



Master's degree thesis

LOG950 Logistics

Network design for road sticks supply

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Preface

Great thanks to my family that supported me all the time and made my study in Molde possible!

I would like to thank Arild Hoff, Irina Gribkovskaya, friends, Sergei Markov, Bach Terje, Jæger Bjørn and The Company.

Summary

Business processes of the case company were observed, own approach developed for planning a network of road stick supply with the help of theory, interviews and data collection.

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1.0 Introduction

1.1 Background for the thesis

Every year millions of road markers, also known as snow poles, are placed around the world along the roads during the winter season and are then removed, as otherwise cutting the grass in a road-related area would be problematic. Snow poles are serving a function of a guide marker, solving the safety issue, in the daytime or especially at night, or in severe weather conditions, i.e. dust, dawn, fog, inclement weather when visibility is considerably reduced (Figure 1). They also help snow plow operators to figure out locations of specific objects such as guard rails and to facilitate the cleaning process of storm drains.



Figure 1. Snow poles at night

As a result of increased visibility, the probability of accidents is lower, as well as the value of the damaged immovable objects, such as curbs, guard rails, etc.

More specifically, approximately 10 million road sticks are used along the Norwegian roads every year, around 30% of which, despite the fact that road sticks are quite visible, disappear or are broken. One stick costs about 20 Kr and the total loss is 60 million Kr.

Nowadays they are mainly imported from China and none of them can be recycled here in Norway. In that manner we can surmise that there are additional costs of sending them back.

An existing system of road markers installation is quite old-fashioned, as it had not been renovated for about 30 years and now it is clearly ready for reconsideration. Here are a few more reasons:

- All of the snow poles are installed manually, and a truck has to stop to place/remove a stick. While they stop, they can create an obstacle in a traffic flow and that can lead to increased chance of an accident (obviously, moving vehicle is better than the one that stops all the time);
- 30% of sticks are lost every year;
- As the installation technology is old, sticks are not firmly fixed in the ground. The deviation from the initial position (Figure 2) is quite large and they can be easily pulled out with bare hands. This lead us to a thought that not being properly mounted is one of the main reasons they get lost;



Figure 2. Road sticks position deviation

- The system is fragmented, as there are many contractors. In total, 109 contractors exist in Norway, excluding municipality contractors. Each entrepreneur is handling all his/her own operations. We should take into consideration the fact that development towards larger administrative regions is in the different road ownership;
- There exist maintenance issues for operations, such as cleaning of used sticks.

One of the companies that devotes many efforts to solve the current renovation problem is the Company, a business incubator in the incubator program of the Incubator, located in Tingvoll municipality at Beiteråsen. It has made a prototype of truck with special

mounting kit (“Stikkesetteren” in Norwegian)¹. Refer to Figure 3 (attached below) to know its appearance.



Figure 3. Company’s truck with a mounting tool

“With this truck, the mounting in goes at about 10 km/h without stopping. Soon it will be fully automatic as well” says the founder of the Company.

1.2 Research tasks

The research objective of this thesis is to develop a methodology for planning a network of road stick supply. This network should represent the number and the locations of production terminals from where the road stick will be transported to cover the needs of all counties in Norway.

The following research tasks are defined:

- 1) Study the business processes of the case company;
- 2) Determining the focus of the research;
- 3) Review existing literature;

¹ There is also a video that shows how this truck mounts sticks - <https://youtu.be/VA0hNqEqNV4>.

- 4) Own approach developing that will solve the designed task;
- 5) Conducting experiments;
- 6) Results' comparison and discussions.

2.0 Literature review

The background for the study described in this master thesis is based on different researches published in several scientific articles and papers. The fundamental problems faced in this work are multi-period, multi-echelon, multi-modal and intermodal network planning. Those subjects were investigated in the sources, which are mentioned below.

The system of methods used in this research is based on quantitative modelling. The analysis of those methods can be found in the article "Operations management research methodologies using quantitative modelling" (Bertrand et al., 2002). Except for operation management, this paper demonstrates modelling approaches from diverse scientific fields.

Multi-modal and intermodal network planning is one of the main issues with which it is needed to deal. Those topics were explored in a number of papers, including "Intermodal routing of Canada-Mexico shipments under NAFTA" (Bookbinder et al., 1998), "A brief overview of Intermodal Transportation" (Bektas et al.), and Chapter 8 "Intermodal transportation" in Handbook in Operations Research and Management Science (Crainic et al., 2007). In the first two articles, the authors provided a description of the problem of intermodal transportation from different positions. As intermodal transportation includes in itself several steps of portage the commodity, those published papers showed the process issues on the sides of supplier and carrier. The scientists mentioned nearly all the possible ways of carriage goods. Those means are vehicle, maritime, and railway transport. In the third paper, authors specify the concepts of intermodal and multimodal transportation, their interactions, congeniality, and distinctions in relation to each other.

The similar ideas were describe in the paper "Opportunities for Operations Research in Intermodal Freight Transport Research: A Review" (Macharis et al., 2004). The difference is this research takes into consideration real-life challenges with which transportation operators need to deal every day, but not particularly abstract academic aspects.

As network planning is a continuous process, which considers a long time horizon where every operation depends on the outcome of the previously made decisions, it is crucial to take into account iterative procedures, what was done in the paper "Planning models for freight transportation" (Crainic et al., 1997). The authors described the network planning techniques paying attention to intermodal freight portage with the continuous time horizon.

Another issue to deal with is a heterogeneous fleet of transport. Several types of transport perform freight portage, and it is vital to take into account how those types influence on the carriage. For instance, the article "Network diversity and maritime flows" (Ducruet, 2013) explores the impact of maritime transport and examine its' features.

To prevent the collapse of the transportation network, it is essential to anticipate delays and be able to deal with them. The effect of breakdowns and repairing means, as well as modelling an intermodal transport system were described in the article "Analyzing the impact a mixof disruptions in intermodal transport networks: A micro simulation-based model" (Burgholzer et al., 2013). It recreates the network system chain elements actions in the simulation-based model.

The subject of multi-commodity was already mentioned, but there are several researches that are going deeper into this topic. The articles "Inventory constrained maritime routing, and scheduling for multi-commodity liquid bulk" (Al-Khayyal et al., 2007) and "Multicommodity Network Design Problem in Rail Freight Transportation Planning" (Yaghini et al., 2012) both provide algorithms to deal with multi-commodity transportation. In the first paper, portage is carried out using a heterogeneous fleet of boats, and the model is utilizing pick-ups and deliveries. In the second paper, train performs transportation and authors provide the model to design a rail freight transportation network considering several stages of decision making.

The article "Two-echelon, multi-commodity supply chain network design with mode selection, lead-times and inventory costs" (Sadjady H. et al., 2012) recount the multi-echelon and multi-commodity network planning problem where it is required to allocate warehouses, determine its' capacity, define the demand of customers and assign them to a certain warehouse as well as choose the type of transportation. Multi-echelon network design is also mentioned in the paper "A computational study for common network design in multi-commodity supply chains" (Ting Wu et al., 2014). Allocation problem is described there to minimize the cost during transportation, location, and inventory.

The topics of multi-commodity, multi-period, multi-echelon, multi-modal and intermodal network planning were examined during the revision of the literature. The remarkable fact is that the most significant part of the articles and papers studies either one of those

subjects or a combination of a few of them. The exclusivity of this master thesis is that the research includes all of the listed topics.

3.0 Case description

3.1 Description

As it was mentioned in the Introduction, there are about 10 million snow poles in Norway, and annually around 3,3 million are lost that is 9 tons of plastic.

Snow poles are to be installed in all 18 counties throughout Norway every year until 1 September. That is not an easy task, as a lot of processes are involved. They can be seen in Figure 4:

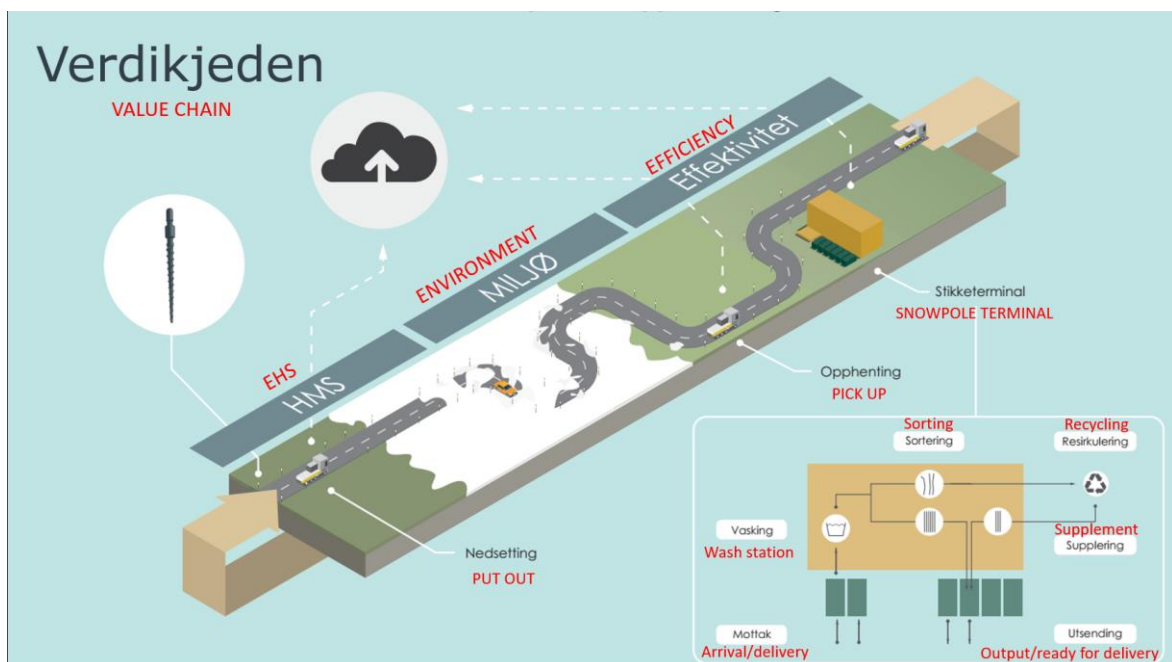


Figure 4. Lifecyle

It starts with:

- 1) Picking up snow poles after season ends up and transportation to the terminals
Picking up.

Picking up usually begins in June. The main reasons are: snow poles could make road repairs in summer quite complicated, for example, cutting the grass in the road-related area; according to statistics, 30% of snow poles are broken or lost and that leads to the increasment of hazardous situations as dangerous parts of the roads are not highlighted due to the lack of sticks; reflecting material can become less

functional and that in turn can lead to a danger. Thus, the repairs of sticks and road-related areas are the most important purpose of picking up snow poles.

Nowadays, picking up process is done manually. It takes too much time as well as it increases the possibility of car accidents, as a truck must stop to pick up a stick. Moreover, such intermittent movement also raises the amount of CO₂ emissions. The aim of the Company is to improve all outdated processes and to modernise the whole system. Special trucks were developed to pick up poles from Norwegian roads, collect them in the 20 feet containers (ten trucks were made, but not in use as the Company is conducting their beta testing). The containers come in different sizes (for example, 10ft, 20ft, 40ft), but, according to the company's research, 20ft one fits the best.

These special trucks could be used to mount the snow poles out of the ground, while limiting the overall process to the number of trucks. As there are missing sticks, containers could be not fully used.

Each county is served by local contractors, and currently there are 109 of them, so the system is quite fragmented, and communication between contractors is difficult.

Picking up is rather a hard task that involves considering logistics and scheduling. There is a limited number of vehicles (the Company has built 10). Moreover, this process should be done in almost all roads.

Transportation.

Right now, the broken poles are sent back to China, and missing ones are ordered from this country.

Moreover, it leads to additional emissions. According to "EUROPEAN COMMISSION", international maritime shipping emits approximately 2-3% of annual CO₂ pollution. (SSB, 2019)

In order to reduce emissions and develop Norwegian own snow poles industry, the Company has already built one terminal near Kristiansund in Møre og Romsdal county.

More information about the terminal line can be found in step 3 (Maintenance).

After snow poles picking up, these 20ft containers are delivered to the terminals (so far just one) for maintenance.

Delivery is carried out by the Norwegian cargo transportation companies, private or public, and it also can intermodal, i.e. by trucks, trains or ships. Depending on

the route, it can include ferries, bridges, etc., which leads to additional costs. Some of the roads can be under repair or blocked for other reasons.

The next step proposed by the Company:

2) Maintenance of snow poles at terminals

On each terminal, containers are unpacked and snow poles are sent to the washing lines. Then the recognition process of the broken poles starts on a sorting line, as each year snow poles tend to break.

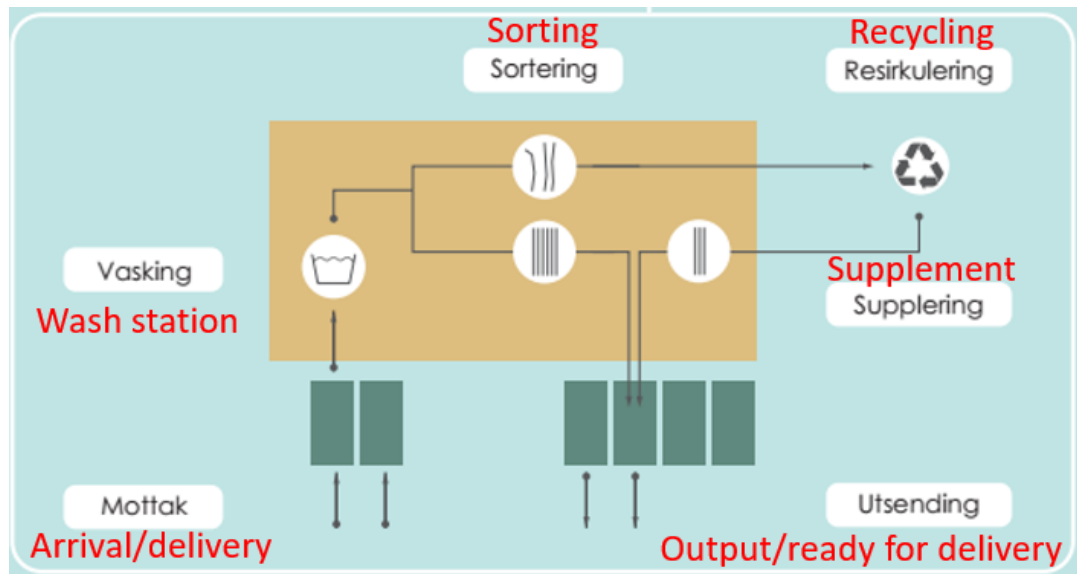


Figure 5. Terminal line.

Therefore, if it's possible the broken ones should be repaired or refurbished or melted down for components to make new snow poles.

Maintenance also includes the renewal of reflecting material or replacing some parts of snow poles, adding some modifications. For example, in the near future the company has a plan to build in special trackers in the snow poles to collect meteo and geodata. The invention of trackers can help to prevent dangerous accidents, that can cause human deaths, by analyzing the changes in various parameters, such as atmospheric pressure, humidity, wind speed, ground vibrations. In addition, lasers or RFID sensors introducing a new concept of "smart" snow poles, with online synchronisation for up-to-date information could be added.

Cleaning is also a task of terminals.

When snow poles are in an appropriate condition to install them in the ground, in that case the following steps are to be done:

3) Packing in snow poles back into containers at terminals

This step is necessary for intermodal transportation to decrease the complexity of transportation. Containers must be labeled with ID since different containers contain different amount of snow poles. Identification is needed to dispatch them further as different counties have different requirements.

4) Transportation to counties

Containers should be sent back to counties.

5) Storing of containers

After the maintenance containers should be stored at terminals in each county during the summer. If terminals are too busy to handle snow poles, containers could be stored there before maintenance.

6) Mounting snow poles in

The process of mounting snow poles must be finished by the end of August.

Local contractors pick up the containers in their counties and start the process of installing the sticks across their county.

New snow poles are to be mounted with the help of appropriate Company's special trucks.

Moreover, these steps are repeated each year.

The transportation is characterized by a scheduled character and a limited number of workers.

Shipment and land transportation are complex and dynamic processes; the price may vary, depending on the season (as is's done in advance or not), size, weight, destination and origin, the workload of delivery companies, types of used vehicles, using toll bridges or roads and additional taxes for ferries.

The scale of the task is enormous. Snow poles are to be installed on all roads, including national, county and municipal roads, which total length is around 94 thousand kilometres. Currently there exists a variety of transportation companies and contractors using their transportation systems.

To limit the task, it is necessary to break it down into several significant logistical subtasks:

1. Terminals' placement;
2. Transportation of containers;
3. Snow poles installation.

3.2 Determining research focus

Terminals play a significant role, as the whole system is based on the correct location of these critical objects.

The location of the terminals and the transportation system itself are closely interlinked.

The main focus, as the objective task of this research states, to develop a methodology for planning a network of road stick supply. This network should represent the number and the locations of production terminals from where the road stick will be transported to cover the needs of all counties in Norway.

4.0 Data and methods and assumptions

4.1 Data and assumptions

There are two categories for data collection methods by the source of data: secondary data collection method (data that was already published) or primary data collection methods. Primary methods, in turn, can be divided into two more categories: qualitative and quantitative.

Questionnaires and meeting with the Company helped to understand the business processes, how production terminals, transportation of road sticks and contractors with their processes are connected.

Partitioning of Norway.

As business processes states, contractors operate in their counties and partitioning Norway into 18 parts, i.e. 18 potential production terminals' locations.

County road sticks demands.

With the help of the data from the Company about the number of sticks in Norway and with public statistics of km of roads in Norway in 18 counties (Figure 6), demands for road sticks in Norwegian counties were estimated. As this statistic is pretty outdated, but there is no relevant one, the actual nowadays demands may vary.

	Km of roads in Norway			
	Total	National	County	Municipal
Total	93 870	10 581	44 318	38 971
Ostfold	3 726	271	1 673	1 782
Akershus	4 716	416	1 816	2 484
Oslo	1 328	186	0	1 142
Hedmark	6 608	702	3 844	2 062
Oppland	5 616	725	3 020	1 871
Buskerud	4 158	592	1 787	1 779
Vestfold	2 711	159	1 213	1 339
Telemark	4 139	456	1 877	1 806
Aust-Agder	3 002	446	1 522	1 034
Vest-Agder	3 980	237	2 066	1 677
Rogaland	6 162	521	2 454	3 187
Hordaland	6 788	765	2 908	3 115
Sogn og Fjordane	5 341	717	2 594	2 030
More and Romsdal	6 495	533	3 087	2 875
Trondelag	10 581	736	5 948	3 897
Nordland	8 905	1 225	4 114	3 566
Troms Romsa	5 408	609	2 912	1 887

Finmark	4 206	1 285	1 483	1 438
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Figure 6. Km of roads in Norway

First, data of km of roads were transformed to show what percentage of roads counties have (Figure 7). To obtain it km of roads in the county should be divided by total km of roads in Norway.

	% of roads			
	Total	National	County	Municipal
Total	100%	11%	47%	42%
Ostfold	4%	0%	2%	2%
Akershus	5%	0%	2%	3%
Oslo	1%	0%	0%	1%
Hedmark	7%	1%	4%	2%
Oppland	6%	1%	3%	2%
Buskerud	4%	1%	2%	2%
Vestfold	3%	0%	1%	1%
Telemark	4%	0%	2%	2%
Aust-Agder	3%	0%	2%	1%
Vest-Agder	4%	0%	2%	2%
Rogaland	7%	1%	3%	3%
Hordaland	7%	1%	3%	3%
Sogn og Fjordane	6%	1%	3%	2%
More and Romsdal	7%	1%	3%	3%
Trondelag	11%	1%	6%	4%
Nordland	9%	1%	4%	4%
Troms Romsa	6%	1%	3%	2%
Finmark	4%	1%	2%	2%

Figure 7. Percent of roads in Norway

Knowing the fact, that there are 10 million sticks in Norway and 100% of the placed aside the roads, it is possible to estimate the number of sticks on roads in counties just by multiplication by the number of sticks, i.e. by 10 million.

A number of sticks in counties is shown in Figure 8.

	№ of sticks			10000000
	Total	National	County	Municipal
Total	10 000 000	1 127 197	4 721 210	4 151 593
Ostfold	396 932	28 870	178 225	189 837
Akershus	502 397	44 317	193 459	264 621
Oslo	141 472	19 815	0	121 658
Hedmark	703 952	74 784	409 503	219 665
Oppland	598 274	77 234	321 722	199 318
Buskerud	442 953	63 066	190 370	189 517
Vestfold	288 804	16 938	129 221	142 644
Telemark	440 929	48 578	199 957	192 394

Aust-Agder	319 804	47 513	162 139	110 152
Vest-Agder	423 991	25 248	220 092	178 651
Rogaland	656 440	55 502	261 425	339 512
Hordaland	723 128	81 496	309 790	331 842
Sogn og Fjordane	568 978	76 382	276 340	216 257
More and Romsdal	691 914	56 781	328 859	306 275
Trondelag	1 127 197	78 406	633 642	415 149
Nordland	948 652	130 500	438 266	379 887
Troms Romsa	576 116	64 877	310 216	201 023
Finnmark	448 066	136 891	157 984	153 191

Figure 7. Percent of roads in Norway

Counties and potential spots for placement production terminals.

There were a few steps to find the spots:

- 1) The administrative centres were picked up. However, on further steps of research shipment was seen as a potential transportation tool, and a lot of the previously chosen administrative centres do not have ports. Trains have also importance. More about trains and ports would be said in the next paragraphs about data.
- 2) For convenience, big port cities were used as the best spots, due to nicely developed routing around it. Preference was given to cities that has ports and train station at the same time, then the ones that have ports, then just train station. If there are no ports and train stations in any of the cities of a county, the biggest or most famous or with highest population city is chosen.

One of the examples how data was structured in one of the final Excel files are in Figure 8.

County	City	Port	PortPlusKm	TrainToOslo	TrainPlusKm
Ostfold	Fredrikstad	1	0	0	0
Akershus	Sorumsand	0	0	0	0
Oslo	Oslo	1	0	1	0
Hedmark	Hamar	0	0	0	0
Oppland	Lillehammer	0	0	0	0
Buskerud	Drammen	0	0	0	0
Vestfold	Larvik	1	0	0	0
Telemark	Skien	0	0	0	0
Aust-Agder	Arendal	0	0	0	0
Vest-Agder	Kristiansand	1	0	1	0
Rogaland	Sandnes	1	0	1	5
Hordaland	Bergen	1	0	1	0
Sogn og Fjordane	Floro	1	0	0	0
More og Romsdal	Kristiansund	1	39	0	0
Trondelag	Trondheim	1	0	1	0
Nordland	Bodo	1	0	1	0
Troms	Tromso	1	0	0	0
Finnmark	Vadso	1	0	0	0

Figure 8. Example of the data file

In the table, columns Port and TrainToOslo show do city has a port or train station. As there is already one terminal built near Kristiansund, so another assumption states that terminal is in Kristiansund but add some additional transportation cost to perform transportation between Kristiansund and that terminal. Sandness does not have a train station, but it has in nearby, just 5 km from it and one more assumption is that Sandness is a train city, but adding some additional fixed transportation cost.

Transportation.

Transportation in this problem is presented by trucks, trains and ships.

According to the Company, the best container to store and transport road sticks is 20 foot one. Assuming this type of container is the only one to be used for by case company, multi-commodity is not needed in the mathematical model for future calculations.

20-foot container is a common intermodal container with the following parameters:

- weight if empty: 2,3 t
- max cargo: 25 t

According to the Company, the container can fit in up to 25 000 snow poles. Knowing weight per one stick. The total container weight fully loaded with snow poles is 11 250 kg. Using weight and container type, further research was performed by multiple email questionnaires sent to well known public and private delivery companies in Norway and also by phone calls.

As a result of delivery companies interviewing, second data was collected about:

- ports
Shipment is well developed in Norway, many ports to ship from and to.
Data: Transportation cost matrix, that shows cost from one port to another one with minimal package price and tables on how to find the cost with a given weight.
- trains
Cargo train system is not well developed in Norway.
Data: a small table that shows the price per container to send from Oslo to an other nine stations.
Data after processing raw spreadsheets and removal of unnecessary columns, knowing the weight of the container filled with snow poles and the type of it, can be seen in figure 9.

County		Oslo
Oslo	Oslo	
Vest-Agder	Kristiansand	2 367
Rogaland	Sandnes	3 380
Hordaland	Bergen	3 233
Trondelag	Trondheim	2 493
Nordland	Bodo	6 498

Figure 9. Railway cost

For data about transportation by truck were performed by email questionnaires sent to well known public and private delivery companies in Norway, and an average estimated price was formed to be around 45 kr per km.

As data or tables of exact transportation cost by truck between chosen county representatives were not obtained, but knowing the average price per km, it will be logical to build a distance matrix, a square matrix containing distances, between the chosen cities and then multiply it by the price per km to get truck transportation costs.

A distance matrix creation.

There are various methods of how to build a distance matrix, for example, by calculation of Euclidian distances (Figure 10.), which could give quite inaccurate costs and results would

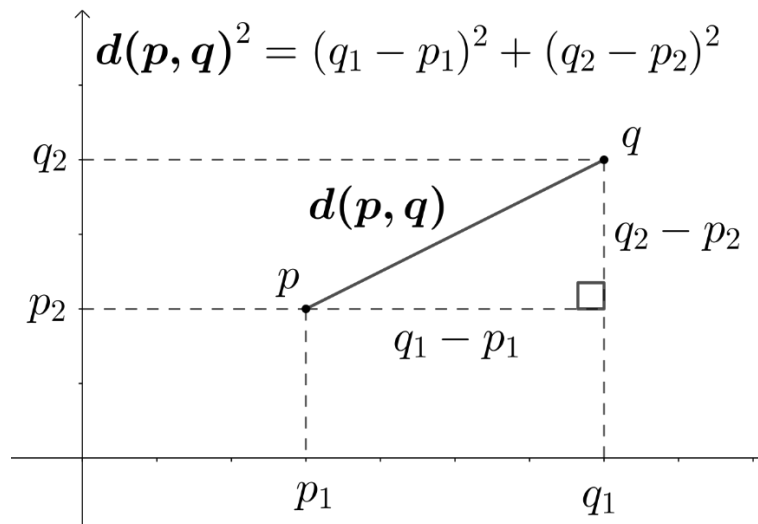


Figure 10. Euclidian distance.

Be rough. However, this thesis will not cover the more precise mathematical ones. It will be cover the modern tools to work with geopositioning.

Mapping tools, or web mapping APIs², are tools to communicate with map services, like Google Maps. In this thesis, API that was used is known as GraphHopper, an open-source one, unlike Google Map. The reason why GraphHopper instead of Google is the size of the

² API - Application Program Interface

distance matrix that can be obtained for free. GraphHopper can cover the problem, while Google requires additional payments.

To get distances between points, for each city the geo-coordinates in decimal form were extracted manually with the help of Google Maps. Figure 11.

County	City	Long, Lat
Ostfold	Fredrikstad	59.218242, 10.937739
Akershus	Sorumsand	60.005833, 11.259444
Oslo	Oslo	59.916667, 10.733333
Hedmark	Hamar	60.799167, 11.056111
Oppland	Lillehammer	61.116667, 10.466667
Buskerud	Drammen	59.737778, 10.205
Vestfold	Larvik	59.081111, 10.016389
Telemark	Skien	59.208056, 9.552778
Aust-Agder	Arendal	58.482222, 8.7825
Vest-Agder	Kristiansand	58.158964, 8.019604
Rogaland	Sandnes	58.845, 5.829444
Hordaland	Bergen	60.389035, 5.329233
Sogn og Fjordane	Floro	61.599688, 5.032083
More og Romsdal	Kristiansund	63.110278, 7.727778
Trondelag	Trondheim	63.43, 10.4
Nordland	Bodo	67.2827, 14.3751
Troms	Tromso	69.651944, 18.953333
Finnmark	Vadso	70.073333, 29.749167

Figure 11. City Coordinates

The result of a request (a list of chosen 18 coordinates) to the mapping service was data file with the distance between chosen locations, i.e. distance matrix 18 x 18, part of which can be seen of Figure 12.

		Ostfold	Akershus	Oslo	Hedmark	Oppland
meters i to j		Fredrikstad	Sorumsand	Oslo	Hamar	Lillehammer
Ostfold	Fredrikstad	0	104417	89966	213619	269118
Akershus	Sorumsand	104468	0	41038	108107	163607
Oslo	Oslo	93402	41822	0	130457	185957
Hedmark	Hamar	212834	106627	128205	0	60066
Oppland	Lillehammer	269831	163624	185202	60211	0
Buskerud	Drammen	105732	83119	42945	171754	197821
Vestfold	Larvik	64292	141109	100935	229745	255812
Telemark	Skien	135959	175799	135625	264435	290502
Aust-Agder	Arendal	229665	301539	261365	390175	416242
Vest-Agder	Kristiansand	288856	360731	320557	449367	475434
Rogaland	Sandnes	518773	590648	550473	679283	550467

Figure 12. Distance Matrix

Additional assumptions.

Introduction of the following assumptions:

- 1) Gets rid of lost sticks uncertainty;

There is no certainty in data regarding the exact number of lost snow poles. This issue leads to uncertainty how much snow sticks are needed to be produced, cleaned at production terminals. Assuming to fix that three million sticks are lost yearly.

- 2)

Production terminal related data. Findings of demand and production terminal capacities.

Terminal setup cost: 1 200 000 Kr

Annual worker salary: 650 000 Kr

Extra machine: 1 000 000 Kr

Washing: during summertime, 90 days

Producing sticks – all year long, but better not in the summertime as we need to utilise the full capacity of machines.

Max machine productivity: 2 shifts, six days

One worker 4200 stick per shift

Total stick demand: 10 million.

Assuming, that broken sticks are also in that 30% uncertainty, so they are lost.

Total sticks to wash is then 7 million.

Total sticks to produce is 3 million.

There is 200 000 km of roads.

So 13 weeks in summertime multiply by 6 working days = 78 days

7 million stk/78 days is around 90 000 stk to handle per day

To satisfy this demand at least $90\,000 \text{ stk} / 8\,400 = 11$ days what means at least 11 machines needed to satisfy demand.

4.2 Data preprocessing

To prepare data for the model, for unification and speeding up the process were developed five Excel macros using Visual Basic that can be found in the Appendix.

First, PDF file with shipment data was parsed online and inserted into Excel.

	Alta	Bergen*	Berlevåg* 1)	Bodø*	Brennøysund* 1)	Båtsfjord*	Finnsnes*	Florø	Fredrikstad	Hammerfest*	Harstad*	Haugesund	Havøysund*	Honningsvåg* 1)	Kirkenes*	Kjøllefjord*	Kristiansand S	Kristiansund N* 1)	Larvik	Mehamn* 1)	Molde	Måløy* 1)	Narvik	Nesna* 1)	Oslo	Risøyhamn*
3500 Alta		21	14	16	18	14	13	22	22	11	14	22	12	12	13	13	23	20	21	13	20	22	15	18	21	15
5000 Bergen*	21		22	17	19	23	20	9	11	22	20	9	22	22	23	23	11	11	11	22	11	9	20	19	10	21
3980 Berlevåg* 1)	14	22		17	19	9	16	22	24	14	17	23	12	11	12	11	24	22	24	9	22	22	17	19	22	17
3000 Bodø*	16	17	17		13	17	13	19	16	16	12	19	17	17	17	17	20	16	17	17	16	19	12	14	16	13
3900 Brennøysund* 1)	18	19	19	13		19	16	19	18	18	16	20	19	19	18	19	19	16	18	19	16	19	16	10	17	16
3990 Båtsfjord*	14	23	9	17	19		16	22	24	14	17	23	13	12	12	11	24	22	24	11	22	22	17	20	22	17
3300 Finnsnes*	13	20	16	13	16	16		21	21	13	11	22	15	15	15	15	22	20	21	15	20	20	11	16	20	11
5900 Florø*	22	9	22	19	19	22	21		16	22	20	11	22	22	22	22	15	11	16	22	11	6	20	19	13	20
1600 Fredrikstad	22	11	24	16	18	24	21	16		22	20	14	23	22	23	23	9	14	9	24	13	16	20	22	8	22
3600 Hammerfest*	11	22	14	16	18	14	13	22	22		14	22	10	11	13	12	23	20	22	13	20	22	15	18	22	15
3400 Harstad*	14	20	17	12	16	17	11	20	20	14		21	15	16	16	16	21	19	21	16	20	20	10	16	20	8
5500 Haugesund	22	9	23	19	20	23	22	11	14	22	21		23	23	23	23	11	13	13	23	13	11	21	22	11	21
3690 Havøysund*	12	22	12	17	19	13	15	22	23	10	15	23		9	14	11	23	21	23	11	22	22	16	19	22	16
3750 Honningsvåg* 1)	12	22	11	17	19	12	15	22	23	11	16	23	9		14	9	23	21	23	11	22	22	17	19	22	16
3900 Kirkenes*	13	23	12	17	18	12	15	22	22	13	16	23	14	14		13	23	21	22	13	21	22	16	18	21	17
3790 Kjøllefjord*	13	23	11	17	19	11	15	22	23	12	16	23	11	9	13		23	22	23	9	22	22	17	19	22	16
4600 Kristiansand S	23	11	24	20	19	24	22	15	9	23	21	11	23	23	23	23		15	8	23	15	15	21	22	9	22
5500 Kristiansund N* 1)	20	11	22	16	16	22	20	11	14	20	19	13	21	21	21	22	15		15	22	7	11	19	17	12	19
3250 Larvik	21	11	24	17	18	24	21	16	9	22	21	13	23	23	22	23	8	15		24	15	16	20	22	8	22
3070 Mehamn* 1)	13	22	9	17	19	11	15	22	24	13	16	23	11	11	13	9	23	22	24		22	22	17	19	22	16

Then with the use of macros to get marked with red and manually unified column and row positions. To the possibility for further connection of cost matrixes

Kr per 10t		Fredrikstad	Sorumsan	Oslo	Hamar	Lillehamm	Drammen	Larvik	Skien	Arendal	Kristiansand	Sandnes	Bergen	Florø	Kristiansund	Trondheim	Bodo	Tromsø	Vadso
Fredriksta	Fredrikstad			1467				1688			1688	2086	2086	3449	2973	2086	3449	5364	5777
Sorumsan	Berlevåg																		
Oslo	Oslo	1467					1467				1688	1860	1860	2757	2490	2086	3449	4942	5364
Hamar	Brennøysund																		
Lillehamm	Båtsfjord																		
Drammen	Drammen																		
Larvik	Larvik	1688	1467								1467	1860	2086	3449	3171	2086	3897	5364	5777
Skien																			
Arendal																			
Kristiansand	Kristiansand	1688	1688				1467					1688	2086	3171	3171	2490	4942	5777	6209
Sandnes	Sandnes	2086	1860				1860				1688	2086	2086	2086	2086	2490	4517	5777	6209
Bergen	Bergen	2086	1860				2086				2086	1688	1688	2086	2086	2490	3897	5364	6209
Florø	Florø	3449	2757				3449				3171	2086	1688	1688	2086	2086	4517	5364	5777
Kristiansund	Kristiansund	2973	2490				3171				3171	2086	2086	2086			1467	3449	4942
Trondheim	Trondheim	2086	2086				2086				2490	2490	2490	2086	1467			2086	4220
Bodo	Bodo	3449	3449				3897				4942	4517	3897	4517	3449	2086		2757	3897
Tromsø	Tromsø	5364	4942				5364				5777	5777	5364	5364	4942	4220	2757		3171
Vadso	Vadso	5777	5364				5777				6209	6209	6209	5777	5364	4942	3897	3171	

Then with macros and then the same with trains and got the final cost matrix with the cheapest preprocessed routes.

Train Ship		Ostfold	Akershus	Oslo	Hedmark	Oppland	Buskerud	Vestfold	Telemark	Aust-Agder	Vest-Agder	Rogaland	Hordaland	Sogn og Fjordane	Møre og Romsdal	Trøndelag	Nordland	Troms	Finmark
mieters 10t	Fredrikstad																		
Ostfold	Fredrikstad	0	6619,24	5043,48	10607,9	13104,4	5736,16	5524,26	7101,19	11341,9	13899,2	23571,8	23571,8	26431,8	30372,5	23571,8	38975,7	60613,2	65280,1
Akershus	Sorumsan	6641,2	0	2846,71	5864,82	8361,42	4687,53	8767,05	8898,63	14584,6	17142	26947,7	23786,1	24270,3	25629,5	22348,9	54067,2	78237,6	88529,6
Oslo	Oslo	5189,23	2881,99	0	6870,57	9367,12	2873,8	6953,32	7084,95	12770,9	3267	3380	3233	22465,1	26635,2	3489	6248	55844,6	60613,2
Hedmark	Hamar	10563,7	5798,22	6769,23	0	3702,97	8610	12689,5	12821,1	18507,1	21064,5	30870,2	22223,8	21956,3	20971,1	18390,8	50109,1	74279,6	84372,4
Oppland	Lillehammer	13168,4	8402,95	9373,96	3709,5	0	9835,98	13915,5	14047,1	19733,1	22290,4	26808,9	20967	20699,5	18433	16217,8	47936,1	67231,3	86890
Buskerud	Drammen	5744,08	4740,36	2932,53	8728,93	9901,99	0	5162,82	5294,4	10980,4	13537,8	23343,5	20834,1	22740,2	27170,1	25213	56931,3	81101,8	91194,5
Vestfold	Larvik	5516,92	8765,11	6957,28	12753,7	13926,7	5159,17	0	2882,17	7122,88	9680,19	19486	20549,2	26764,9	31194,9	23571,8	44036,1	80613,2	65280,1
Telemark	Skien	7104,3	8910,96	7103,13	12899,6	14072,6	5305,02	3039,81	0	6568,3	9125,65	18931,4	19133,7	25584,6	31340,7	29383,6	61101,9	85272,4	95365,1
Aust-Agder	Arendal	11321,1	14569,3	12761,4	18557,9	19730,9	10963,3	7256,58	6581,53	0	4036,11	13841,9	21920	32569,1	36999	35041,9	66760,2	90930,7	101023
Vest-Agder	Kristiansand	13887	17135,2	3267	21123,8	22296,8	13529,2	9822,48	9147,43	4024,05	0	3747	5900	31741,5	35832,8	4860	8868	65190,1	70161,7
Rogaland	Sandnes	23571,8	26950,6	3380	30939,3	26791,9	23344,7	19638	18962,9	13839,5	3747	0	8643	21754,4	23571,8	3873	9878	65190,1	70161,7
Hordaland	Bergen	23571,8	23696,3	3233	22253,3	21013,3	20860,5	20736	19167,1	21938,6	5900	8613	0	11504,1	23571,8	3728	9731	60613,2	70161,7
Sogn og Fjordane	Florø	26586,8	24166,6	22471,7	21964,2	20724,3	22683,4	26762,9	25598,9	32580,5	31709,5	21779,5	11467,4	0	17233,8	23571,8	51042,1	60613,2	65280,1
Møre og Romsdal	Kristiansund	30556,9	25791,4	26762,5	21098	18573,5	27224,5	31304	31435,6	37121,6	35832,8	23571,8	23571,8	17240,9	0	9918,69	38975,7	55844,6	60613,2
Trøndelag	Trondheim	23571,8	22346,7	3489	18392,1	16355,8	25158,6	23571,8	29369,7	35055,7	4860	5873	3728	33971,8	9905,31	0	8991	47686	55844,6
Hordaland	Bodo	38975,7	54067	6488	50112,4	48076,1	56878,8	84036,1	61089,9	66775,9	5865	9878	7791	54042,1	38975,7	8991	0	25154,5	44036,1
Troms	Tromsø	60613,2	78322,3	55844,6	74367,6	67421,5	81134,1	80613,2	85345,2	91051,2	65280,1	65280,1	60613,2	60613,2	55844,6	47686	25201,3	0	35832,8
Finmark	Vadso	65280,1																	

4.3 Methods

The issue raised in this master thesis will be examined, using the empirical research for determine all the restrictions and limits for each link and transpiration mode. Since the goals specified in this work are to identify the best sticks flow, transport directions, the methodology of operational research, such as cost minimization has been used.

Network depends on arcs, that are various options of transport modes and nodes. They represent different important locations of the possible route, such as location of origin and destination point, as well as the other points that are within the route, as train stations or ports.

The study will be focused on the middle-term horizon and various types of operators. This research will provide empirical examination and network design tackling the transportation of snow poles. The models that would minimize the total costs and provide permanent secure shipment of snow poles, such as low-cost multi-echelon flow model, are used.

The models of mathematical optimization are to be developed in AMPL language and run in CPLEX. Furthermore, the achieved results have been analyzed in economic terms. In this research a number of experiments tackling the defined issues can be found. The result is in shaping the decision concerning the optimal solution.

This master thesis will provide the solution for current existing problem through network design. The implemented study also contributes to conducting various theoretical researches, as new models of network optimization for various combinations of intermodal, multi-modal, multi- period and multi-echelon transportation networks have been developed. In addition, the mathematical models that have been developed for this study can be used for various types of cargo transportation with any other combinations of modes of transport.

5.0 Mathematical model

Mathematical optimization model

Formulation:	AMPL names:
(1) $\max \sum_{i \in I} s y_i + t(2-l) \sum_{i \in I, j \in J} \left\lceil \frac{x_{ij}}{c} \right\rceil h_{ij} + t \sum_{i \in I} z_i w + \sum_{i \in I} z_i m$	Total_cost
(2) $\sum_{i \in I} x_{ij} \geq d_j(1-l)$	st1 {j in J}
(3) $z_i \leq y_i u$	st2 {i in I}
(4) $\sum_{j \in J} x_{ij} \leq z_i p$	st3 {i in I}
(5) $y_{M\ddot{o}re\ og\ Romsdal} = 1$	st4
Sets:	
I – set of possible locations for factories	I
J – set of counties	J
Parameters:	
s – setup cost of factory	setup_cost
t – time horizon	t
l – percentage of lost sticks	lost
c – capacity of container in sticks	cont_cap
h_{ij} – transportation cost for 1 container from factory i to county j	cost{I,J}
w – annual salary for 1 worker	sal
m – setup cost of 1 machine	mach_cost
Variables:	
x_{ij} – number of sticks to transport from factory i to county j	x{I,J}
y_i – 1 if factory is built in county i, 0 otherwise	y{I}

z_i – number of machines at factory in county i	$z\{I\}$
---	----------

Description:

The objective function (1) expresses the total cost calculated from the transportation cost of sticks, building factories, buying machines and workers' salary.

Constraint (2) represents lower bound on the amount of sticks sent to county j from all factories.

Constraint (3) is upper bound on a number of machines at a factory in county i.

Constraint (4) is upper bound on the amount of sticks sent from factory in county i. It is the same as upper bound on production at a factory in county i.

Constraint (5) shows that the factory in Møre og Romsdal is already built.

5.1 Implementation in AMPL

A mathematical model was written in AMPL using CPLEX. And can be found in Appendix.

Experiments

X shows what routes are picked and from what terminal demand is satisfied

Y for locations of terminals

Z number of machines in that county

For these experiments parameter t (time horizon) was changed to observe differences

'1 years'

Total_cost = 25040800

x :=

More_and_Romsdal	Finnmark	61727.4
More_and_Romsdal	More_and_Romsdal	484340
More_and_Romsdal	Sogn_og_Fjordane	398285
More_and_Romsdal	Trondelag	158847
Oslo	Akershus	351678
Oslo	Aust-Agder	223863
Oslo	Buskerud	310067
Oslo	Hedmark	492766
Oslo	Hordaland	506190
Oslo	Nordland	664056
Oslo	Oppland	418792
Oslo	Oslo	99030.4
Oslo	Ostfold	277852
Oslo	Rogaland	459508
Oslo	Telemark	308650
Oslo	Trondelag	630190
Oslo	Vest-Agder	296794
Oslo	Vestfold	202163
Troms_Romsa	Finnmark	251919
Troms_Romsa	Troms_Romsa	403281

;

y [*] :=

More_and_Romsdal	1
Oslo	1
Troms_Romsa	1

;

z [*] :=

More_and_Romsdal	2
Oslo	8
Troms_Romsa	1

;

3 years

Total_cost = 45729800

x [*,*]

```
:
      Akershus Aust-Agder Buskerud Finnmark Hedmark Hordaland :=
More_and_Romsdal  0      0      0      61727.4  0      0
Oslo              351678  223863  310067   0      492766  456475
Sogn_og_Fjordane  0      0      0      0      0      49714.7
Troms_Romsa      0      0      0      251919  0      0
```

```
:
      More_and_Romsdal Nordland Oppland Oslo Ostfold Rogaland :=
More_and_Romsdal  484340  0      0      0      0      0
Oslo              0      664056  418792  99030.4  277852  459508
```

\$1 = Sogn_og_Fjordane

```
:
      $1 Telemark Troms_Romsa Trondelag Vest-Agder Vestfold :=
More_and_Romsdal  0      0      0      109133  0      0
Oslo              0  308650  0      679905  296794  202163
Sogn_og_Fjordane  398285  0      0      0      0      0
Troms_Romsa      0      0  403281  0      0      0
;
```

y [*] :=

```
More_and_Romsdal  1
      Oslo 1
Sogn_og_Fjordane  1
      Troms_Romsa 1
;
```

z [*] :=

```
More_and_Romsdal  1
      Oslo 8
Sogn_og_Fjordane  1
      Troms_Romsa 1
;
```

12 years

Total_cost = 127716000

x [*,*]

```
:      Akershus Aust-Agder Buskerud Finnmark Hedmark Hordaland :=
Finnmark      0      0      0 313646      0      0
Oppland        0      0      0  0 236408      0
Oslo           351678      0 310067      0 256358 481180
Sogn_og_Fjordane  0      0      0  0  0 25009.6
Telemark       0 223863      0  0  0  0
```

\$1 = More_and_Romsdal

```
:      $1 Nordland Oppland Oslo Ostfold Rogaland :=
More_and_Romsdal 48434 0  0  0  0  0  0
Nordland         0  655200  0  0  0  0
Oppland          0  0  418792  0  0  0
Oslo             0 8856.4  0 99030.4 277852 459508
```

\$1 = Sogn_og_Fjordane

```
:      $1 Telemark Troms_Romsa Trondelag Vest-Agder Vestfold :=
More_and_Romsdal  0  0  0 133838  0  0
Oslo              0  0  0  0 296794 79475.9
Sogn_og_Fjordane 398285  0  0  0  0  0
Telemark          0 308650  0  0  0 122687
Troms_Romsa      0  0 403281  0  0  0
Trondelag        0  0  0 655200  0  0
;
```

y [*] :=

```
      Finnmark 1
More_and_Romsdal 1
      Nordland 1
      Oppland 1
      Oslo 1
Sogn_og_Fjordane 1
      Telemark 1
      Troms_Romsa 1
      Trondelag 1
;
```

z [*] :=

```
      Finnmark 1
More_and_Romsdal 1
      Nordland 1
      Oppland 1
      Oslo 4
Sogn_og_Fjordane 1
      Telemark 1
      Troms_Romsa 1
      Trondelag 1;
```

We can see that:

1 years Total_cost = 25040800 Average per year 25 040 800

3 years Total_cost = 45729800 Average per year 15 243 266

12 years Total_cost = 127716000 Average per year 10 643 000

The average cost for the system differs. Its because of fixed costs to open new terminals/buy more machines. In short time the price is high due to fixed costs high demand that can't be satisfied with small number of machies (we need at least 11). But when time horizon is longer, it's better to have machines in all counties to lower the price for transportation.

6.0 Conclusion

6.1 Research summary

Company going to analyze results given in this thesys for the use in their business.

6.2 Managerial implications

The developed methodology has the possibility to be further developed into a decision support tool where one could investigate different scenarios for the placement of terminals as well as different time horizons and

6.3 Suggestions for further research

1. Schedule for trucks

The whole mounting process should be done within a time window of 1 month from 1 September till 1 October.

2. A more in-depth intermodal transportation with schedules

References

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Appendix

Data processing in Excel using macroses written in Visual Basic

- 1) Replaces cell value with another cell value, if a rule is satisfied

```
Sub Preprocess()  
    Dim cell As Range  
    Dim cell2 As Range  
    For Each cell2 In Range("A115:A153")  
        For Each cell In Range("E70:AT111")  
            If cell.Value = cell2.Value Then  
                cell.Value = cell2.Offset(0, 4).Value  
            End If  
        Next cell  
    Next cell2  
End Sub
```

- 2) Marking in red color a range of cells to help with manual removal of unnecessary columns and rows for unification matrixes

```
Sub Mark()  
    Dim cell As Range  
    Dim cell2 As Range  
    For Each cell In Range("B29:B46")  
        For Each cell2 In Range("D93:D134")  
            If cell.Value = cell2.Value Then  
                cell2.Interior.Color = RGB(255, 0, 0)  
            End If  
        Next cell2  
    Next cell  
End Sub
```

- 3) Macro to copy range of cells to another position instead of doing it manually with specifying to remove interior cell color (set it to blank)

```
Sub Truck()  
    Dim cell As Range  
    For Each cell In Range("C3:T20")
```



```

    cell.Value = cell.Offset(44, 0).Value
    cell.Interior.ColorIndex = 0
Next cell
End Sub

```

- 4) Update cells (multiply by 0.045) and if cells isn't empty add 1000 (additional fixed cost)

```

Sub TruckPrice()
Dim cell As Range
For Each cell In Range("C3:T20")
    cell.Value = cell.Value * 0.045
    If cell.Value <> 0 Then
        cell.Value = cell.Value + 1000
    End If
Next cell
End Sub

```

- 5) Macro to update cells with new values and mark with red if the comparison cells aren't empty and values are lower

```

Sub TruckPriceShipUpdate()
Dim cell As Range
For Each cell In Range("C3:T20")
    If IsEmpty(cell.Offset(22, 0)) = False And cell.Value > cell.Offset(22,
0).Value * 11.3 Then
        cell.Value = cell.Offset(22, 0).Value * 11.3
        cell.Interior.Color = RGB(255, 0, 0)
    End If
Next cell
End Sub

```

- 6) Macro to update cell with new values and mark with green if the comparison cells aren't empty and values are lower

```

Sub TruckPriceTrainUpdate()
Dim cell As Range

```

```

For Each cell In Range("C3:T20")
    If IsEmpty(cell.Offset(66, 0)) = False And cell.Value > cell.Offset(66, 0).Value
Then
    cell.Value = cell.Offset(66, 0).Value
    cell.Interior.Color = RGB(0, 255, 0)
    End If
Next cell
End Sub

```

AMPL implementation:

Pmed_max.mod:

```

set I;
set J;

param demand{J};
param cost{I, J};
param setup_cost;
param cont_cap;
param lost;
param prod;
param sal;
param mach_cost;
param t := 1;

var x{i in I, j in J} >=0;
var y{I} binary;
var z{I} integer >=0;

minimize Total_cost:
    setup_cost * sum{i in I} y[i] + t*sum{i in I, j in J} (x[i,j]/cont_cap)*cost[i,j] * (2 - lost) + t*sum{i
in I} z[i] * sal + sum{i in I} z[i]*mach_cost;

s.t. st1{j in J}:
    sum{i in I} x[i,j] >= demand[j]*(1-lost);

s.t. st2{j in J}:
    z[j] <= y[j] * 11;

s.t. st3{i in I}:
    sum{j in J} x[i,j] <= z[i] * prod;

s.t. st4:
    y['More_and_Romsdal'] = 1;

```

Pmed_max.dat:

```

set I = Ostfold Akershus Oslo Hedmark Oppland Buskerud Vestfold Telemark Aust-Agder Vest-Agder
Rogaland Hordaland Sogn_og_Fjordane More_and_Romsdal Trondelag Nordland Troms_Romsa Finnmark;
set J = Ostfold Akershus Oslo Hedmark Oppland Buskerud Vestfold Telemark Aust-Agder Vest-Agder
Rogaland Hordaland Sogn_og_Fjordane More_and_Romsdal Trondelag Nordland Troms_Romsa Finnmark;

```

```

param demand :=
Ostfold          396932
Akershus         502397
Oslo             141472
Hedmark         703952
Oppland         598274
Buskerud        442953
Vestfold        288804
Telemark        440929
Aust-Agder      319804
Vest-Agder      423991
Rogaland        656440
Hordaland       723128
Sogn_og_Fjordane 568978
More_and_Romsdal 691914
Trondelag       1127197
Nordland        948652
Troms_Romsa     576116
Finnmark        448066
;

```

```

param setup_cost := 1200000;
param cont_cap := 25000;
param lost := 0.3;
param prod := 655200;
param sal := 650000;
param mach_cost := 1000000;

```

Here also should be cost matrix but it is huge, 18 x18 and does not fit in even in landscape orientation. Part of it looks like that and basically it is the same data as in 4.2 Data processing with ships, trucks and trains:

```

param cost:
      Ostfold Akershus Oslo Hedmark Oppland Buskerud
Ostfold 0 6619.24 5043.475 10607.86 13104.415 5
Akershus 6641.2 0 2846.71 5864.815 8361.415 4687.525
Oslo 5189.23 2881.99 0 6870.565 9367.12 2873.8 6953.32 7
Hedmark 10563.67 5798.215 6769.225 0 3702.97 8
Oppland 13168.405 8402.95 9373.96 3709.495 0 9835.975
Buskerud 5744.08 4740.355 2932.525 8728.93 9901.99 0 5
Vestfold 5516.92 8765.11 6957.28 12753.73 13926.745 5159.17 6
Telemark 7104.295 8910.955 7103.125 12899.575 1
Aust-Agder 11321.065 14569.255 12761.425 18557.875 1
Vest-Agder 13886.965 17135.2 2367 21123.775 22296.79 1
Rogaland 23571.8 26950.645 3380 30939.265 26791.93 2
Hordaland 23571.8 23696.335 3233 22253.32 21013.345 2
Sogn_og_Fjordane 26586.775 24166.585 22471.66 21964.195 2
More_and_Romsdal 30556.9 25791.445 26762.455 21097.99 18573.535
Trondelag 23571.8 22346.74 2493 18392.095 16355.8 25158.565
Nordland 38973.7 54067.015 6498 50112.37 48076.075 5
Troms_Romsa 60613.2 78322.285 55844.6 74367.64 67421.53 8
Finnmark 65280.1 88513.255 60613.2 84425.725 86892.175 9
;

```

Pmed_max.run:

```

model Pmed_max.mod
data Pmed_max.dat
option solver cplex;

solve;

display "12 years" > ans_max.sol;

```

```

display Total_cost > ans_max.sol;
display x > ans_max.sol;
display y > ans_max.sol;
display z > ans_max.sol;

```

Solution file Pmed_max.sol:

```

'12 years' = '12 years'
Total_cost = 25040800

```

```

x [*,*]
:      Akershus Aust-Agder Buskerud Finnmark Hedmark Hordaland :=
Akershus      0      0      0      0      0      0
Aust-Agder    0      0      0      0      0      0
Buskerud      0      0      0      0      0      0
Finnmark      0      0      0      0      0      0
Hedmark       0      0      0      0      0      0
Hordaland     0      0      0      0      0      0
More_and_Romsdal 0      0      0      0 61727.4 0      0
Nordland      0      0      0      0      0      0
Oppland       0      0      0      0      0      0
Oslo          351678 223863 310067 0 492766 506190
Ostfold       0      0      0      0      0      0
Rogaland      0      0      0      0      0      0
Sogn_og_Fjordane 0      0      0      0      0      0
Telemark      0      0      0      0      0      0
Troms_Romsa   0      0      0 251919 0      0
Trondelag     0      0      0      0      0      0
Vest-Agder    0      0      0      0      0      0
Vestfold      0      0      0      0      0      0

:      More_and_Romsdal Nordland Oppland Oslo Ostfold Rogaland :=
Akershus      0      0      0      0      0      0
Aust-Agder    0      0      0      0      0      0
Buskerud      0      0      0      0      0      0
Finnmark      0      0      0      0      0      0
Hedmark       0      0      0      0      0      0
Hordaland     0      0      0      0      0      0
More_and_Romsdal 484340 0      0      0      0      0
Nordland      0      0      0      0      0      0
Oppland       0      0      0      0      0      0
Oslo          0      664056 418792 99030.4 277852 459508
Ostfold       0      0      0      0      0      0
Rogaland      0      0      0      0      0      0
Sogn_og_Fjordane 0      0      0      0      0      0
Telemark      0      0      0      0      0      0
Troms_Romsa   0      0      0      0      0      0
Trondelag     0      0      0      0      0      0
Vest-Agder    0      0      0      0      0      0
Vestfold      0      0      0      0      0      0

# $1 = Sogn_og_Fjordane
:      $1 Telemark Troms_Romsa Trondelag Vest-Agder Vestfold :=
Akershus      0      0      0      0      0      0
Aust-Agder    0      0      0      0      0      0
Buskerud      0      0      0      0      0      0
Finnmark      0      0      0      0      0      0
Hedmark       0      0      0      0      0      0
Hordaland     0      0      0      0      0      0
More_and_Romsdal 398285 0      0 158847 0      0

```

Nordland	0	0	0	0	0	0	
Oppland	0	0	0	0	0	0	
Oslo	0	308650	0	630190	296794	202163	
Ostfold	0	0	0	0	0	0	
Rogaland	0	0	0	0	0	0	
Sogn_og_Fjordane	0	0	0	0	0	0	0
Telemark	0	0	0	0	0	0	
Troms_Romsa	0	0	0	403281	0	0	0
Trondelag	0	0	0	0	0	0	
Vest-Agder	0	0	0	0	0	0	
Vestfold	0	0	0	0	0	0	

;

y [*] :=

Akershus 0
 Aust-Agder 0
 Buskerud 0
 Finnmark 0
 Hedmark 0
 Hordaland 0
 More_and_Romsdal 1
 Nordland 0
 Oppland 0
 Oslo 1
 Ostfold 0
 Rogaland 0
 Sogn_og_Fjordane 0
 Telemark 0
 Troms_Romsa 1
 Trondelag 0
 Vest-Agder 0
 Vestfold 0

;

z [*] :=

Akershus 0
 Aust-Agder 0
 Buskerud 0
 Finnmark 0
 Hedmark 0
 Hordaland 0
 More_and_Romsdal 2
 Nordland 0
 Oppland 0
 Oslo 8
 Ostfold 0
 Rogaland 0
 Sogn_og_Fjordane 0
 Telemark 0
 Troms_Romsa 1
 Trondelag 0
 Vest-Agder 0
 Vestfold 0

;