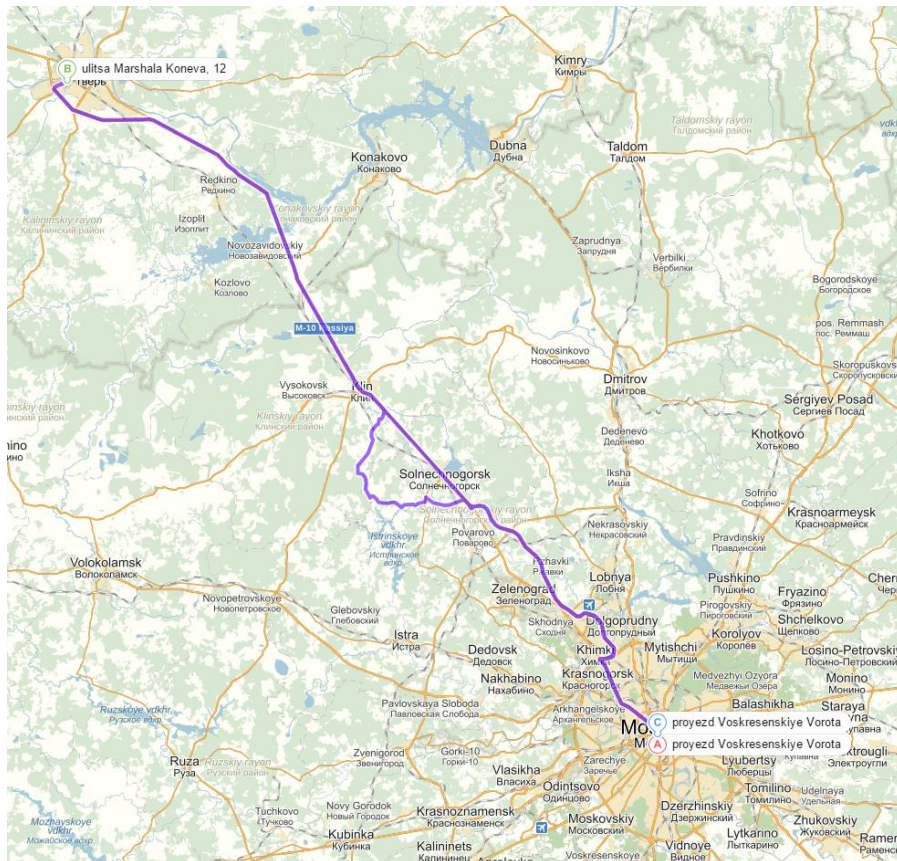


10.15 MPVRPmTW results for Scenario 4

10.15.1 MPVRPmTW results for Scenario 4 first cluster

	Arrival Time	Departure Time	Visit Day	Waiting time
MoscowDepot	12.01	5.63		0
Tver_LENTA	8	8.2	Fr	0
Tver_ATAKo	8.29	8.49	Fr	0
Tver_Magnit	8.78	8.98	Fr	0
Tver_ATAKmk	9.29	9.49	Fr	0
Computational time (sec):				0.0625
Total Travel Cost (NOK):				419.5
Route Duration (Hours):				5.58

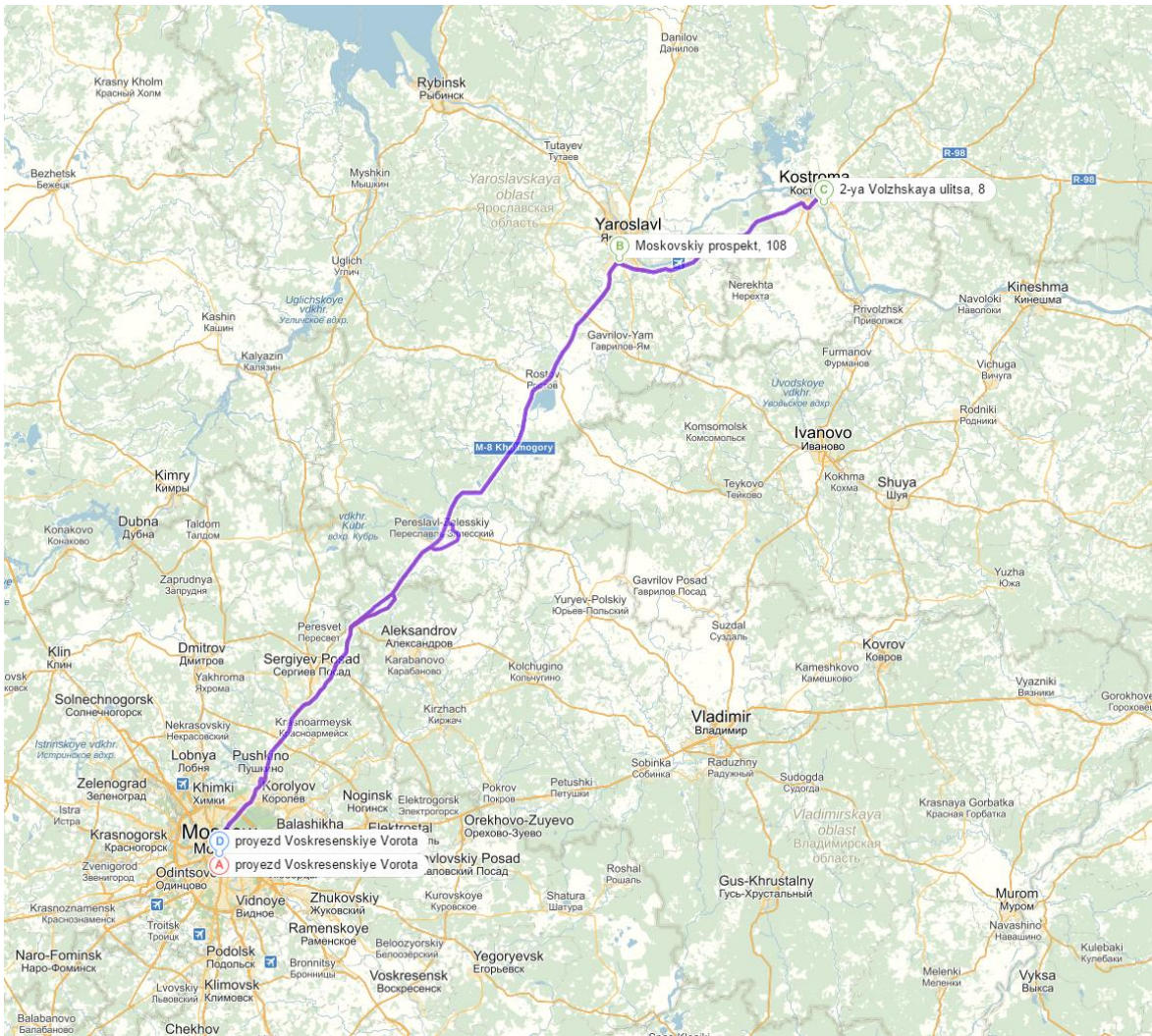
10.15.1.1 MPVRPmTW route for Scenario 4 first cluster



10.15.2 MPVRPmTW results for Scenario 4 second cluster

	Arrival Time	Departure Time	Visit Day	Waiting time
MoscowDepot	17.61	5.67		0
Yaroslavl_ASHANn	9	9.2	Wed	0
Yaroslavl_7Continent	9.24	9.44	Wed	0
Yaroslavl_LENTA	9.76	9.96	Wed	0
Yaroslavl_ASHANp	10.03	10.23	Wed	0
Yaroslavl_LENTA1	10.31	10.51	Wed	0
Yaroslavl_Giperglobus	10.71	10.91	Wed	0
Yaroslavl_ATAK	11.38	11.58	Wed	0
Yaroslavl_Magnit	11.65	11.85	Wed	0
Kostroma_7Continent	12.75	12.95	Wed	0
Kostroma_ASHAN	13.07	13.27	Wed	0
Computational time (sec):				2.26562
Total Travel Cost (NOK):				746.5
Rout Duration (Hours):				9.94

10.15.2.1 MPVRPmTW route for Scenario 4 second cluster

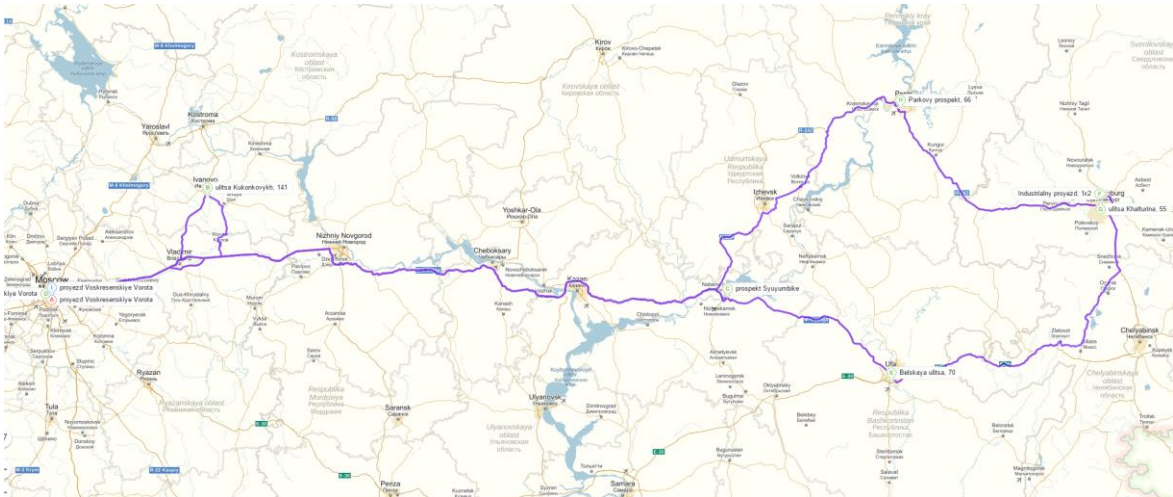


10.15.3 MPVRPmTW results for Scenario 4 third cluster

	Arrival Time	Departure Time	Visit Day	Waiting time
MoscowDepot	10.39	10.61	Mon-Wed	0
Ivanovo_Magnit	14.87	15.07	Mon	0
Ivanovo_Okey	15.16	15.36	Mon	0
Ivanovo_ASHAN	15.52	15.72	Mon	0

Ivanovo_7Continent	15.8	16	Mon	0
NaberezhnyeChelny_LENTA	3.8	7.2	Tue	3.2
Ufa_Magnit	10.98	11.18	Tue	0
Ufa_ASHAN	11.42	11.62	Tue	0
Ufa_OKEYmj	11.97	12.17	Tue	0
Ufa_OKEYk	12.32	12.52	Tue	0
Ufa_OKEYe	12.58	19	Tue	6.22
Ufa_LENTA	19.17	19.37	Tue	0
Pyshma_Perekrestok	4.94	7.2	Tue	2.06
Yekaterinburg_ASHANh	9.95	10.15	Wed	0
Yekaterinburg_ASHANm	10.38	10.58	Wed	0
Perm_LENTA	15.3	15.5	Wed	0
Computational time (sec):				1664.7
Total Travel Cost (NOK):				1102
Rout Duration (Hours):				68.78

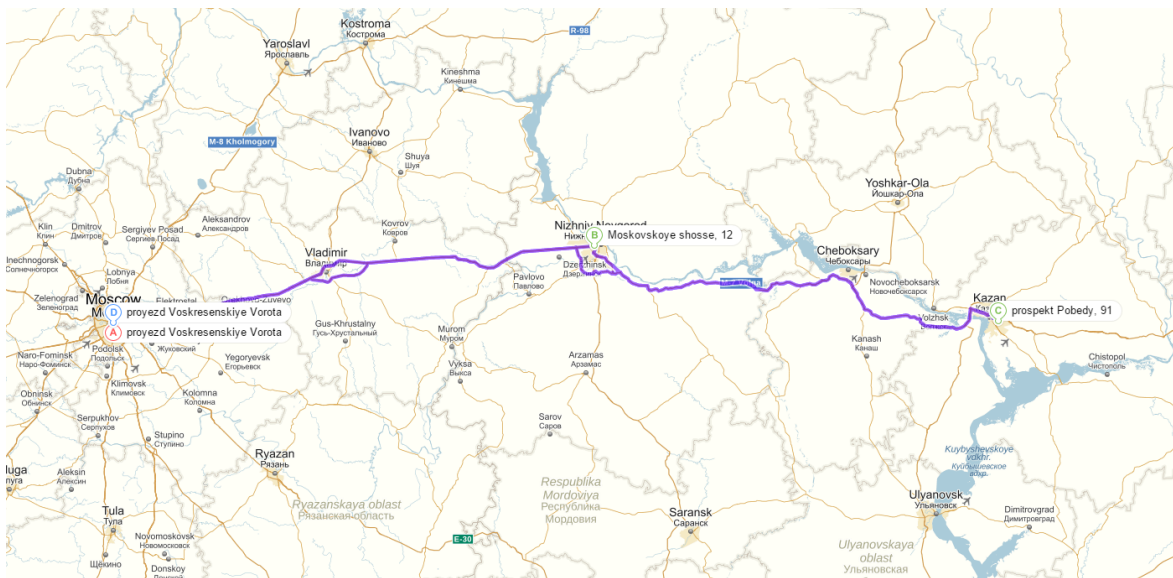
10.15.3.1 MPVRPmTW route for Scenario 4 third cluster



10.15.4 MPVRPmTW results for Scenario 4 forth cluster

	Arrival Time	Departure Time	Visit Day	Waiting time
MoscowDepot	3.55	2.17	Wed-Thu	
NNovgorod_METROm	7.74	7.94	Wed	0
NNovgorod_LENTA	8	8.2	Wed	0
NNovgorod_ASHANb	8.4	8.6	Wed	0
NNovgorod_ASHANm	8.88	9.08	Wed	0
NNovgorod_METROn	9.27	9.47	Wed	0
NNovgorod_Magnit	9.67	9.87	Wed	0
NNovgorod_Okey	10.02	10.22	Wed	0
Kazan_ASHANp	15.68	15.88	Wed	0
Kazan_Zelgros	16.05	16.25	Wed	0
Kazan_ASHANy	16.52	16.72	Wed	0
Computational time (sec):				8.85938
Total Travel Cost (NOK):				1754.5
Rout Duration (Hours):				23.38

10.15.4.1 MPVRPmTW route for Scenario 4 forth cluster

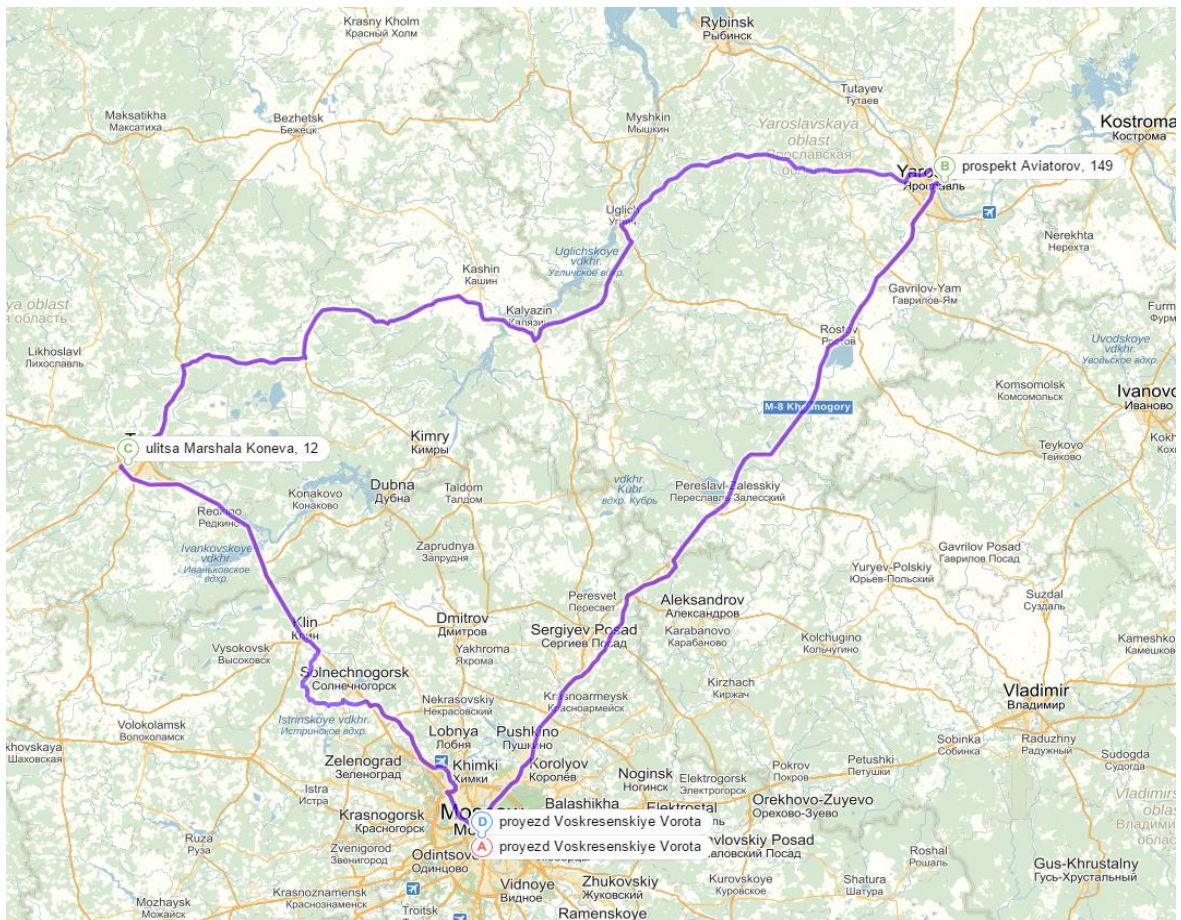


10.16 MPVRPmTW results for Scenario 5

10.16.1 MPVRPmTW results for Scenario 5 first cluster

	Arrival Time	Departure Time	Visit Day	Waiting time
MoscowDepot	11.11	5.01	Wed-Thu	0
Yaroslavl_7Continent	8.33	8.53	Wed	0
Yaroslavl_ATAK	8.72	8.92	Wed	0
Yaroslavl_Magnit	8.99	9.19	Wed	0
Yaroslavl_ASHANn	9.42	9.62	Wed	0
Yaroslavl_LENTA	9.96	10.16	Wed	0
Yaroslavl_Giperglobus	10.32	10.52	Wed	0
Yaroslavl_ASHANp	10.78	10.98	Wed	0
Yaroslavl_LENTA1	11.06	11.26	Wed	0
Tver_ATAKo	15.37	15.57	Wed	0
Tver_ATAKmk	15.8	16	Wed	0
Tver_Magnit	16.27	8.2	Thu	15.73
Tver_LENTA	8.51	8.2	Thu	0
Computational time (sec):				3086.94
Total Travel Cost (NOK):				1386.38
Rout Duration (Hours):				27.7

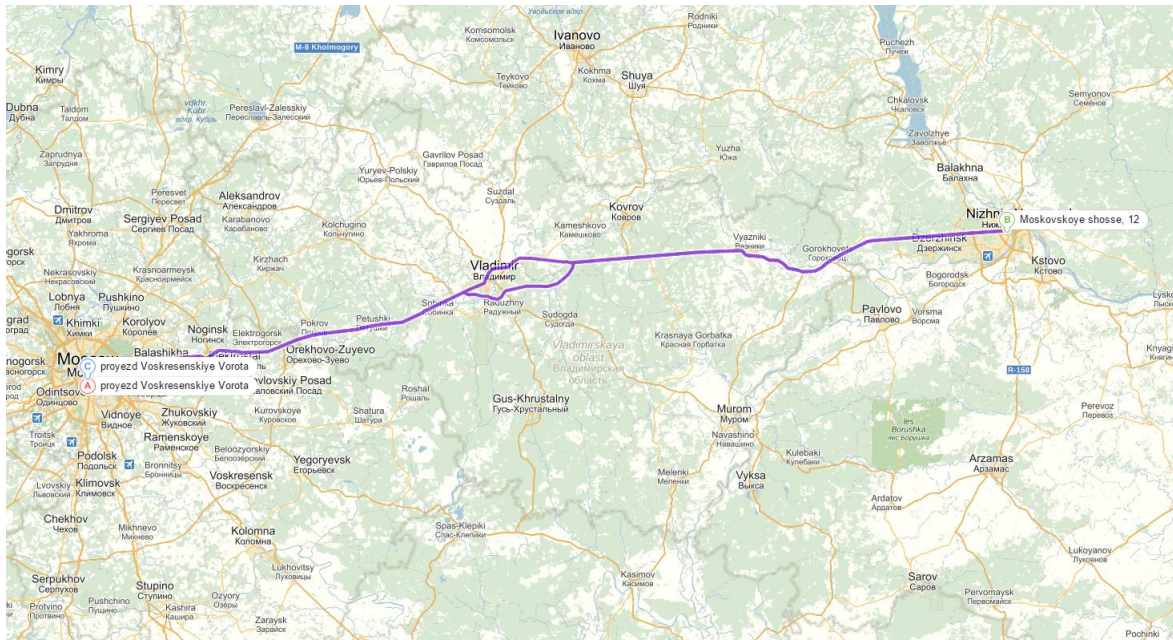
10.16.1.1 MPVRPmTW route for Scenario 5 first cluster



10.16.2 MPVRPmTW results for Scenario 5 second cluster

	Arrival Time	Departure Time	Visit Day	Waiting time
MoscowDepot	14.92	1.63	Wed	0
NNovgorod_Magnit	7.16	7.36	Wed	0
NNovgorod_METROn	7.55	7.75	Wed	0
NNovgorod_LENTA	8	8.2	Wed	0
NNovgorod_ASHANb	8.4	8.6	Wed	0
NNovgorod_METROm	8.85	9.05	Wed	0
Computational time (sec):				0.234375
Total Travel Cost (NOK):				907.75
Rout Duration (Hours):				12.09

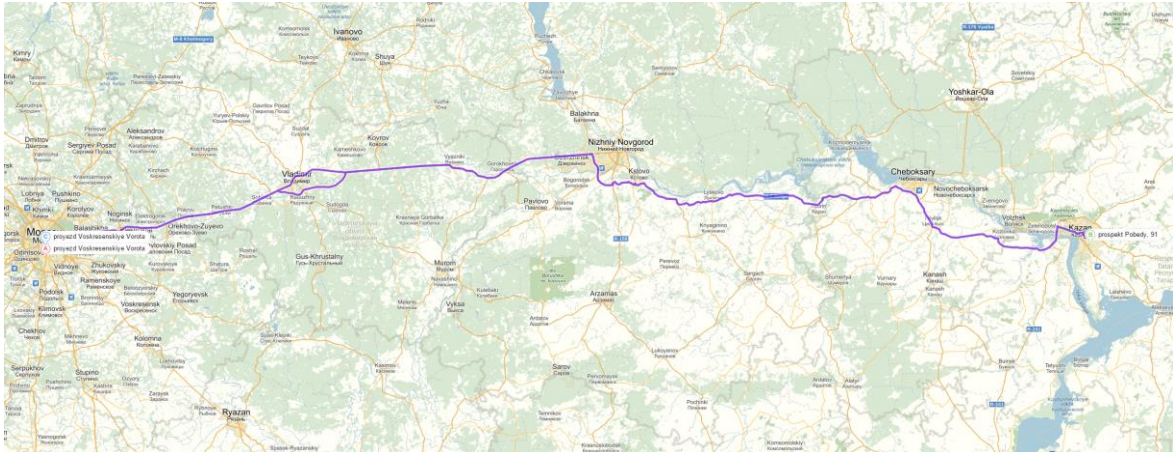
10.16.2.1 MPVRPmTW route for Scenario 5 second cluster



10.16.3 MPVRPmTW results for Scenario 5 third cluster

	Arrival Time	Departure Time	Visit Day	Waiting time
MoscowDepot	0.87	2.11	Mon-Tue	0
Kazan_ASHANp	13	13.2	Mon	0
Kazan_Zelgros	13.37	13.57	Mon	0
Kazan_ASHANy	13.84	14.04	Mon	0
Computational time (sec):				0.046875
Total Travel Cost (NOK):				1663
Rout Duration (Hours):				22.16

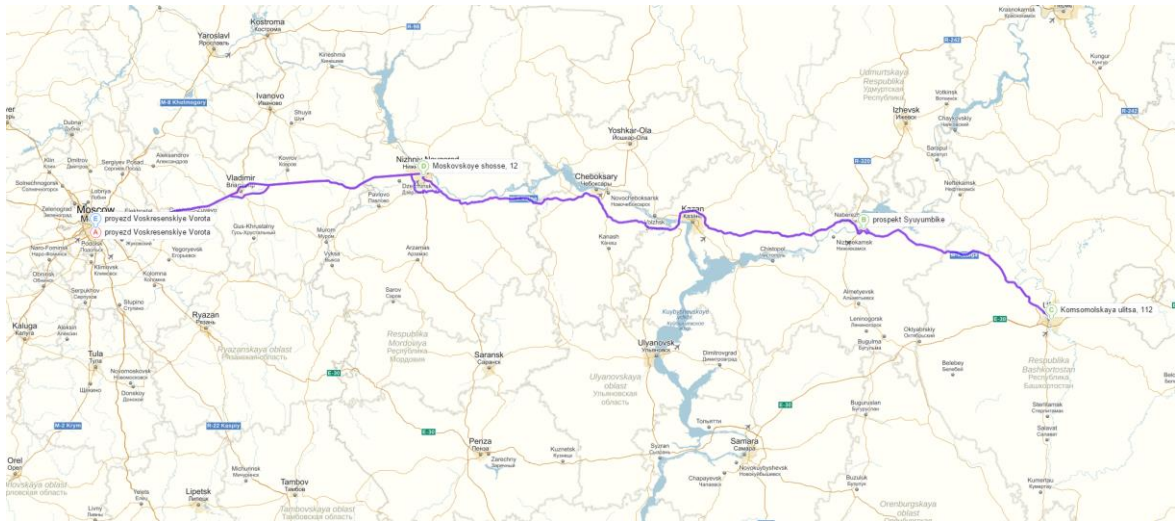
10.16.3.1 MPVRPmTW route for Scenario 5 third cluster



10.16.4 MPVRPmTW results for Scenario 5 fourth cluster

	Arrival Time	Departure Time	Visit Day	Waiting time
MoscowDepot	13.86	22.12	Tue-Thu	0
NaberezhnyeChelny_LENT A	11.82	12.02	Wed	0
Ufa_Magnit	15.8	16	Wed	0
Ufa_ASHAN	16.24	16.44	Wed	0.35
Ufa_LENTA	17	17.2	Wed	0
Ufa_OKEYmj	17.48	17.68	Wed	0
Ufa_OKEYe	17.8	18	Wed	0
Ufa_OKEYk	18.07	18.27	Wed	0
NNovgorod_Okey	6.21	8.2	Thu	1.79
Computational time (sec):				73.4375
Total Travel Cost (NOK):				2767.34
Rout Duration (Hours):				38.14

10.16.4.1 MPVRPmTW route for Scenario 5 fourth cluster



10.16.5 MPVRPmTW results for Scenario 5 fifth cluster

	Arrival Time	Departure Time	Visit Day	Waiting time
MoscowDepot	14.5	16.72	Mon-Fr	0
Yekaterinburg_ASHANm	15.8	16	Wed	0
Pyshma_Perekrestok	18.67	8.54	Thu	13.67
Yekaterinburg_ASHANh	11.29	11.49	Thu	0
Perm_LENTA	16.33	16.53	Thu	0
Kostroma_ASHAN	7	7.2	Fr	0
Kostroma_7Continent	7.33	7.53	Fr	0
Ivanovo_Okey	8.97	9.17	Fr	0
Ivanovo_Magnit	9.26	9.46	Fr	0
Ivanovo_7Continent	9.62	9.82	Fr	0
Ivanovo_ASHAN	9.9	10.1	Fr	0
Computational time (sec):				1772.45
Total Travel Cost (NOK):				4483.02
Rout Duration (Hours):				67.78

10.16.5.1 MPVRPmTW route for Scenario 5 fifth cluster

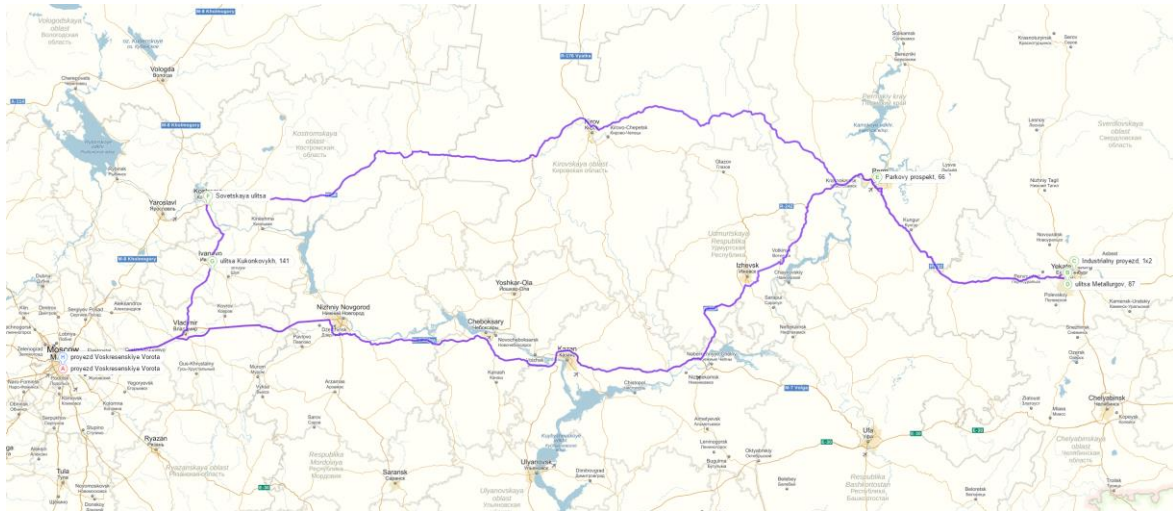


10.17 MPVRPmTW results for Scenario 6

10.17.1 MPVRPmTW results for Scenario 6 first cluster

	Arrival Time	Departure Time	Visit Day	Waiting time
MoscowDepot	12.01	5.63	Fr	0
Tver_LENTA	8	8.2	Fr	0
Tver_ATAKo	8.29	8.49	Fr	0
Tver_Magnit	8.78	8.98	Fr	0
Tver_ATAKmk	9.29	9.49	Fr	0
Computational time (sec):				0.0625
Total Travel Cost (NOK):				419.5
Rout Duration (Hours):				5.58

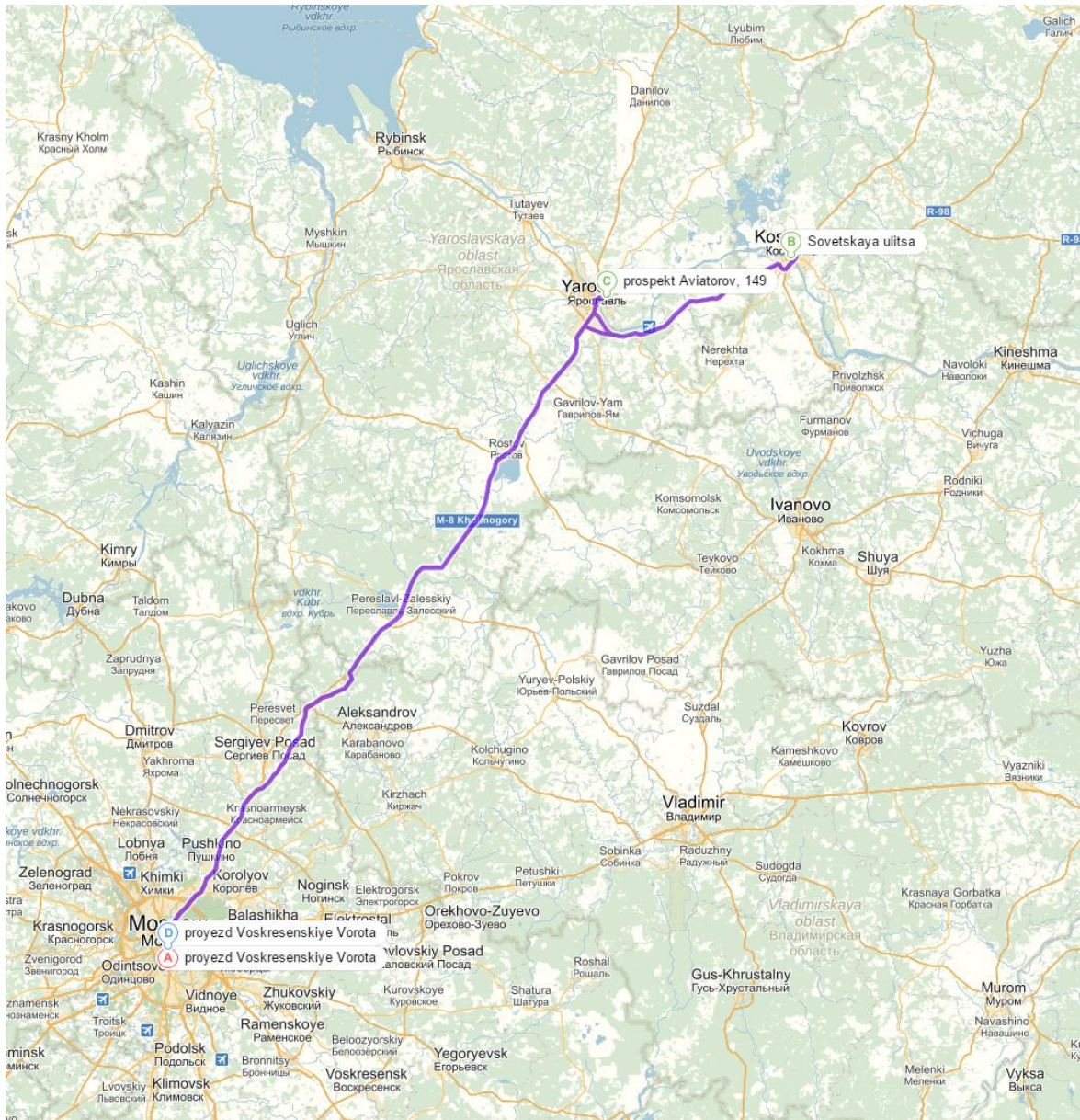
10.17.1.1 MPVRPmTW route for Scenario 6 first cluster



10.17.2 MPVRPmTW results for Scenario 6 second cluster

	Arrival Time	Departure Time	Visit Day	Waiting time
MoscowDepot	14.37	2.78	Wed	
Kostroma_7Continent	7	7.2	Wed	0
Yaroslavl_Magnit	8.1	8.3	Wed	0
Yaroslavl_ATAK	8.38	8.58	Wed	0
Yaroslavl_LENTA	8.92	9.12	Wed	0
Yaroslavl_Giperglobus	9.28	9.48	Wed	0
Yaroslavl_ASHANp	9.74	9.94	Wed	0
Yaroslavl_LENTA1	10.02	10.22	Wed	0
Yaroslavl_7Continent	10.49	10.69	Wed	0
Yaroslavl_ASHANn	10.73	10.93	Wed	0
Computational time (sec):				0.984375
Total Travel Cost (NOK):				735.25
Rout Duration (Hours):				9.79

10.17.2.1 MPVRPmTW route for Scenario 6 second cluster

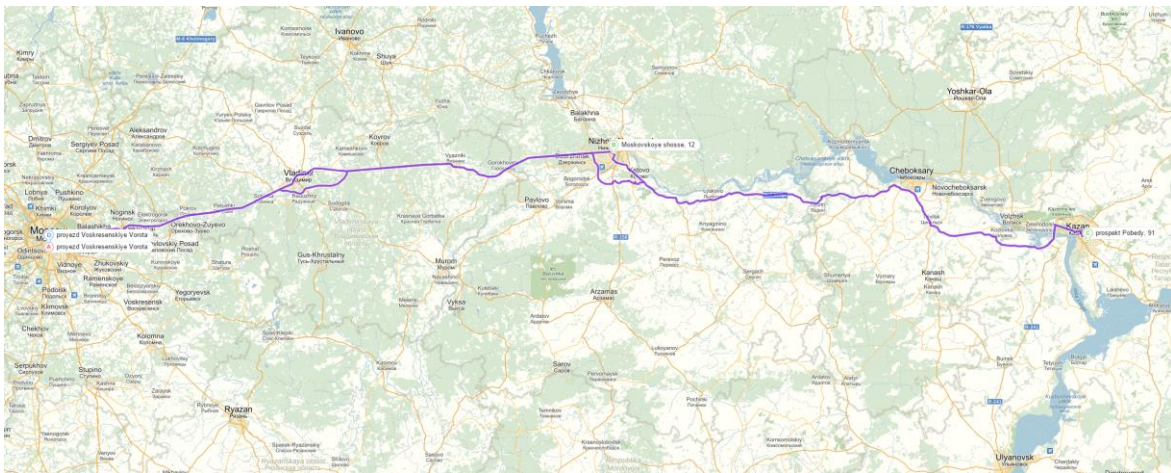


10.17.3 MPVRPmTW results for Scenario 6 third cluster

	Arrival Time	Departure Time	Visit Day	Waiting time
MoscowDepot	27.55	2.17	Wed	
NNovgorod_METROm	7.74	7.94	Wed	0
NNovgorod_LENTA	8	8.2	Wed	0
NNovgorod_ASHANb	8.4	8.6	Wed	0
NNovgorod_ASHANm	8.88	9.08	Wed	0

NNovgorod_METROn	9.27	9.47	Wed	0
NNovgorod_Magnit	9.67	9.87	Wed	0
NNovgorod_Okey	10.02	10.22	Wed	0
Kazan_ASHANp	15.68	15.88	Wed	0
Kazan_Zelgros	16.05	16.25	Wed	0
Kazan_ASHANy	16.52	16.72	Wed	0
Computational time (sec):				8.78125
Total Travel Cost (NOK):				1754.5
Rout Duration (Hours):				23.38

10.17.3.1 MPVRPmTW route for Scenario 6 third cluster

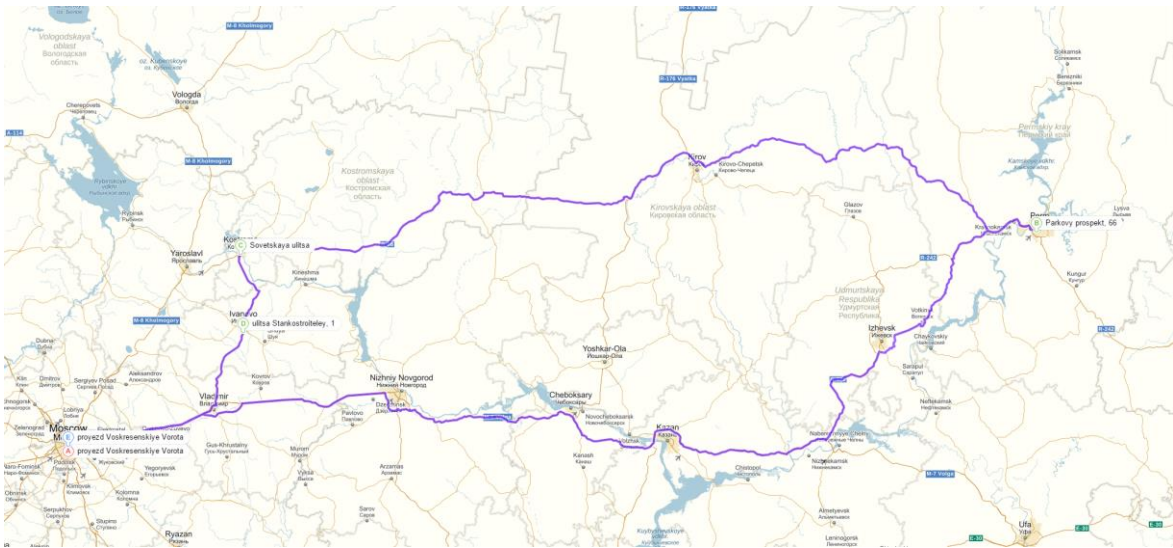


10.17.4 MPVRPmTW results for Scenario 6 fourth cluster

	Arrival Time	Departure Time	Visit Day	Waiting time
MoscowDepot	14.3	21.63	Wed-Fr	0
Perm_LENTA	16.33	16.53	Thu	0
Kostroma_ASHAN	7	7.2	Fr	0
Ivanovo_Okey	8.77	8.97	Fr	0
Ivanovo_7Continent	9.15	9.35	Fr	0
Ivanovo_ASHAN	9.43	9.63	Fr	0

Ivanovo_Magnit	9.8	10	Fr	0
Computational time (sec):	1.3125			
Total Travel Cost (NOK):	2961.25			
Rout Duration (Hours):	39.47			

10.17.4.1 MPVRPmTW route for Scenario 6 forth cluster



10.17.5 MPVRPmTW results for Scenario 6 fifth cluster

	Arrival Time	Departure Time	Visit Day	Waiting time
MoscowDepot	9.92	22.12	Wed-Sat	0
NaberezhnyeChelny_LENTA	11.82	12.02	Thu	0
Ufa_Magnit	15.8	16	Thu	0
Ufa_ASHAN	16.24	16.44	Thu	0
Ufa_LENTA	17	17.2	Thu	0
Ufa_OKEYk	17.41	17.61	Thu	0
Ufa_OKEYmj	18	18.2	Thu	0
Pyshma_Perekrestok	3.81	7.2	Fr	3.19

Yekaterinburg_ASHANh	9.95	10.15	Fr	0.35
Yekaterinburg_ASHANm	10.38	10.58	Fr	0
Computational time (sec):				521.281
Total Travel Cost (NOK):				4180.24
Rout Duration (Hours):				58.16

10.17.5.1 MPVRPmTW route for Scenario 6 fifth cluster

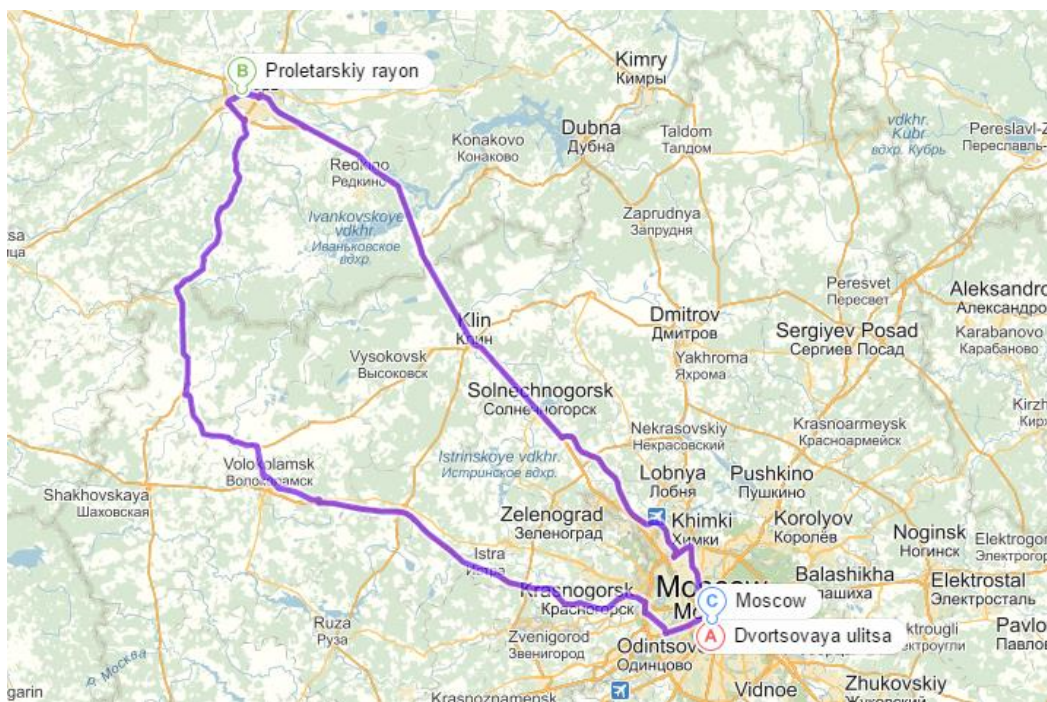


10.18 MPVRPmTW results for Scenario 7

10.18.1 MPVRPmTW results for Scenario 7 first cluster

	Arrival Time	Departure Time	Visit Day	Waiting time
MoscowDepot	12.01	5.63	Fr	0
Tver_LENTA	8	8.2	Fr	0
Tver_ATAKo	8.29	8.49	Fr	0
Tver_Magnit	8.78	8.98	Fr	0
Tver_ATAKmk	9.29	9.49	Fr	0
Computational time (sec):				0.0625
Total Travel Cost (NOK):				419.5
Rout Duration (Hours):				5.58

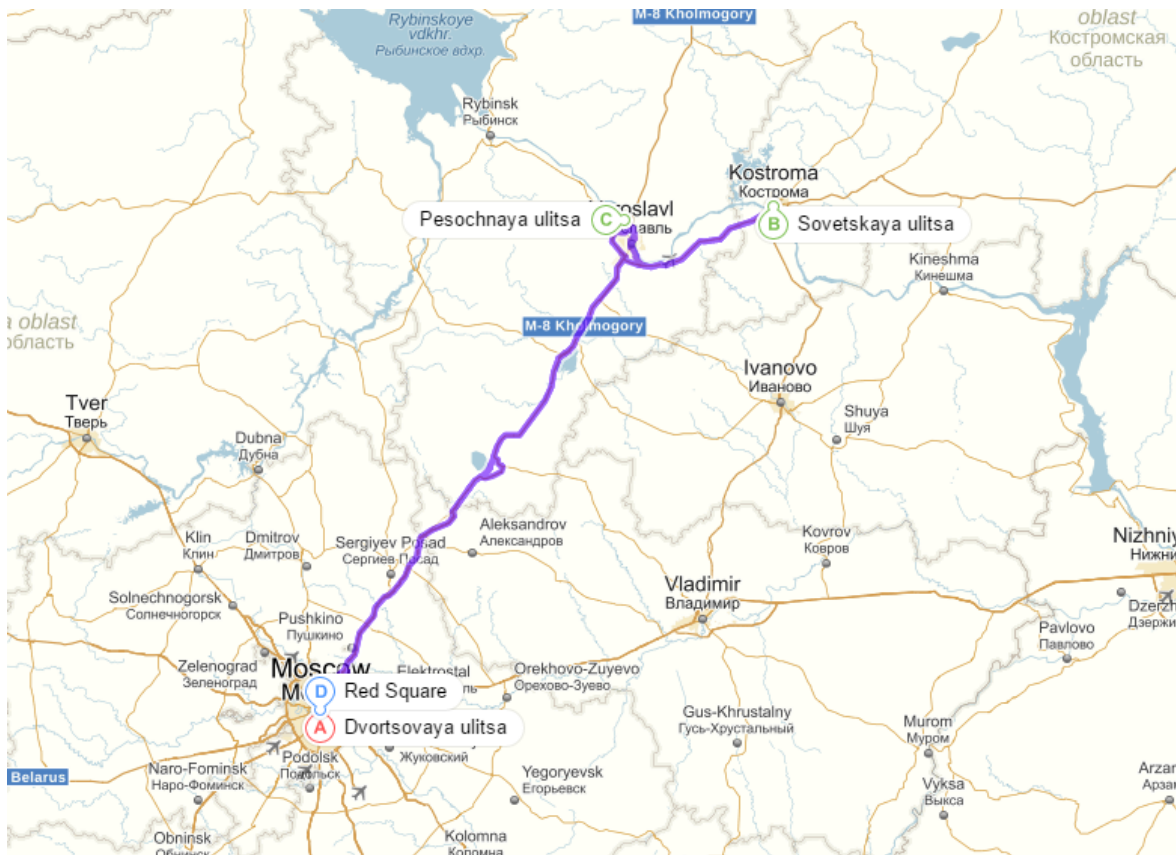
10.18.1.1 MPVRPmTW route for Scenario 7 first cluster



10.18.2 MPVRPmTW results for Scenario 7 second cluster

	Arrival Time	Departure Time	Visit Day	Waiting time
MoscowDepot	12.53	2.74	Mon	0
Ivanovo_Magnit	7	7.2	Mon	0
Ivanovo_Okey	7.29	7.49	Mon	0
Ivanovo_ASHAN	7.25	7.45	Mon	0
Ivanovo_7Continent	7.93	8.13	Mon	0
Computational time (sec):				0.10938
Total Travel Cost (NOK):				675.25
Rout Duration (Hours):				8.99

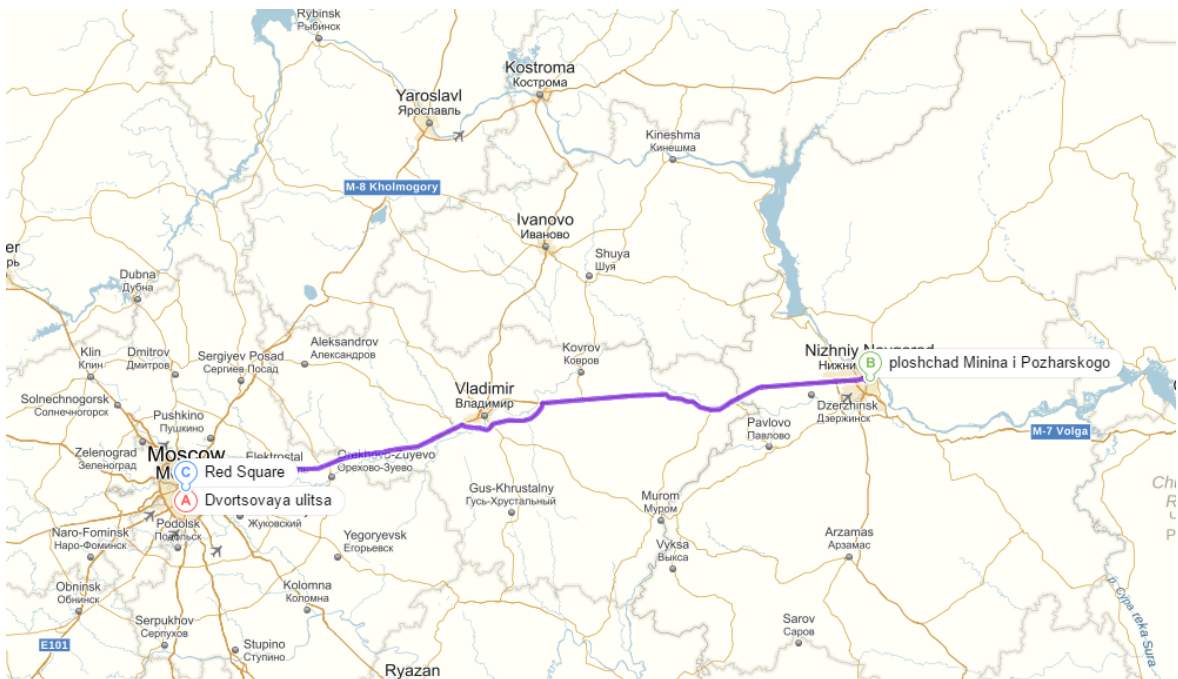
10.18.2.1 MPVRPmTW route for Scenario 7 second cluster



10.18.3 MPVRPmTW results for Scenario 7 third cluster

	Arrival Time	Departure Time	Visit Day	Waiting time
MoscowDepot	14.3	2.08	Thu	0
NNovgorod_Magnit	7.61	7.81	Thu	0
NNovgorod_LENTA	8	8.2	Thu	0
NNovgorod_ASHANb	8.4	8.6	Thu	0
NNovgorod_METROm	8.85	9.05	Thu	0
NNovgorod_ASHANm	9.12	9.32	Thu	0
Computational time (sec):				0.20313
Total Travel Cost (NOK):				889
Rout Duration (Hours):				11.84

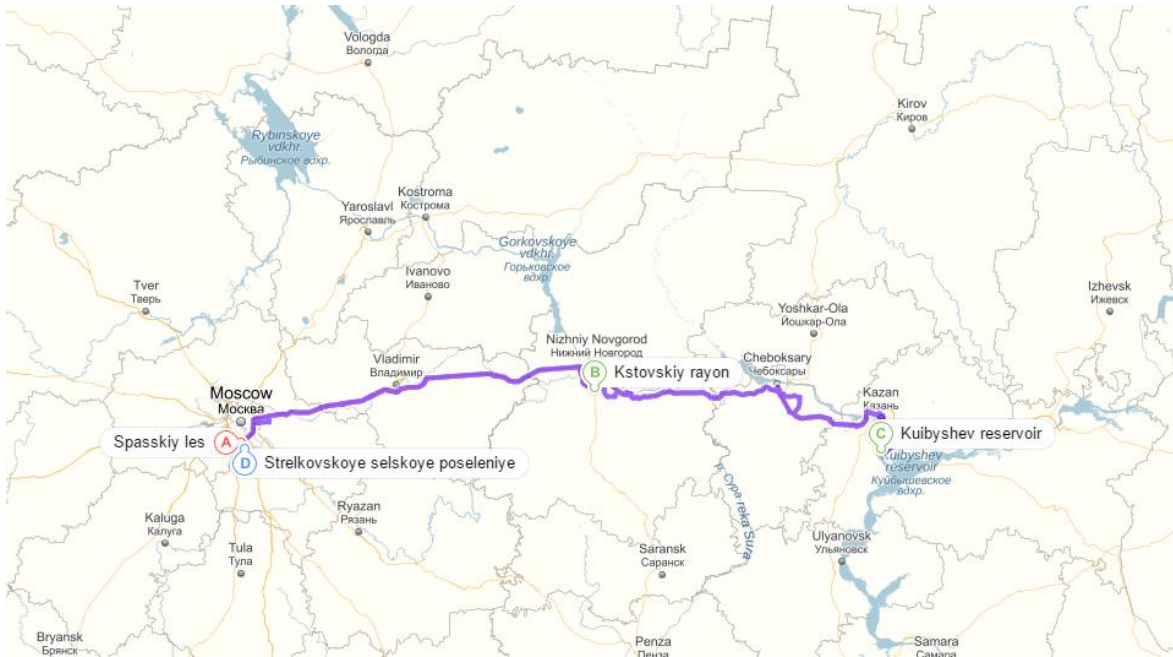
10.18.3.1 MPVRPmTW route for Scenario 7 third cluster



10.18.4 MPVRPmTW results for Scenario 7 forth cluster

	Arrival Time	Departure Time	Visit Day	Waiting time
MoscowDepot	13.86	2.01	Thu-Wed	0
Kazan_Zelgros	18.94	19.14	Thu	0
Kazan_ASHANp	19.47	19.67	Thu	0
Kazan_ASHANy	19.8	20	Thu	0
NNovgorod_METROn	1.31	7.68	Wed	6.17
NNovgorod_Okey	8	8.2	Wed	0
NaberezhnyeChelny_LENTA	15.71	15.92	Wed	0
Computational time (sec):				5.25
Total Travel Cost (NOK):				2328.27
Rout Duration (Hours):				34.65

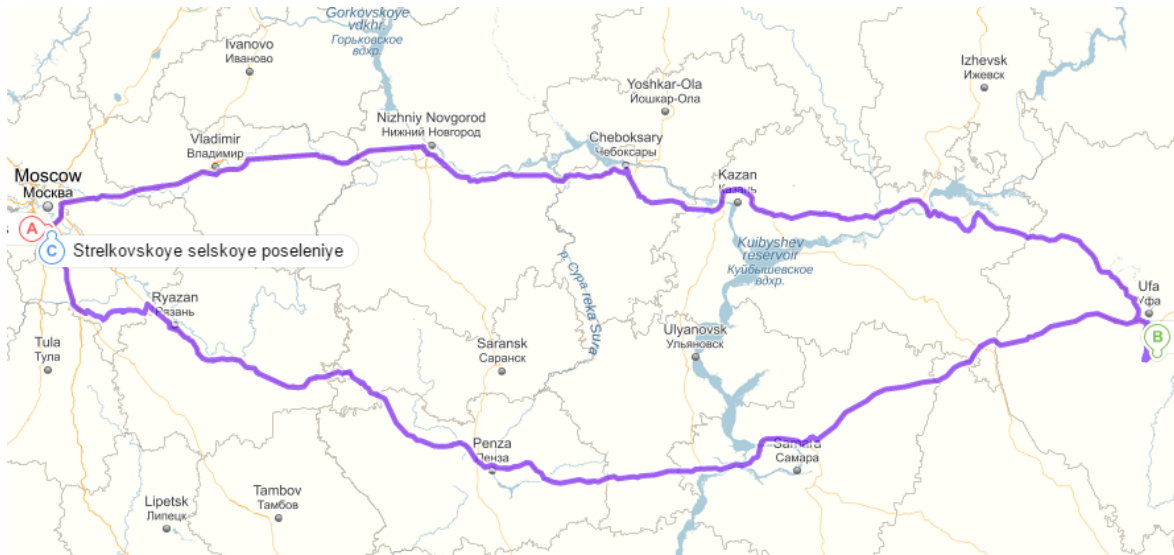
10.18.4.1 MPVRPmTW route for Scenario 7 forth cluster



10.18.5 MPVRPmTW results for Scenario 7 fifth cluster

	Arrival Time	Departure Time	Visit Day	Waiting time
MoscowDepot	11.74	22.53	Tue-Thu	0
Ufa_Magnit	15.8	16	Wed	0
Ufa_ASHAN	16.24	16.79	Wed	0.35
Ufa_LENTA	17	17.2	Wed	0
Ufa_OKEYmj	17.48	17.68	Wed	0
Ufa_OKEYe	17.8	18	Wed	0
Ufa_OKEYk	18.07	18.27	Wed	0
Computational time (sec):				1.29688
Total Travel Cost (NOK):				2686.35
Rout Duration (Hours):				36.01

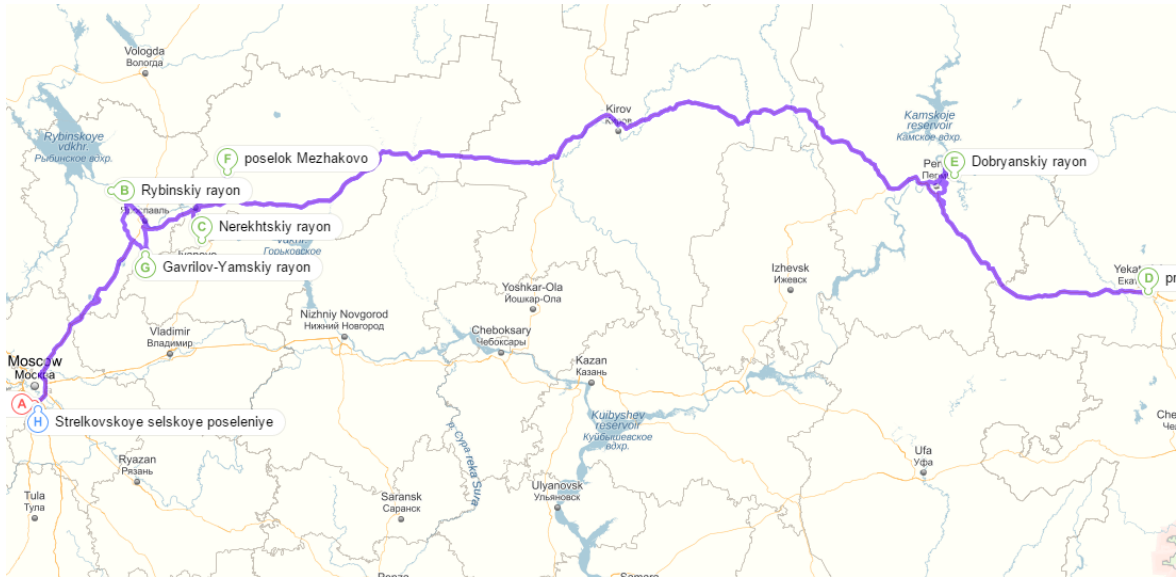
10.18.5.1 MPVRPmTW route for Scenario 7 fifth cluster



10.18.6 MPVRPmTW results for Scenario 7 sixth cluster

	Arrival Time	Departure Time	Visit Day	Waiting time
MoscowDepot	15.71	7.39	Mon-Thu	0
Yaroslavl_ASHANn	10.72	10.92	Mon	0
Kostroma_ASHAN	12	12.2	Mon	0
Yekaterinburg_ASHANm	7	7.2	Tue	0
Pyshma_Perekrestok	9.87	10.07	Tue	0
Yekaterinburg_ASHANh	12.82	13.02	Tue	0
Perm_LENTA	17.86	18.06	Tue	0
Kostroma_7Continent	8.59	8.79	Wed	0
Yaroslavl_Magnit	9.69	9.89	Wed	0
Yaroslavl_ATAK	9.97	10.17	Wed	0
Yaroslavl_ASHANp	10.43	10.63	Wed	0
Yaroslavl_LENTA1	10.71	10.91	Wed	0
Yaroslavl_LENTA	11.11	11.31	Wed	0
Yaroslavl_Giperglobus	11.47	11.67	Wed	0
Yaroslavl_7Continent	12.08	12.28	Wed	0
Computational time (sec):				1493.78
Total Trevel Cost (NOK):	4015			
Rout Duration (Hours):	53.52			

10.18.6.1 MPVRPmTW route for Scenario 7 sixth cluster

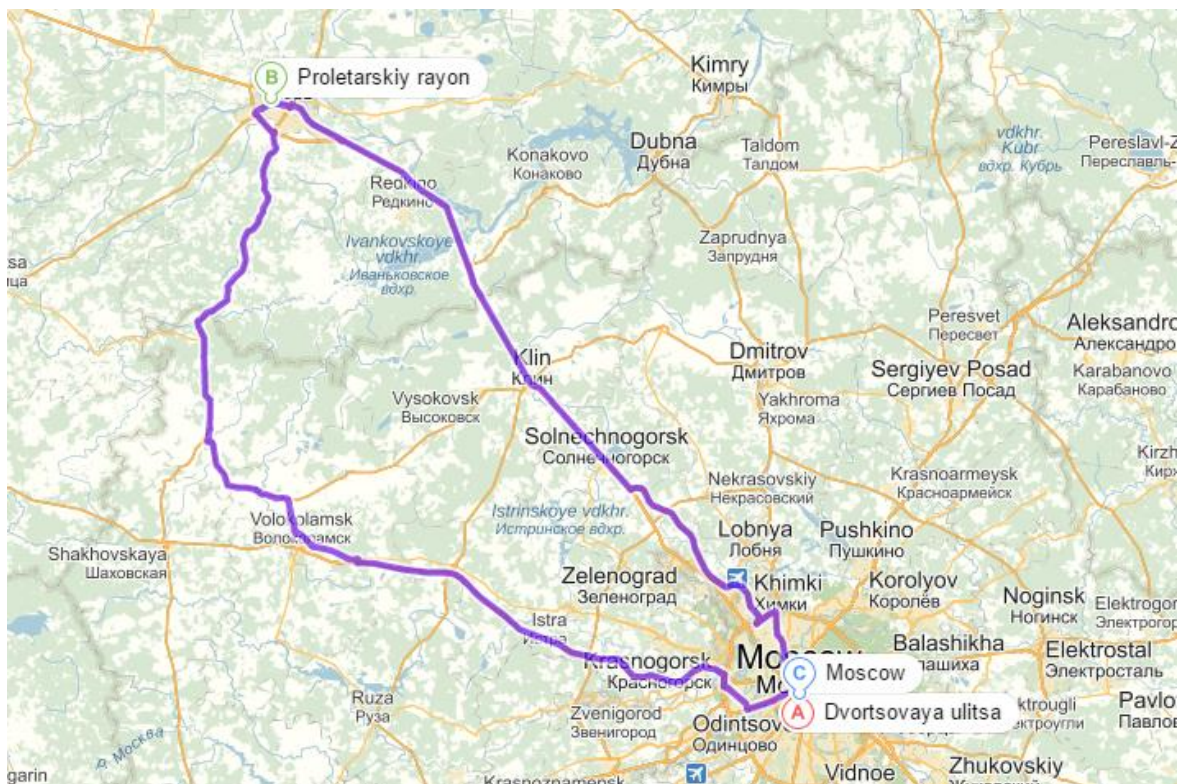


10.19 MPVRPmTW results for Scenario 8

10.19.1 MPVRPmTW results for Scenario 7 first cluster

	Arrival Time	Departure Time	Visit Day	Waiting time
MoscowDepot	12.1	5.63	Thu	0
Tver_LENTA	8	8.2	Thu	0
Tver_ATAKo	8.29	8.49	Thu	0
Tver_Magnit	8.78	8.98	Thu	0
Tver_ATAKmk	9.29	9.49	Thu	0
Computational time (sec):				0.04688
Total Travel Cost (NOK):				419.5
Rout Duration (Hours):				5.58

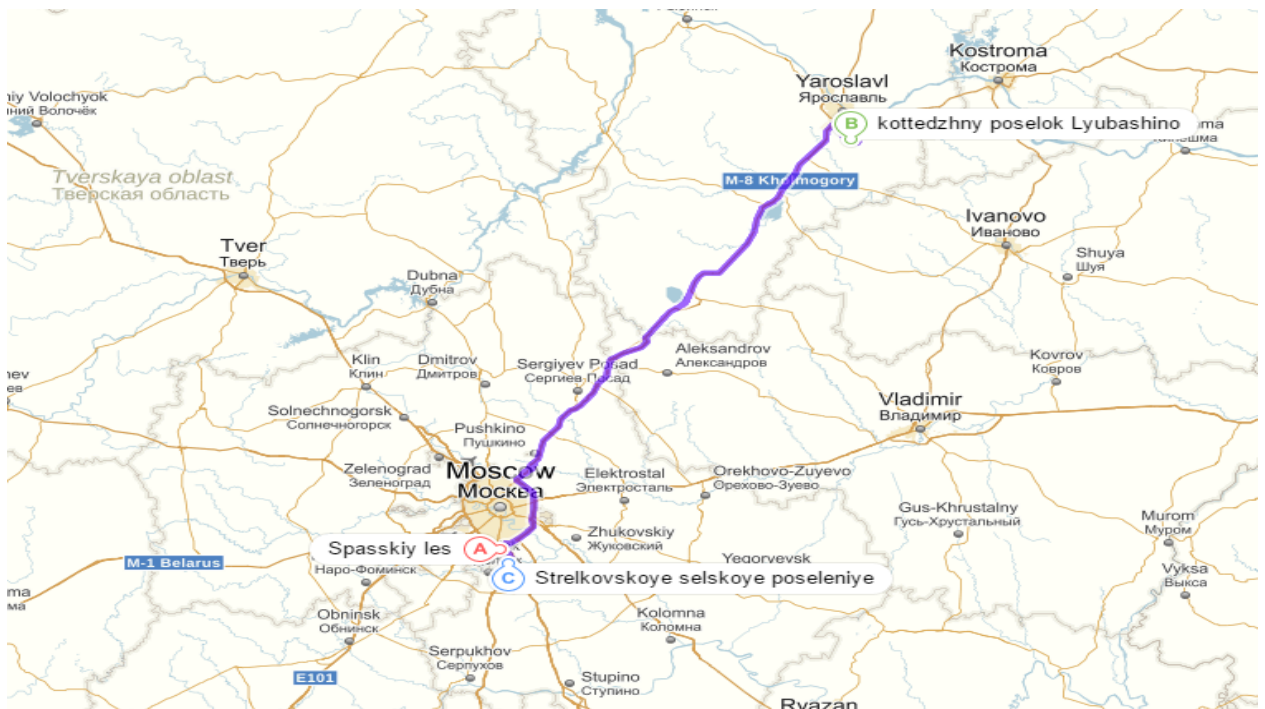
10.19.1.1 MPVRPmTW route for Scenario 7 first cluster



10.19.2 MPVRPmTW results for Scenario 7 second cluster

	Arrival Time	Departure Time	Visit Day	Waiting time
MoscowDepot	13.63	3.86	Tue	
Yaroslavl_Magnit	7.36	7.56	Tue	0
Yaroslavl_ATAK	7.64	7.84	Tue	0
Yaroslavl_LENTA	8.18	8.38	Tue	0
Yaroslavl_Giperglobus	8.54	8.74	Tue	0
Yaroslavl_ASHANp	9	9.2	Tue	0
Yaroslavl_LENTA1	9.28	9.48	Tue	0
Yaroslavl_7Continent	9.75	9.95	Tue	0
Yaroslavl_ASHANn	9.99	10.19	Tue	0
Computational time (sec):				1.29688
Total Travel Cost (NOK):				613.75
Rout Duration (Hours):				8.17

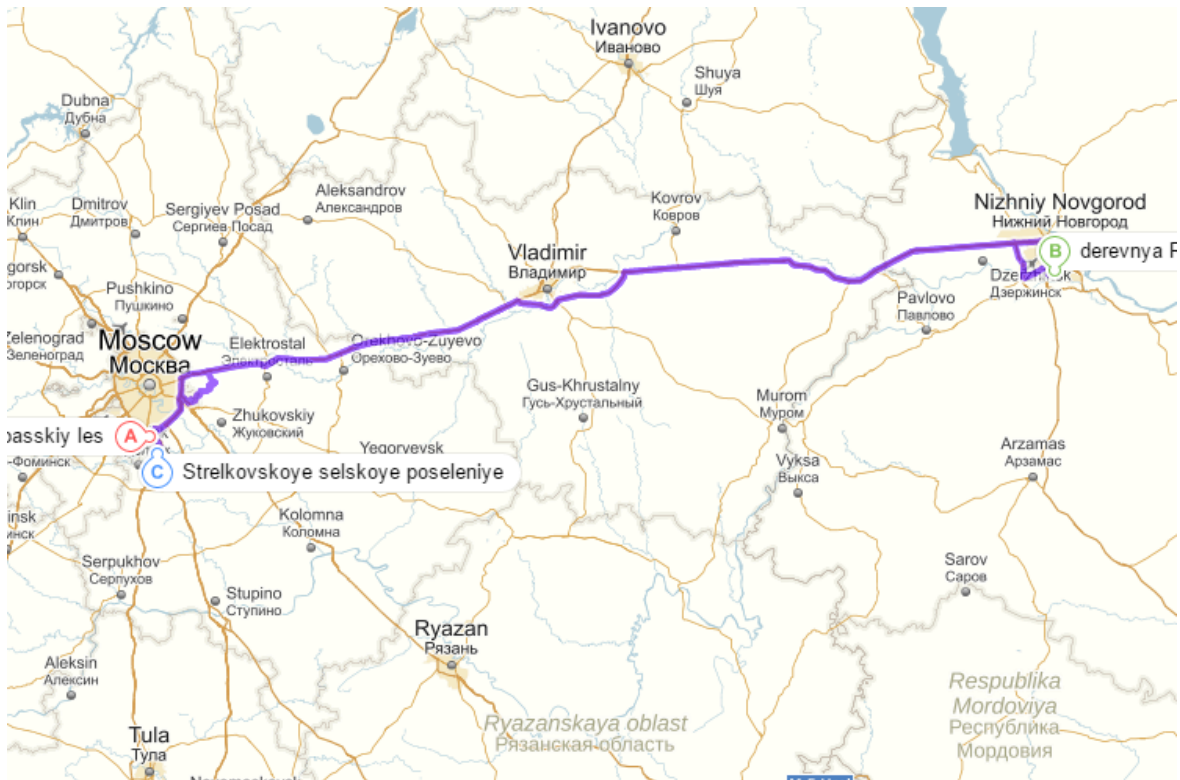
10.19.2.1 MPVRPmTW route for Scenario 7 second cluster



10.19.3 MPVRPmTW results for Scenario 7 third cluster

	Arrival Time	Departure Time	Visit Day	Waiting time
MoscowDepot	13.63	1.63	Tue	
NNovgorod_Magnit	7.16	7.36	Tue	0
NNovgorod_METROn	7.55	7.75	Tue	0
NNovgorod_LENTA	8	8.2	Tue	0
NNovgorod_ASHANb	8.4	8.6	Tue	0
NNovgorod_METROm	8.85	9.05	Tue	0
NNovgorod_ASHANm	9.12	9.32	Tue	0
Computational time (sec):				0.28125
Total Travel Cost (NOK):				907.75
Rout Duration (Hours):				12.09

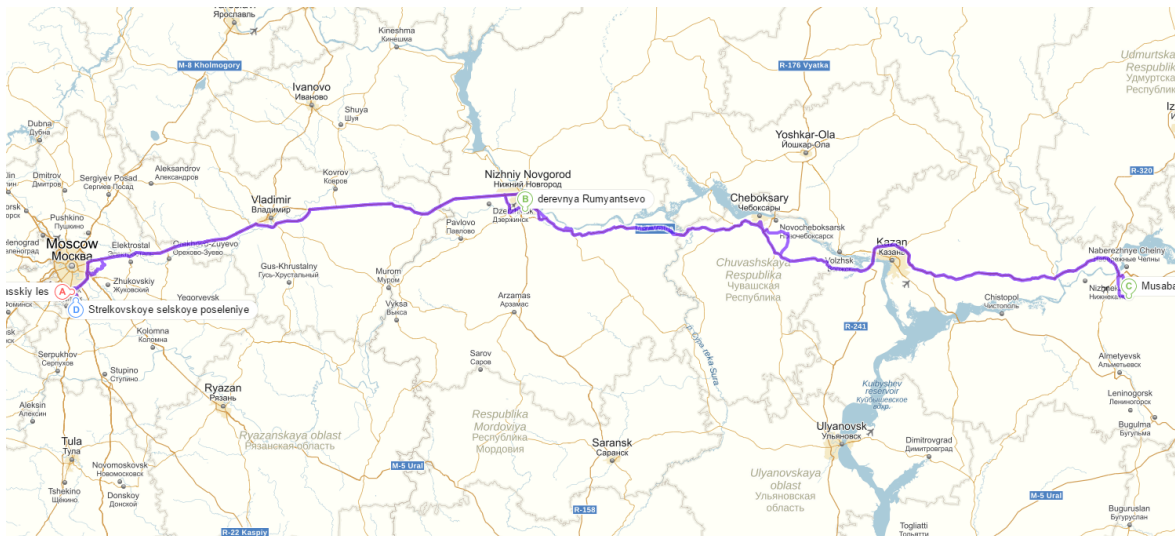
10.19.3.1 MPVRPmTW route for Scenario 7 third cluster



10.19.4 MPVRPmTW results for Scenario 7 forth cluster

	Arrival Time	Departure Time	Visit Day	Waiting time
MoscowDepot	13.86	2.1	Mon-Tue	
NaberezhnyeChelny_LENTA	15.8	16	Mon	0
NNovgorod_Okey	0.29	8.2	Tue	7.71
Computational time (sec):				0.140625
Total Trevel Cost (NOK):				2313.76
Rout Duration (Hours):				35.36

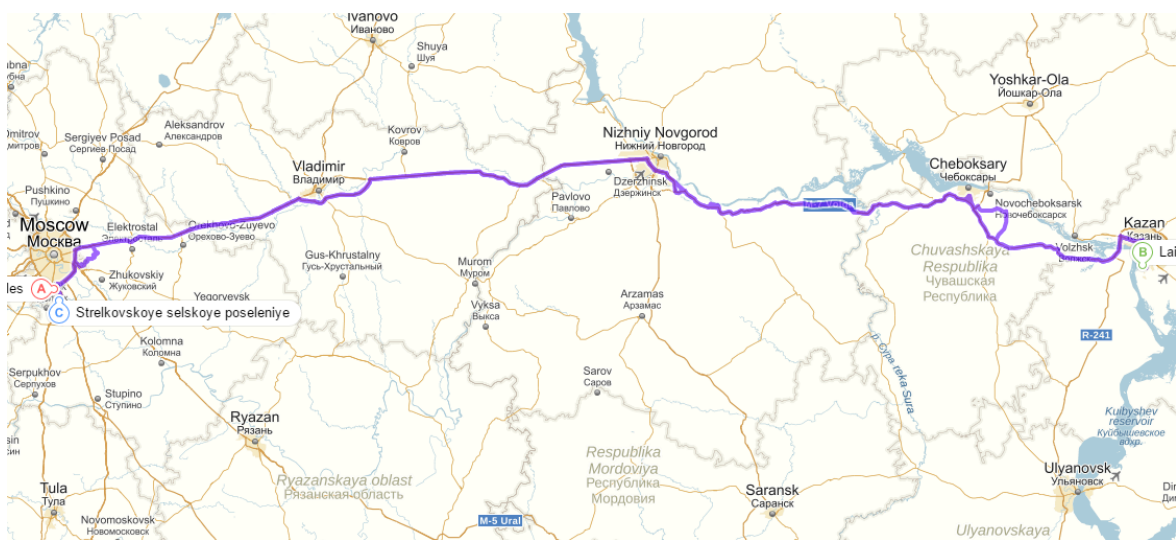
10.19.4.1 MPVRPmTW route for Scenario 7 forth cluster



10.19.5 MPVRPmTW results for Scenario 7 fifth cluster

	Arrival Time	Departure Time	Visit Day	Waiting time
MoscowDepot	0.5	2.12	Mon-Tue	
Kazan_Zelgros	13	13.2	Mon	0
Kazan_ASHANy	13.47	13.67	Mon	0
Computational time (sec):				0.015625
Total Trevel Cost (NOK):				1649.5
Rout Duration (Hours):				21.98

10.19.5.1 MPVRPmTW route for Scenario 7 fifth cluster



10.19.6 MPVRPmTW results for Scenario 7 sixth cluster

	Arrival Time	Departure Time	Visit Day	Waiting time
MoscowDepot	18.09	17.43	Tue-Fr	
Yekaterinburg_ASHANh	9.95	10.15	Wed	0
Yekaterinburg_ASHANm	10.38	10.58	Wed	
Ufa_ASHAN	11.14	11.34	Wed	0

Ufa_OKEYk	11.62	11.82	Wed	0
Ufa_OKEYmj	12.01	12.21	Wed	0
Perm_LENTA	18.8	19	Wed	0
Pyshma_Perekrestok	2.23	7.2	Thu	4.77
Ivanovo_7Continent	10.5	10.7	Fr	0
Ivanovo_ASHAN	10.78	10.98	Fr	0
Ivanovo_Magnit	11.15	11.35	Fr	0
Ivanovo_Okey	11.44	11.64	Fr	0
Kostroma_ASHAN	13.21	13.41	Fr	0
Kostroma_7Continent	13.54	13.74	Fr	0
Computational time (sec):				2694.45
Total Trevel Cost (NOK):				5000.62
Rout Duration (Hours):				69.46

10.19.6.1 MPVRPmTW route for Scenario 7 sixth cluster

