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Resilience assessment of the transport corridor From Stokmarknes to Stockholm

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Abstract (max 150 words):
Timely delivery of the required goods plays an important role in meeting the availability and reducing the downtime of Markets. Salmon transport logistics is affected in complex ways while operating in the Arctic, since the area is sparsely populated and has insufficient infrastructure. It is also greatly affected by the distinctive operational environment of the region, such as cold temperature, varying forms of ice, blizzards, heavy fog, etc. Therefore, in order to have an effective transport and logistics plan, the effect of all influencing factors, called covariates, on the transportation of the spare parts need to be identified, modelled and quantified using an appropriate dynamic model. The traditional models, however, lack the comprehensive integration of the effect of covariates on the transportation modes. The purpose of this thesis is to introduce the concept of a dynamic model for transportation in Arctic conditions by considering time to delivery as the main attribute. The model continuously updates the prior probabilities according to the most recent time to delivery estimations. The application of the model is illustrated using a case study.

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Thank you

Behrooz Ashrafi

Abstract

Timely delivery of the required goods plays an important role in meeting the availability and reducing the downtime of Markets. Salmon transport logistics is affected in complex ways while operating in the Arctic, since the area is sparsely populated and has insufficient infrastructure. It is also greatly affected by the distinctive operational environment of the region, such as cold temperature, varying forms of ice, blizzards, heavy fog, etc. Therefore, in order to have an effective transport and logistics plan, the effect of all influencing factors, called covariates, on the transportation of the spare parts need to be identified, modelled and quantified using an appropriate dynamic model. The traditional models, however, lack the comprehensive integration of the effect of covariates on the transportation modes. The purpose of this thesis is to introduce the concept of a dynamic model for transportation in Arctic conditions by considering time to delivery as the main attribute. The model continuously updates the prior probabilities according to the most recent time to delivery estimations. The application of the model is illustrated using a case study.

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1 Introduction

1.1 Background

Seafood production is one of the most important industries in Norway. According to (Eurofish, 2018) Norway is the world's leading producer of Atlantic salmon and 2nd largest seafood exporter in the world and the largest supplier of fish and other aquaculture products in the whole Europe (Bizvibe, 2018). Transportation of seafood from northern Norway to the southern cities for the products to be transported to Europe via Oslo, Stockholm or Helsinki is of utmost importance in this industry (Salmonbusiness, 2019). Transport corridors and logistic support between Stokmarknes and Stockholm have a great impact on the availability of the food market and on all the fish markets around the globe. The importance of having resilient and available roads that can help the salmon to be transported on a regular and fast basis is crucial. This is particularly important in the Arctic because of its potentially fragile ecosystem so the roads need to be maintained and inspected more regularly for them to be always available. Therefore, to reduce the health, safety, and environmental (HSE) impact of the transportation activities, the need for a resilient and high-performance transportation and logistics of roads and railway is becoming imperative. (Argyroudis, Mitoulis, Winter, & Kaynia, 2019)

For mitigating the consequences of failures in the distribution of salmon via transport corridors, there is a need to estimate the time that the salmon will need to reach the markets and be distributed. This time is reliant on the availability, reliability, and resilience of the transportation network (railway or road). To achieve this there is need to develop a model that can assure the right transport mode and route will be used. Due to the reduction of time and increasing of the safety of roads (less accidents) the availability of the salmon in the market will increase which in turn will increase the overall effectiveness of the system. However, lack of proper transport infrastructure, road conditions and long distances, harsh operational condition in the arctic will make the transportation of the salmon an arduous challenge. (Jacobsen & Gudmestad, 2012; Markeset, 2008)

The conditions that are present in the arctic region can cripple the transportation network for a while. Blizzards will make going outside for human beings almost impossible. Ice and snow accretion during this kind of weather will accumulate much faster than they could be cleared. Systems that were designed to manage and detect ice cannot work efficiently and because of this, roads will become almost unavailable and trucks cannot operate. For these days, it is impossible to cross the bridges that are important in the transport corridors in Norway. (Jacobsen & Gudmestad, 2012)

In the literature, there are some models and approaches that have been developed to measure and understand the effect of dynamic environment and to find and calculate the mean of the transportation time in the transportation networks.

The problem with the following models is that, they have been developed in a way that it is not possible to use them for the Arctic conditions and they have not considered many of the factors/hazards that will make the arctic conditions severe. There are some models available that have tried to study the dynamic behavior of transportation networks and the effect of time to delivery. The main problem in all the literature regarding this is to model the dynamic operating environment that is present in the Arctic. But when studying the ever-changing Arctic conditions trying to model the dynamic behavior will prove to be a hard task. And to make matters even worse there is a need to completely understand the effects of this phenomenon that can lead to a bad model which won't be able to estimate the transportation time and probabilities. So, the model that developed in this thesis must be able to model the dynamic operating environment on the transportation time.

The final goal of this thesis is to be able to find the best possible option for transportation of goods from Stokmarknes to Stockholm with a decision-based model. The model will be produced considering different transportation modes and routes, and it will help to model the effects of the time to delivery as a main attribute on the probability of choosing each set of routes.

1.1.1 Challenges in the Salmon transportation sector

The salmon transportation industry has several challenges that are affecting the industries everyday business. Resolving these challenges is the first step towards a sustainable and profitable transportation industry.

Harsh operational conditions: The harsh operational conditions are one of the most common issues in the Arctic, these conditions can include, ice and snow accretion, blizzards, wind, heavy rain, fogs etc. These conditions will disrupt the normal transportation schedules and will either make the routes inaccessible or will make them hard to use which will cause significant delays.

Custom stations: The custom stations in Bjørnfjell which is the primary route for salmon transportation is not open all day and, in the weekends is only open for 13 hours each day. This will cause significant delays if the schedule cannot meet the time before the custom stations are closed.

1.2 Legal regulations

This section will discuss the regulations regarding the transportation of aquaculture animals in Norway.

The main concern is to make sure that the quality of the product doesn’t change during transportation, doing so requires that the product is not exposed to changing temperatures or open air that might meddle with the quality of the product. The temperature should not increase over four degrees during the transportation. To address this requirement, the trucks and railcars should be equipped with high quality compartments that do not allow the temperature to deviate from the required range. The salmon will be packed with ice in boxes to keep it cool during transportation. The transportation vehicle should be smooth and easy to clean, and it should be free of pockets, cracks, sharp angels etc. to strengthen the cleaning process. All areas on the transport unit must be inspected in a satisfactory way, grid plates, covers, hinges etc. must be modular in a way that they can be demounted so the inspection can be carried out. (Lovdata, 2017)

1.3 Certificates in salmon production and transportation in Norway

This section will discuss the certificates required to safely process and transport aquaculture products including salmon in Norway:

MSC (Marine Stewardship Council): This certificate will show that: (Marine Stewardship Council, 2019)

- Fish does not come from overfished stocks and the fishing process does not violate the regulations that are set forth to protect the marine ecosystem and it is not hazardous to the environment and fish population.
- This certificate has a standard named Chain and custody, this standard will guarantee that the labelled product comes from MSC sustainable fishing.

DEBIO/KRAV: this label will approve that the product is in line with the rules for the process and selling of organic products. (Debio, 2019)

KOSHER: This certificate indicated that the product is of high quality and consumable. The word Kosher means suitable or pure which will ensure fitness for consumption. (Koshercertification, 2019)

HACCP: This organization will ensure food safety by monitoring and controlling the stages that the food go through to make it to the market these stages can be: (Aquatiq, 2019)

- Raw material handling
- Processing of the raw material
- Handling of the finished products

BRC (British Retail Consortium): This standard will set the requirement for the products safety, quality and hygiene. This standard applies to both the food production and packaging. (British Retail Consortioum, 2019)

Professional transportation act (Norway): This act will ensure the qualification of transport by motor vehicles or vessels in Norway. (Norway Government, 2019)

CMR (International treaty regarding the transportation of goods): The international treaty that will discuss the transportation of products via land across country borders. (JUS.UIO, 2019)

1.4 Problem formulation and objective

The aquaculture industry in vesterålen is expected to significantly increase its production in upcoming decades. The infrastructure for transporting the output to markets, Central Europe, East Asia and the US, is already strained. In order to absorb this increase, both improved logistics efficiency and investments into the infrastructure will be necessary.
The current main routes are:

• By car directly from factories to markets, through either the Bjørnfjell or Skibotn border crossings, with associated customs declaration.

• By car to Narvik Godsterminal Fagernes, reloaded onto trains to either Oslo Godsterminal Alnabru or Padborg, and then again by car to markets.

It is a stated goal of the Norwegian transport authorities that freight be transferred from road transport to sea or railway. However, transport by car is more flexible and often faster and cheaper, and without the inherent capacity limitation of railroad transportation.

Some specific challenges for this corridor is reduced road service levels in winter, limited customs opening hours, and lack of railway capacity.

The problem here is a dynamic goods transportation problem which as we discussed before, the model is going to consider both time-independent and time-independent covariates of the operating environment. The idea here is to find the best possible option from a limited number of routes and transport modes which is either the better transportation mode, or the faster route which will bring us more economical advantage. But, considering the dynamicity of the operational conditions in the Arctic which will affect the time to deliver and the overall cost, this will create a time-dependent decision-making process, or an optimization problem, because we are considering the operating environment to be a covariate.

Optimization of the transport time will lead to the selection of the transport mode; the model will assess the operating environment constantly with the help of probability models. The model wants to understand and infuse the effect of the dynamicity of the Arctic operating environment with the transportation models that are already in use. The model is trying to capture the effects of various factors like operating conditions, weather conditions, road swaps, transport mode swaps etc. on the time to delivery of the products.

1.4.1 Objectives

The objective of the thesis will be to find the best option to transport the salmon from Stokmarknes to Stockholm, and the effect of two proposed investments, namely increased opening hours of the Bjørnfjell customs office, and gradually increase capacity of Ofotbanen, with the goal being double-track railway for the entire stretch.

2 Literature review

There are various stages of literature review throughout this thesis. Each stage will be explained thoroughly in the following sections. These stages consist of searching for different terms that will be used throughout the thesis. For example, the first term(s) that are being reviewed are dynamic transportation networks. For this section a method of systematic literature review has been used. During these years a systematic literature review has become an important criterion in acceptance of a scientific work (compared to more traditional literature reviews). To have an effective systematic literature review there are twelve steps that must be carried out. These steps can be described as:

1. Purpose statement:

Here the purpose of the literature review should be expressed and clarified in clear terms for the reader to know why this systematic literature review has been conducted. The purpose in this literature review is to find the literature about the models that is being used for modeling the dynamicity of transportation networks, the usage of truck/train in the transportation of refrigerated products (namely salmon).

2. Database, search engines used

In this part, the database and search engines that has been used in the literature review needs to be mentioned. There are several good databases and search engines available on the web, (google scholar, the UiT library, Scopus…) but, for the scope of this literature review, which is more engineering based, the best database and search engine is Scopus. In this literature review, the only database and search engine that has been used is "Scopus".

3. Search limits

The limits that have been imposed on searches need to be specified as there was a limitation on the date of the literature, language or other attributes. This step will be discussed in each section separately because the limitation that are imposed on each search term is different.

4. Inclusion and exclusion criteria

In step four, the inclusion and exclusion criteria will be listed to avoid missing important or including irrelevant literature into the review. This point will be explained for each respective section separately.

5. Search terms:

After, the terms used for searching should be listed:

- Dynamic transportation networks

6. Exact searches per database, search engine and the results

According to (Kable, Pich, & Sian, 2012), this step can be described as: "*Document the search process for each search engine including search engine, terms and number retrieved on a search results table.*" As mentioned before, the only search engine and database used in this review is "Scopus" and the search results will be explained respectively in each section.

7. Relevance assessment of the retrieved literature

Here the relevance of the articles found will be tested regarding the inclusion and exclusion criteria. There will be three screening stages for achieving this step. First the articles are screened by title, if the title is relevant, they will move to the 2nd stage in which they will be screened by reading the entire abstract. If the abstract is promising for the work the articles will move to the 3rd stage of the literature review which they will be fully reviewed and used in the work. This step will also be explained in each section respectively.

8. Table reporting literature included in the review

This step includes the key data such as title, author, but also research subject and findings.

9. Document final number of search results

A statement should be provided regarding the number of final articles that has been used in the final screening process. This also will be explained in each section respectively.

10. Quality assessment of retrieved literature

According to (Kable, Pich, & Sian, 2012) quality assessment of retrieved literature can be expressed as: "*Conduct quality appraisal of retrieved literature. Quality appraisal will assist to exclude papers that are poorly designed/executed/ inadequately described studies, where results are biased, or affected by study limitations*"

11. Review

A review of the final chosen articles will be presented in this step. A review of the chosen articles will be preseeted in each section respectively.

12. Accurate complete reference list

The reference list is provided in the reference. Not all of the articles have been included only the final chosen articles.

2.1 Dynamic Transportation Networks

The main scope of this thesis is to find the best model to show the dynamicity of transportation networks. To find this the search term "Dynamic transportation networks" has been used in Scopus. The first two steps in the systematic literature review is constant in all the searches that is going to be conducted. The fifth step is also not being discussed separately here. This section will discuss from the 3rd step in the systematic literature review. A total number of 6565 documents has been initially found in the search at Scopos database.

- Search limits:

The search limits here are, all the articles that are not in English language will not be considered. There are no limits on date and all the articles that are available in the database will be reviewed.

- Inclusion and exclusion criteria:

Here due to the high number of articles found, there is a need to filter some of these articles by limiting the subject area to "engineering" and "decision science". All of the subjects' areas and their inclusion exclusion criteria has been shown in Table 1. Another criterion is to only include the papers that have the keyword "Transportation" in them, all the keywords and their inclusion/exclusion criteria can be found in Table 2. The remaining articles will go through the screening stages. After this inclusion/exclusion process, 1142 articles have remained.

Table 1 inclusion/exclusion criteria by subject area

Subject Area	Inclusion	Exclusion
Engineering	✓	×.
Computer Science	×	✓
Mathematics	×	✓
Decision Sciences	✓	×
Environmental Sciences	×	✓
Business, Management and Accounting	×	✓
Earth and Planetary Sciences	×	✓
Physics and Astronomy	×	✓
Energy	×	✓

Table 2 inclusion/exclusion criteria by keywords

Keywords	Inclusion	Exclusion
Transportation	✓	×.
Traffic Control	×	✓
Motor Transportation	×	✓
Roads and Streets	×	✓
Intelligent Systems	×	✓

The Inclusion/exclusion criteria for the screening stages are:

First Stage:

- Find some resemblance to the model that this thesis is going to build in the title of the article (a dynamic decision-based model)

2nd Stage:

- Finding if the dynamic decision-making model is about the transportation system.

3rd Stage:

    - The reviewed papers will be assessed by the amount of materials that they have and their usefulness for the topic of the thesis.
- Search terms used:

Search terms are used for this literature review session is “dynamic transportation networks”

- Exact searches per database, search engine and the results:

The only database that is being used in this literature review is Scopus. The results of the search were at first without the exclusion/inclusion criteria were 6607 articles.

- Relevance assessment of the retrieved literature:

After the initial inclusion/exclusion (subject area and keywords) 1140 articles remained. The 1140 remained articles have been screened by title in the first stage which led to 34 being picked for the final two stages of the screening process. The second stage was screening the 34 picked articles by abstract. This stage lead to 17 articles being selected for the final stage of the screening process. The final 17 articles have been read thoroughly for the information that will be used throughout the thesis. After reading these papers only 9 of them have been found useful for the purpose of this thesis.

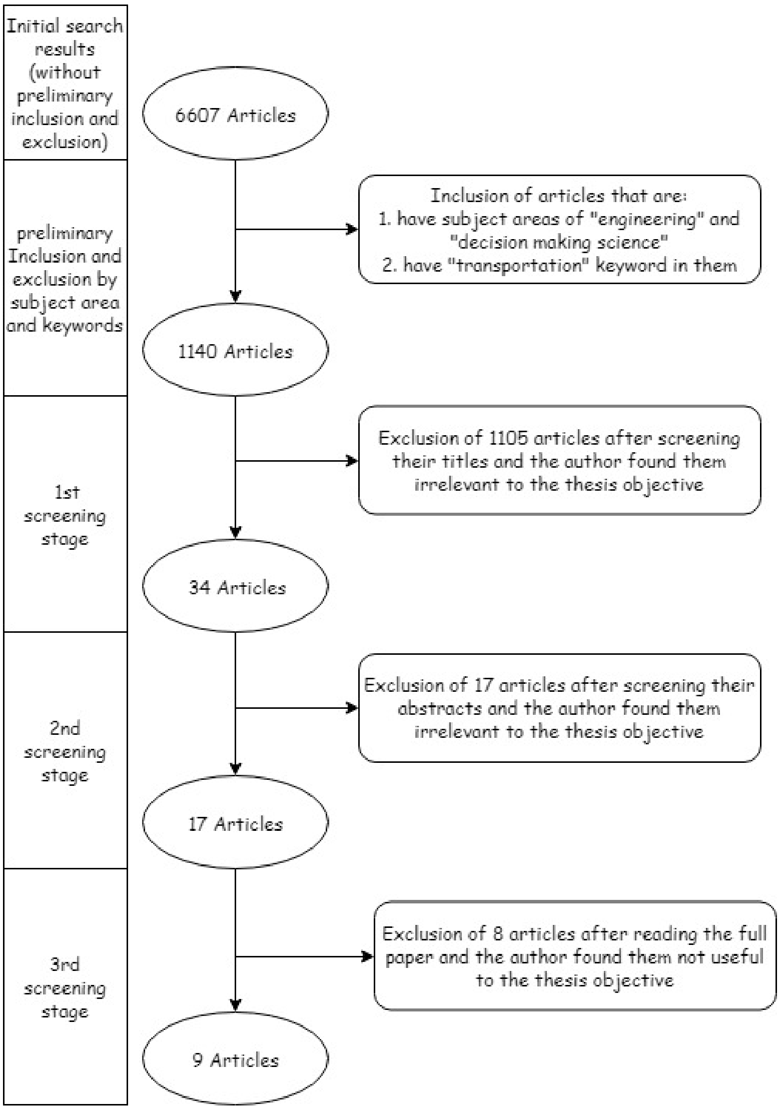

Figure 1 Screening process

- Table reporting included literature in the report:

Table 3 will show the final 17 articles that were screened completely for the usage in this thesis. This table shows the papers with their respective screening stage.

Table 3 literature used in the thesis

Article	2nd stage	3rd stage
Novoa, C., & Storer, R. (2009). An approximate dynamic programming approach for the vehicle routing problem with stochastic demands. *European journal of operational research*, *196*(2), 509-515. (Novoa & Storer, 2009)	✓	×
Musa, R., Arnaout, J. P., & Jung, H. (2010). Ant colony optimization algorithm to solve for the transportation problem of cross-docking	✓	×

network. *Computers & Industrial Engineering*, *59*(1), 85-92. (Musa, Arnaout , & Jung, 2010)		
Miller-Hooks, E., & Mahmassani, H. (2003). Path comparisons for a priori and time-adaptive decisions in stochastic, time-varying networks. *European Journal of Operational Research*, *146*(1), 67-82. (Miller-Hooks & Mahmassani, 2003)	✓	✓
Fosgerau, M., Frejinger, E., & Karlstrom, A. (2013). A link-based network route choice model with unrestricted choice set. *Transportation Research Part B: Methodological*, *56*, 70-80. (Fosgerau, Frejinger, & Karlstorm, 2013)	✓	✓
Larsen, A., Madsen, O. B., & Solomon, M. M. (2008). Recent developments in dynamic vehicle routing systems. In *The vehicle routing problem: Latest advances and new challenges* (pp. 199-218). Springer, Boston, MA (Larsen, Madsen , & Solomon , 2008)	✓	✓
Güner, A. R., Murat, A., & Chinnam, R. B. (2012). Dynamic routing under recurrent and non-recurrent congestion using real-time ITS information. *Computers & Operations Research*, *39*(2), 358-373. (Güner, Murat, & Chinnam, 2012)	✓	✓
Mahmoudi, M., & Zhou, X. (2016). Finding optimal solutions for vehicle routing problem with pickup and delivery services with time windows: A dynamic programming approach based on state–space–time network representations. *Transportation Research Part B: Methodological*, *89*, 19-42. (Mahmoudi & Zhou, 2016)	✓	×
Bookbinder, J. H., & Sethi, S. P. (1980). The dynamic transportation problem: A survey. *Naval Research Logistics Quarterly*, *27*(1), 65-87. (Bookbinder & Sethi, 1980)	✓	×
Qingyun, WANG (2008). Ideology and Practice of Systems Engineering in Multi-Modal Transport Planning. *Journal of Transportation Systems Engineering and Information Technology*, *8*(1), 11-16. (Quingyn, 2017)	✓	×
Xiong, C., & Zhang, L. (2017). Dynamic travel mode searching and switching analysis considering hidden model preference and behavioral decision processes. *Transportation*, *44*(3), 511-532. (Xiong & Zhang, 2017)	✓	✓
Nogal, M., Martinez-Pastor, B., O’Connor, A., & Caulfield, B. (2015). Dynamic restricted equilibrium model to determine statistically the resilience of a traffic network to extreme weather events. In *Proceedings of the 12th International Conference on Applications of Statistics and Probability in Civil Engineering, ICASP12, Vancouver, Canada*. (Nogal, Martinez-Pastor, O'Conner, & Caulfield, 2015)	✓	×
Ayele, Y. Z., Barabadi, A., & Barabady, J. (2016). Dynamic spare parts transportation model for Arctic production facility. *International Journal of System Assurance Engineering and Management*, *7*(1), 84-98. (Ayele, Barabadi , & Barabady, 2016)	✓	✓
Guo, X., & Liu, H. X. (2011). Day-to-Day Dynamic Model in Discrete–Continuum Transportation Networks. *Transportation Research Record*, *2263*(1), 66-72. (Guo & Liu, 2011)	✓	×
Yerra, B. M., & Levinson, D. M. (2005). The emergence of hierarchy in transportation networks. *The Annals of Regional Science*, *39*(3), 541-553. (Yerra & Levinson, 2005)	✓	✓
Li, Y., Tan, Z., & Chen, Q. (2012). Dynamics of a transportation network model with homogeneous and heterogeneous users. *Discrete Dynamics in Nature and Society*, *2012*. (Li, Tan, & Chen, 2012)	✓	×

Ayele, Y. Z., Barabadi, A., & Markeset, T. (2013). Spare part transportation management in High North. (Ayale, Barabadi, & Markeset, 2013)	✓	✓
Haghani, A., & Jung, S. (2005). A dynamic vehicle routing problem with time-dependent travel times. *Computers & operations research*, *32*(11), 2959-2986. (Haghani & Jung, 2005)	✓	✓

- Document final number of search results

The final number of the used articles in this thesis is 9 papers. These 9 papers have been read throughout and the findings are presented.

- Quality assessment of retrieved literature
- Review

Here a short summary of some of the papers that had promising results will be presented:

➢ A dynamic vehicle routing problem with time dependent travel times:

This paper presents a formulation for a dynamic routing problem. It will solve a problem with multiple pick-up and delivery nodes in a system. The formulation will consider real-time variation between travel times, vehicles with different capacities and real time service requests. The proposed formulation is too long and will not be presented here. (Haghani & Jung, 2005)

➢ A link-based network route choice model with unrestricted choice set:

This paper discusses a path choice problem with a random utility model for the path choice. (Fosgerau, Frejinger, & Karlstorm, 2013) proposes an attribute link size that correct the utilities of overlapping paths. The model can handle a network with more than 3000 nodes and 7000 links. The proposed formulation is too long and will not be presented here. (Fosgerau, Frejinger, & Karlstorm, 2013)

➢ Dynamic spare parts transportation model for Arctic production facility

This paper discusses a model for spare part transportation. (Ayele, Barabadi , & Barabady, 2016) utilizes a specialized dynamic reliability block diagram (DRBD) to model a spare part transportation network with multiple transport modes for the delivery of spare parts (dynamic spare part transportation model/block diagram DSTBD). The model uses probability to choose from each transport mode. Each of the transport modes has a deliverability (a probability that the spare parts will be delivered, under a given condition, within a scheduled delivery time) attribute along with a MTTD (mean time to delivery). The probability follows a discrete multinomial logit model. (Ayele, Barabadi , & Barabady, 2016)

- Accurate complete reference list

The articles that has been thoroughly reviewed is presented in table 3 and in the reference section 7.

3 Methodology

3.1 Dynamic transportation model

The idea here is adapted from (Ayele, Barabadi , & Barabady, 2016) dynamic spare parts transportation model/block diagram (DSTBD) which is a specialized type of flowchart for dynamic transport network systems and the interfaces involved between different modes of transport.

The main idea here is to find the best possible route that the goods can be transported from Stokmarknes to Stockholm. There are two different transport modes into play (air can be used as well but this thesis won't consider that because air transport is significantly more costly than transport by railroad and roads) which is railroad cargo and truck cargo. For the railroad there is only one possible route available starting from Narvik and arriving at Stockholm. For the truck cargo however, there are several routes available from Narvik to Stockholm. These routes are presented in the flowchart which is shown in figure 2 there are a total number of five possible options to choose from for this optimization problem. All of them have the first section which is Stokmarknes to Narvik with truck cargo from Narvik there are two possible transport mode options first one is to continue with the truck cargo through either Bjørnfjell customs or Helligskogen customs and the other one is to unload the truck and load the train to go straight to Stockholm.

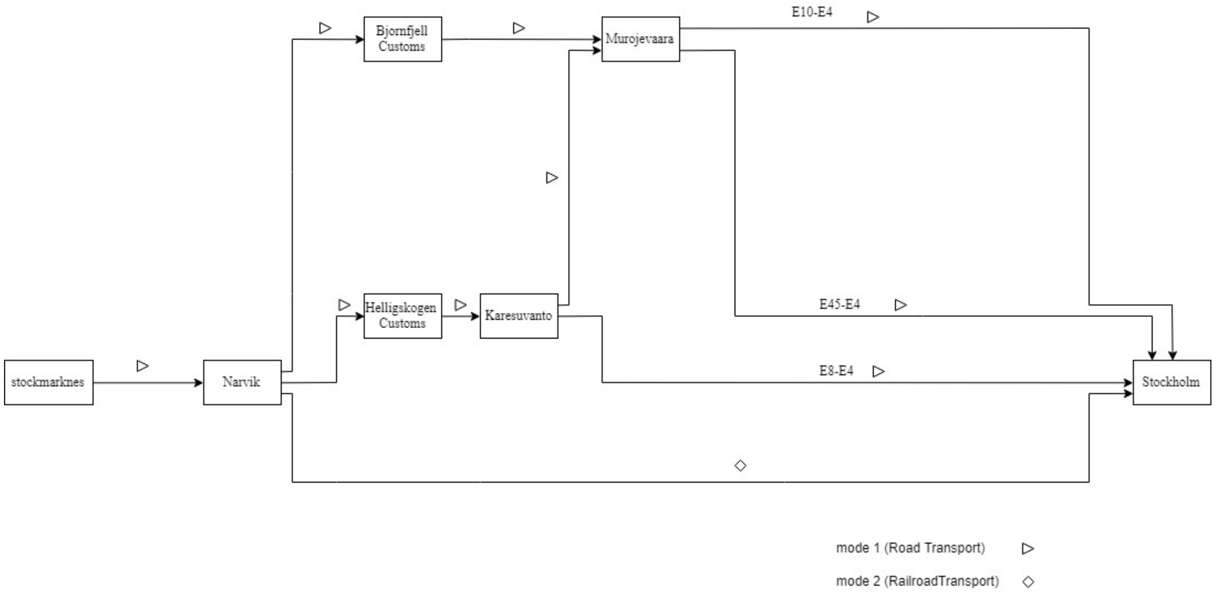

Figure 2 initial schematics of the routes

The model consists of a starting point from Stokmarknes and an output point which is Stockholm (in the future derivations the model can use Oslo or Helsinki as an output as well in this thesis the emphasis is on Stockholm as an output). The transport modes will be presented in the model as a set of blocks the diagram shows how the modes can be combined to operate effectively. Different routes in each transport mode is also shown by blocks. There are decision nodes in the diagram which show that a decision needs to be made in terms of either the transport mode or the route to be taken in the current transport mode.

Figure 3 shows the example of the model, there is a starting point and end point which the goods are transported from and delivered to. There are two possible transport modes which will be chosen by the decision maker based on the P_i, each of this transport modes has their own utility which is the measure of how effective (based on MTTD and disruptions that can occur in each of these blocks) this transport mode is (U_i). Another factor for each mode which will affect the utility is mean time to delivery which is how fast this mode of transportation is $(MTTD_i)$. Decision nodes are there for the model to decide which transport mode to take based on the probability (P_i). After the decision has been made on the transport mode there are checkpoints on the way that will cause the mean time to delivery and utility of a transport mode to vary based on the characteristics of these checkpoints (in this thesis these checkpoints are there to represent the custom stations which have their own opening and closing time which will affect utility and mean time to delivery of a chosen transport mode). Again, there is a probability P_i for each of these checkpoints to be chosen and afterwards based on the conditions they will have their own utility and mean time to delivery ($U_i\ andMTTD_i$). There are some route options as well that again based on the conditions will affect the deliverability and mean time to delivery ($U_i and\ MTTD_i$). Finally the decision nodes are there to show there is a need for a decision to be made either between different transport modes, checkpoints or routes, these decision nodes will make their decision based on how high is the probability P_i of each of the modes, routes or checkpoints to be taken.

To use the model first of all there is a need for all the actors to be identified (see section 3.2) and on top of that there is a need to identify if these actors can act as disturbances or derivations for the model. In this thesis these actors, are factors which will affect the transportation due to either operating conditions or human factors. After identifying these actors there is a need to calculate the probability P_i, utility U_i and mean time to delivery $MTTD_i$ of each of the transport modes, checkpoints and routes.

However, this model considers a full set of all the transport modes, routes and checkpoints from starting point to the end. For example, transport mode 1, necessary checkpoint location 3, and route 1 will form a set that will deliver the goods from starting point location 1 to End point location 2. This model will use the set concept and will find a total probability for each possible set which will consists of each of the modes, routes and checkpoints probability. Although, if needed, one can estimate each of the probabilities using the MTTD of each of the modes and then compare them at each intersection.

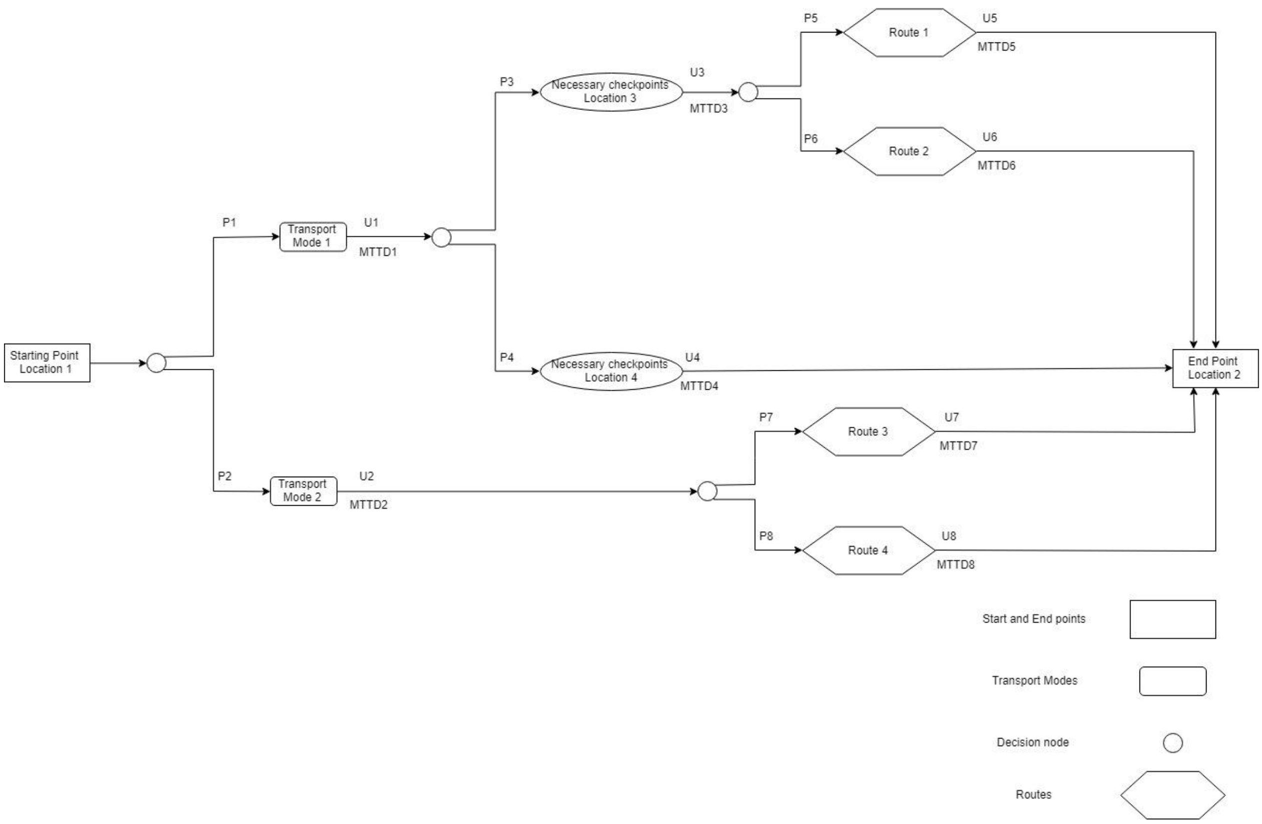

Figure 3 schematics of the model

3.1.1 Time to Delivery (TTD) and mean time to delivery (MTTD)

Time to delivery is the time that is required for the cargo to reach from point a to point b in a single delivery. Mean time to delivery (MTTD) is the average time in which the cargo has been transported from point a to point b on various deliveries. Both parameters are useful in calculating the probability of the decision maker choosing each set of routes to reach the destination. Mean time to delivery however is a better parameter since it shows how a specific set of routes, modes or checkpoints will act over time and in different periods. However, if there are specific conditions about the delivery, which can be the departure is on a specific time or some other disturbances in the system MTTD will become less useful and using a specific time to delivery for that specific conditions will be beneficial.

3.1.2 Probability

For calculating the probability $P_i$of each of the choices represented in the model (routes, checkpoints and transport modes) the discrete choice model will be used. This probability distribution works when facing a discrete set of different choices. This model has been chosen because it can model the complex network behaviors with simple math (logit model) (Khan, 2007)). The logit models use the theory of utility maximization. Utility here denotes to the assets that the decision maker will make after choosing a transport mode, route or checkpoint. The decision maker will choose the mode with the highest net asset (utility). For using the logit model in this thesis model, the way to implement it is to see the decision maker choosing mode or route I from N alternatives which can be expressed by the multinomial logit (MNL) and can be expressed as (Ben-akiva & Lerman, 1985):

$$P_{(i,j)} = \frac{e^{U_{(i,j)}}}{\sum_{\forall(l,k)} e^{U_{(l,k)}}}$$

Equation 1 probability equation

where:

- $P_{(i,j)}$ is the probability of the set of routes (i,j) to be used.
- $U_{(i,j)}$ is utility of set of routes (i,j).
- $U_{(l,k)}$is utility of set of (l,k)

3.1.3 Defining the Utility function

To calculate the probability of a combination of transport routes, checkpoints and modes that is being used there is need to define the utility function for the complete path (from Stokmarknes to Stockholm). The parameter that is going to be used for defining the utility function is time. For each set of routes there is a time to delivery of normal operation that shows the time to delivery when there are no disturbances in the delivery.

$$MTTD_{Actual} = MTTD_{Normal\ Operation} + T_{Delay} + T_{Loading} + T_{Unloading} + T_{Rest}$$

Equation 2 MTTD calculations

Where:

- $MTTD_{Actual}$is the actual mean time of delivery
- $MTTD_{Normal\ Operation}$is the mean time to delivery when there is no delay, loading, unloading or rest in the system.
- T_{Delay} is the time that will be added to actual time to delivery due to road closure, it can be weather effects in the roads. (only applicable to truck cargo)
- $T_{Loading}\ and\ T_{Unloading}$ are the time that is required to load the train at departure and unload it at destination. (only applicable to train cargo)

- T_{Rest} is the total time that the drivers need to rest due to the long driving hours. (only applicable to truck cargo.

$$U_{(i,j)} = \frac{1}{\frac{MTTD_{actual}}{500}}$$

Equation 3 Utility function

Where:

- $U_{(i,j)}$ is the utility of the set of routes i and j.
- The reason for dividing the $MTTD_{actual}$ by 500 is that this will make the model more sensitive to small changes in time to delivery and will be more accurate. It will make the probability of the decision maker choosing the set of routes that has for example 1 hour less time to delivery much higher than the alternate one, which is more realistic.

3.2 General Model

The model as described before is about decision making at some key points and in the end choosing the best option for the transportation. To have a well working model first there is a need to understand and know all the actors and stakeholders that play a role in the model. They all interact with each other, some of them not directly and some indirectly.

- Salmon market
- Salmon production facilities
- Road administration
- Railroad administration
- Truck driver
- Train driver
- Weather conditions
  - Fog
  - Rain
  - Snow
  - Ice
  - Blizzards
- Custom stations
  - Bjørnfjell
  - Helligskogen
- Load and unloading personnel
- Road maintenance personnel
- Railroad maintenance personnel
- Road infrastructure
- Railroad infrastructure

The relationship between these actors is shown in figure 4. These are the identified factors which can be used to strengthen the model. However, since this thesis is only considering time as a parameter, only the effects of weather conditions and custom stations will be directly inserted in the model. Other actors are there but it’s for the future work and will not be accounted for in the scope of this thesis. The model has been built using the Vensim PLE modeling software. (Vensim, 2019)

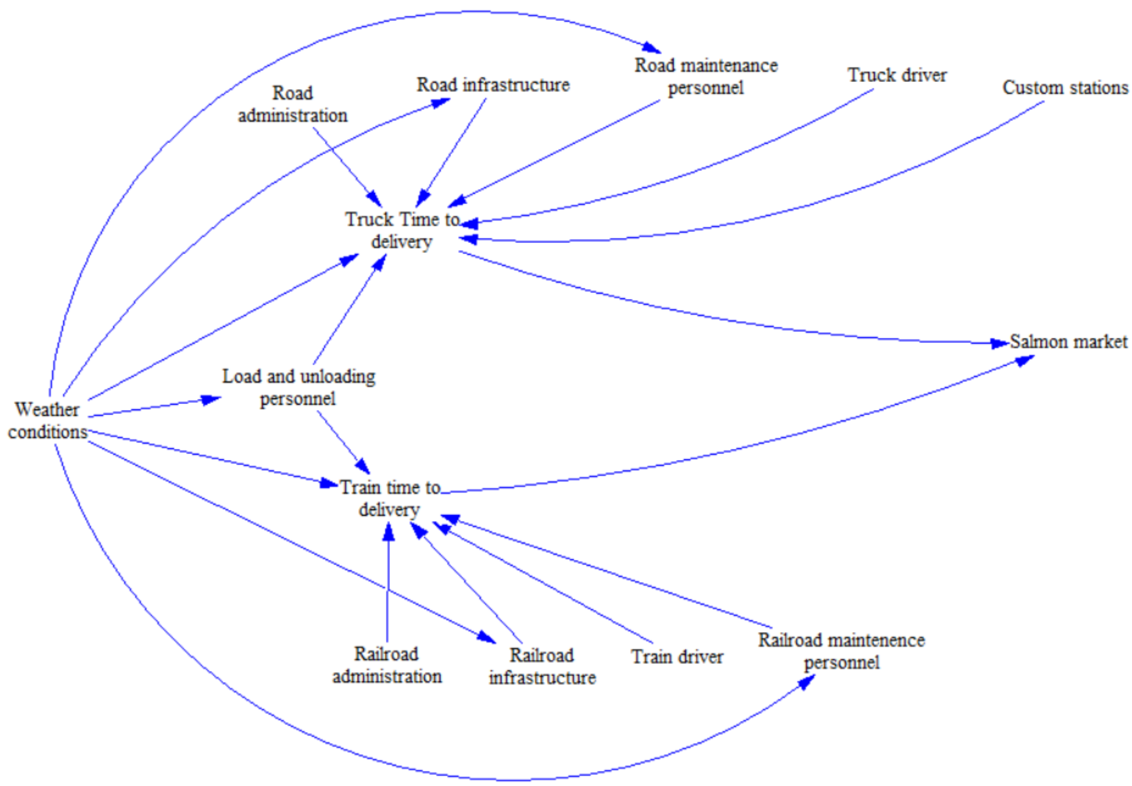

Figure 4 Actors and their relations *(Vensim, 2019)*

4 Case study: Salmon Transportation from Stokmarknes to Stockholm

The model that has been developed in section 3 will be used for a case study that will talk about salmon transportation from Stokmarknes to Stockholm. Stokmarknes is where the salmon production facilities have been located and there is a need to send the salmon south to the transportation hubs for distribution throughout Europe. This case study will only discuss Stockholm as a primary hub of distribution for the salmon market. The destination of case study (Stockholm) is one of the primary hubs in Scandinavia for the salmon market. There are different scenarios in which the salmon can be transported from Stokmarknes to Stockholm which will be discussed further in the case. The case study will discuss the effect of different actors (and covariates) when the decision maker is trying to find the following aspects:

- find the best transport mode, route or checkpoint for delivering the salmon.
- Be able to predict the probability and utility as well as the mean time to delivery.

4.1 Case Description

The case here is multiple transport modes, routs and checkpoints that can be chosen based on the probability, utility and mean time to delivery parameters. Figures 5,6,7 and 8 shows the transport routes from Stokmarknes to Stockholm through with different transport modes and through different checkpoints which here are custom stations.

The first milestone in going from Stokmarknes to Stockholm, the reason for differentiating between the first milestone and the other places is the fact that there is transport mode change option in Narvik, the decision maker can choose to change from the truck and use the train to go on the rest of the way. The reason for having two options in this route is the fact that the Arctic operational conditions can make it difficult sometimes to use one of the routes (roads being closed in winter due to harsh conditions) but one of the routes is the fastest option the other one is for the situations when the main route (E10) cannot be taken.

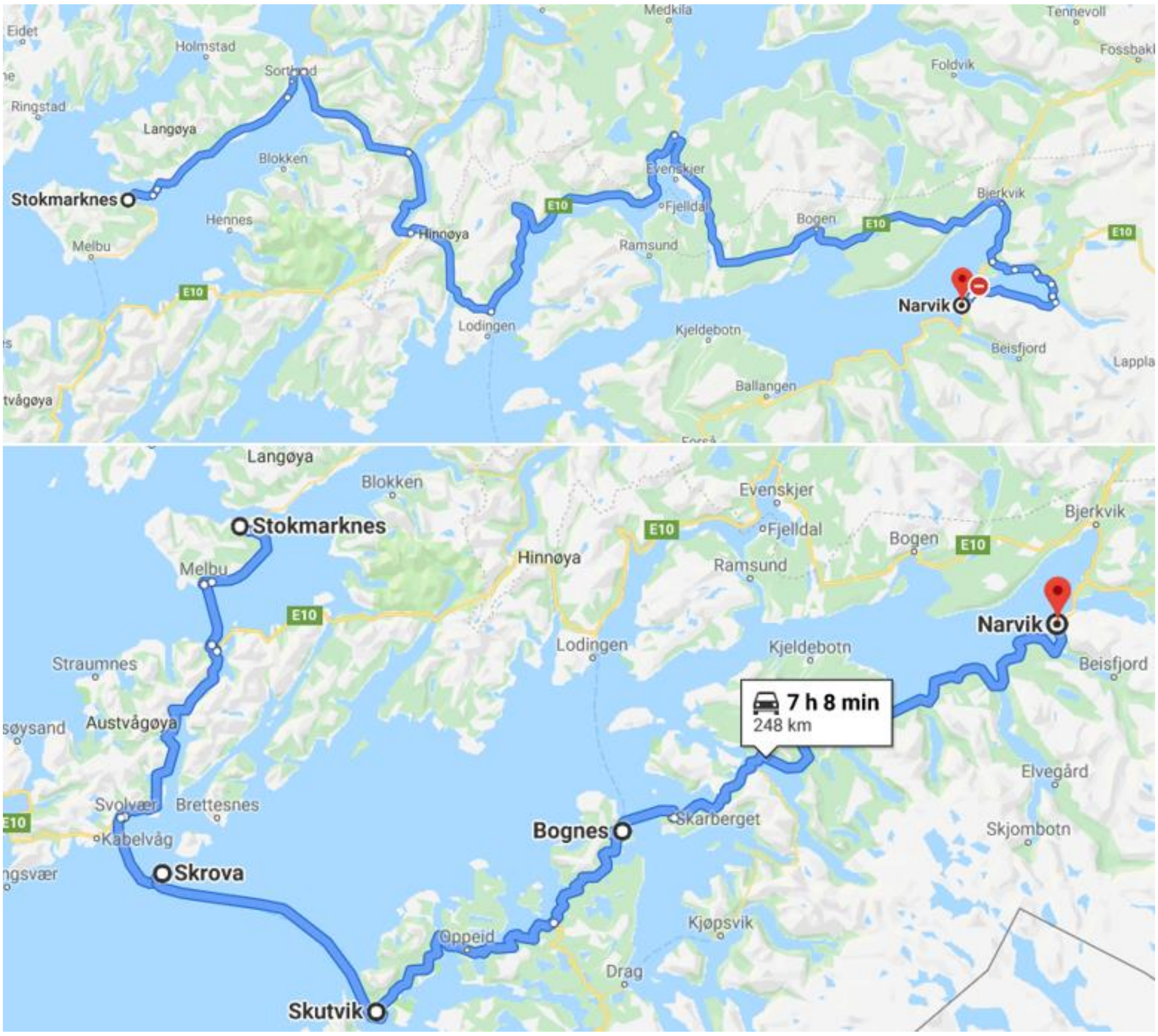

Figure 5 Stokmarknes to Narvik route 1 and 2 (Google, 2019)

Figure 5 shows the possible routes from Narvik to Stockholm via Bjørnfjell customs, again here there are two possible options for the decision maker to choose from, and it is apparent from the google maps data that one of them (via Gallivare and Ostersund) is slightly longer and time consuming. But for the same reason as having harsh operational conditions in the Arctic will eventually cause problems for the roads so there is a need to always have alternative options in these conditions. The Bjørnfjell customs station however is not open always the (see section 4.2.1) so in case of late-night delivery schedules these two routes cannot be taken.

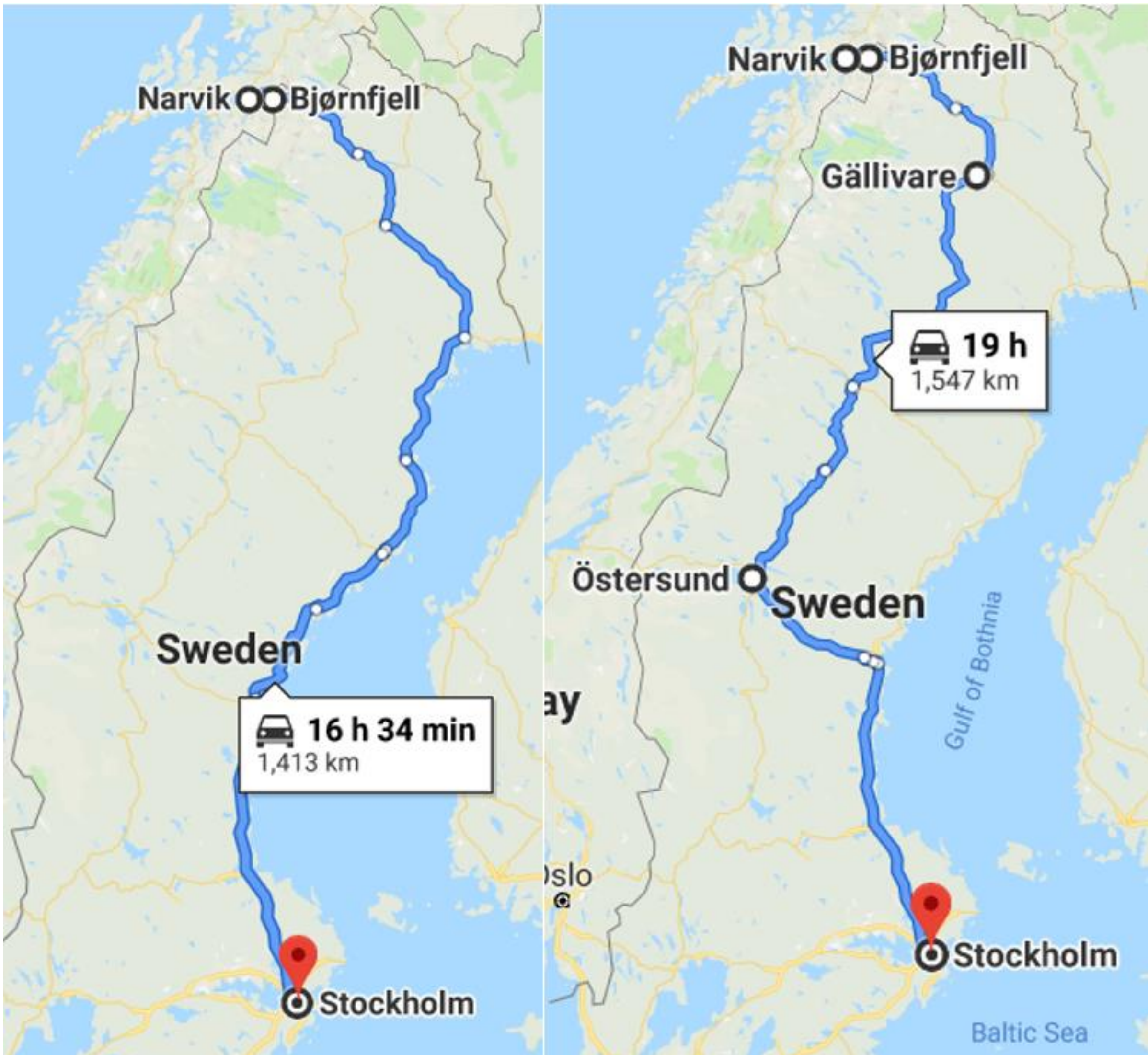

Figure 6 Narvik to Stockholm via Bjørnfjell route 3 and 4 (Google, 2019)

Figure 6 shows the possible routes from Narvik to Stockholm via Helligskogen, there are two possible options for the decision maker to choose from. The reasoning behind having two possible options is again the same as before, one of the roads might be closed/hard to use due to the operational conditions, and decision maker can decide to use either one of the options. These routes will go through the Helligskogen customs which is located in the border of Norway and Finland, this routes will take longer than the routes 3 and 4 because to get to the Helligskogen customs there is a need to go far up north and come back down but because of the fact that this customs station is always open there is a need to use these routes from time to time.

Figure 7 Narvik to Stockholm via Helligskogen route 5 and 6 (Google, 2019)

Figure 7 shows the train route from Narvik to Stockholm, there is only one railroad track to use in this mode of transportation, but there won't be any sort of custom control problems with the train. There is, however, the problem of unloading the salmon cargo in Narvik and load the cargo in train which costs both time and money and to unload the train in Stockholm and distribute it. These extra costs otherwise could have been avoided with the truck cargo.

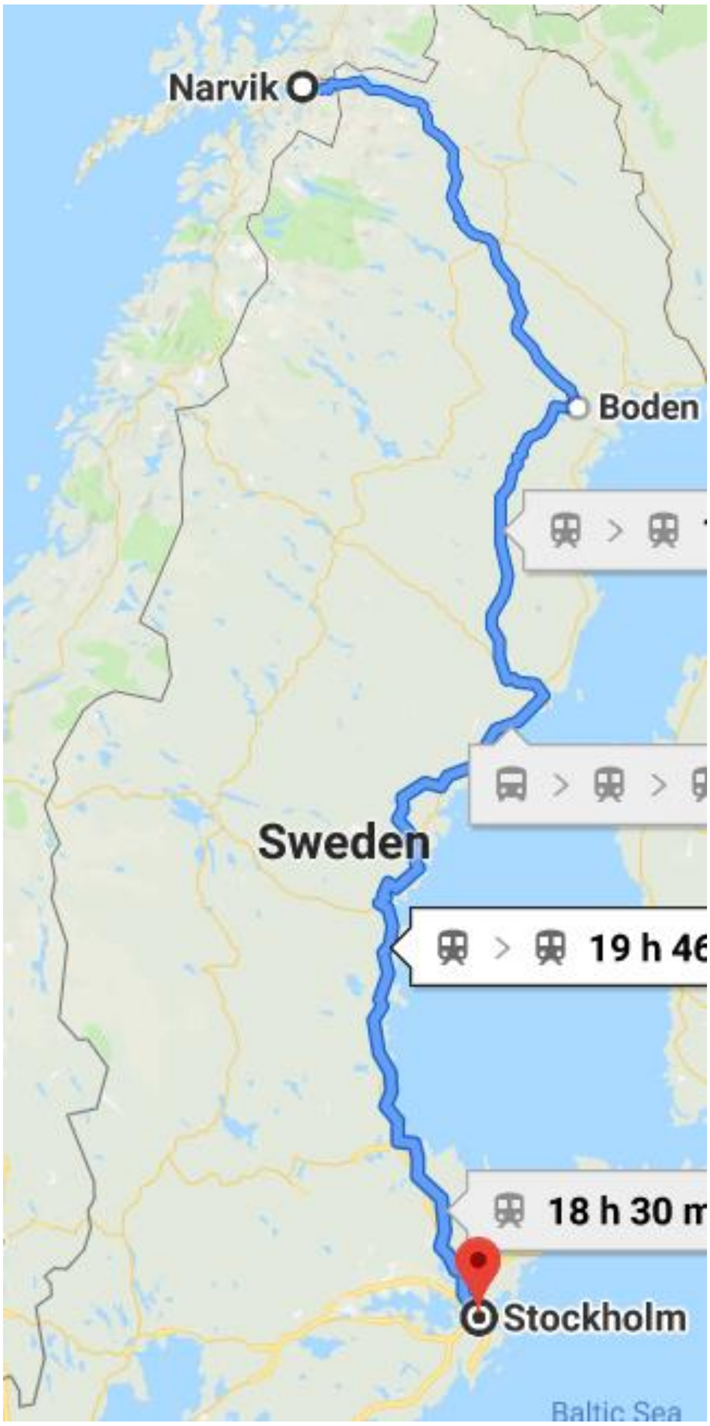

Figure 8 Narvik to Stockholm train route (Google, 2019)

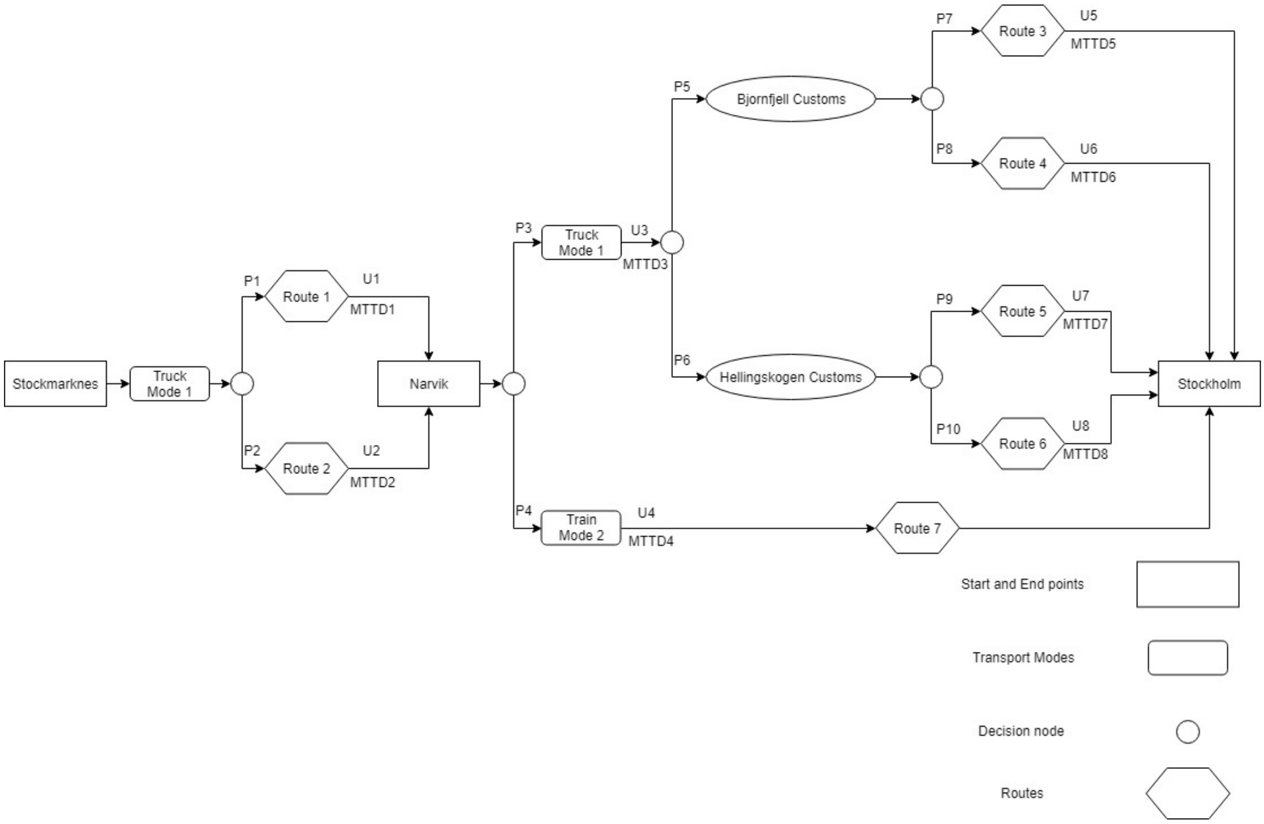

Figure 9 Schematics of the model for the case study

Figure 9 shows the schematics of the model for this case study.

4.2 Custom stations description

This section will discuss the custom stations and their attributes and how they will affect the utility and mean time to delivery in the model.

4.2.1 Bjørnfjell customs staion

Bjørnfjell customs station is located in the border between Norway and Sweden with a latitude 68.434523 and longitude of 18.111051, this station is the main customs for transporting the salmon to Stockholm but there is a problem that it’s not always open, and the opening hours are different in different periods of year. The opening and closing times of this customs stations is represented in table 4. It is apparent that if the passage for truck cargo cannot be arranged around 02:00 to 08:00 AM in the period between January to April and 08:00 to 23:00 in the period of May to December. There are some days that this customs station will be always closed which has been shown in table 4. (Norwegian Customs, 2018)

Table 4 Bjørnfjell opening/closing time

January-April	
Monday-Friday	08:00-02:00
Saturday	08:00-23:00
Sunday	13:00-23:00
May-December	
Monday-Friday	08:00-23:00
Saturday	08:00-23:00
Sunday	13:00-23:00

Special always closed
1st, 10th, 19th and 20th May

4.2.2 Helligskogen Customs station

Helligskogen customs office is located at the border of Norway and Finland with a latitude of 69.109388 and a longitude of 20.751238. This custom station is open all the time, even in the national holidays. The problem with this customs station is the fact that it is farther north than the Bjørnfjell customs station. But in some situations, it is the better option since its always open. (Norwegian Customs, 2018)

4.3 Railroad description

The railroad from Narvik to Stockholm is the 2nd transport mode for delivering the cargo after it has been transported from Stokmarknes to Narvik via truck cargo. Railroad is a better form of transport than road, since there is no need to pass the customs stations and it will go directly from Narvik to Stockholm without any stops. Also, there is no need for rest for the drivers in a train which will decrease time to delivery. The problems however are loading at departure and unloading in the destination which will increase time to delivery. Also, trains leave at a specific time from Narvik, so the cargo needs to wait in case it wants to move with the train.

4.3.1 Train timetable Narvik-Stockholm

Trains leave once a day from Narvik to Stockholm. The time has been shown in table 5. (Train Stockholm, 2019)

Table 5 Train departure time

Departure time (Narvik)	Arrival time (Stockholm)
15:15	10:15

4.4 Ferries description

There are some ferries in alternate route 2 that can be used in case of extreme weather and road closure on route 1. These ferries have specific departure times and respective timetables. Since the trucks need to wait for the ferries to depart to continue the ferry timetable is going to be important in this thesis.

4.4.1 Melbu-Fiskebøl ferry

Melbu-Fiskebøl ferry is the first ferry in the route. The timetable for this ferry is shown in table 6. From the table it is apparent that with a uniform dispatch time distribution, there are a lot of waiting time at Melbu. For example, all departures from Stokmarknes before 6:00 need to wait for the first ferry in the morning. (torghatten nord, 2019)

Table 6 Melbu-Fiskebøl ferry timetable

	Weekdays	Saturday	Sunday
Departure time	6:20	6:20	N.A.
	7:50	7:50	7:50
	9:50	9:50	9:50
	11:10	11:10	11:10
	12:30	12:30	12:30
	14:00	14:00	14:00

	15:20	15:20	15:20
	16:40	16:40	16:40
	18:30	18:30	18:30
	20:15	20:15	20:15
	21:30	21:30	21:30

4.4.2 Svolvær-Skutvik ferry

Svolvær-Skutvik ferry is the second ferry in the route. The timetable for this ferry is shown in table 7. This ferry is the weakest link in the chain that will cause most of the delay for its fewer departure times during a day. The truck needs to wait a long time for this ferry. (torghatten nord, 2019)

Table 7 Svolvær-Skutvik ferry timetable

	Weekdays	Saturday	Sunday
Departure time	6:45	9:00	13:00
	14:00	15:00	16:00
	16:00	N.A.	20:45
	20:45	N.A.	N.A.

4.4.3 Bognes-Skarberget ferry

Bognes-Skarberget ferry is the third ferry in the route. The timetable for this ferry is shown in table 8. This ferry has 21 departure times during various times of a day and will not cause delays in the route. (torghatten nord, 2019)

Table 8 Bognes-Skarberget ferry timetable

	Weekdays	Saturday	Sunday
Departure time	00:15	00:15	00:15
	04:00	04:00	04:00
	05:35	05:35	05:35
	06:50	06:50	06:50
	08:00	08:00	08:00
	09:10	09:10	09:10
	10:00	10:00	10:00
	10:30	10:30	10:30
	11:25	11:25	11:25
	11:45	11:45	11:45
	13:10	13:10	13:10
	14:05	14:05	14:05
	14:45	14:45	14:45
	15:30	15:30	15:30
	16:15	16:15	16:15
	17:00	17:00	17:00
	18:00	18:00	18:00
	18:30	18:30	18:30
	19:45	19:45	19:45
	21:15	21:15	21:15
	22:45	22:45	22:45

4.5 Data Collection

The data for this thesis has been collected with the help of SINTEF. After consulting them it has been established that the best way to estimate the time to delivery for the routes that have been chosen for the model is to use the google maps data. And for the weather conditions the Meterologisk institute database have been used. Some of the routes will use ferries for crossing the water, the schedule for the ferries throughout the year have been used. The dispatch times for the trucks from Stokmarknes has been assumed to be uniform through a half an hour interval from 6-21 (6-6:30-7-7.30 …). The data from google maps has been extracted from point to point, with respect to ferry times, opening hours of the custom stations and other checkpoints along the map. These extracted data have been stored in an excel sheet which will be presented in the final transcript as an appendix. (Google, 2019)

4.6 Routes advantages and disadvantages

There are a total number of 7 routes that have been identified as the possible corridors from Stokmarknes to Stockholm. Each of these routes have their own advantages and disadvantages. These advantages and disadvantages are explained below:

Main route 1:

- ✓ Advantages:
  - o It is 3.713 hours faster than its counterpart alternative route 2.
  - o There are no waiting times in this route (waiting time includes waiting for Ferries, waiting at custom stations or wait for loading and unloading)
- ✗ Disadvantages:
  - o In case of a severe weather condition this route will experience some delays due to multiple bridges that are on this route.

Alternative Route 2:

- ✓ Advantages:
  - o This route is immune to severe weather conditions and won't face any delays since it uses ferries and won't experience delays in case of a severe weather.
- ✗ Disadvantages:
  - o This route will take longer than its counterpart main route 1 in normal operations.
  - o There are multiple waiting times in this route due to the ferries schedule. There are 3 ferries on this route with different departure times that will cause delays in the final delivery time.

Main route 3:

- ✓ Advantages:
  - o It is 2.08 hours faster than its counterpart alternative route 4.
- ✗ Disadvantages:
  - o This route will go through Bjørnfjell customs station which will cause delays in certain times of the day.

Alternative route 4:

- ✓ Advantages:
  - o This route is only implemented in the model in case of an emergency scenario (which has not been analyzed further in the thesis) in main route 3.
- ✗ Disadvantages:

    - This route will go through Bjørnfjell customs station which will cause delays in certain times of the day.
    - It is 2.08 hours slower than its counterpart main route 3.

Main route 5:

- ✓ Advantages:
    - This route will go through Helligskogen customs station and won't face any delays.
    - This route is 2.32 hours faster than its counterpart alternative route 6.
- ✗ Disadvantages:
    - Because of the time to reach Helligskogen, this route will inherently take more time than both main route 3 and alternative route 4.

Alternative route 6:

- ✓ Advantages:
    - This route is only implemented in the model in case of an emergency scenario (which has not been analyzed further in the thesis) in main route 5.
- ✗ Disadvantages:
    - Because of the time to reach Helligskogen, this route will inherently take more time than both main route 3 and alternative route 4.
    - It is 2.32 hours slower than its counterpart main route 5.

Main route 7:

- ✓ Advantages:
    - This route is a train route and will go from Narvik to Stockholm without any further delays.
- ✗ Disadvantages:
    - There is a need to unload the trucks and load them into the train which will cause delays.
    - Train leaves only once every day from Narvik to Stockholm, which will cause significant waiting times for the cargo.

4.7 Route set definitions

Route sets are the combination of multiple routes (without considering the transport mode) that will deliver the salmon from Stokmarknes to Stockholm. In this thesis there are a total number of 10 route sets that can be utilized for that purpose. These route sets have a combined probability of the transport routes, checkpoints and modes that have been used in these route sets. A schematic of all these route sets is shown in figure 9.

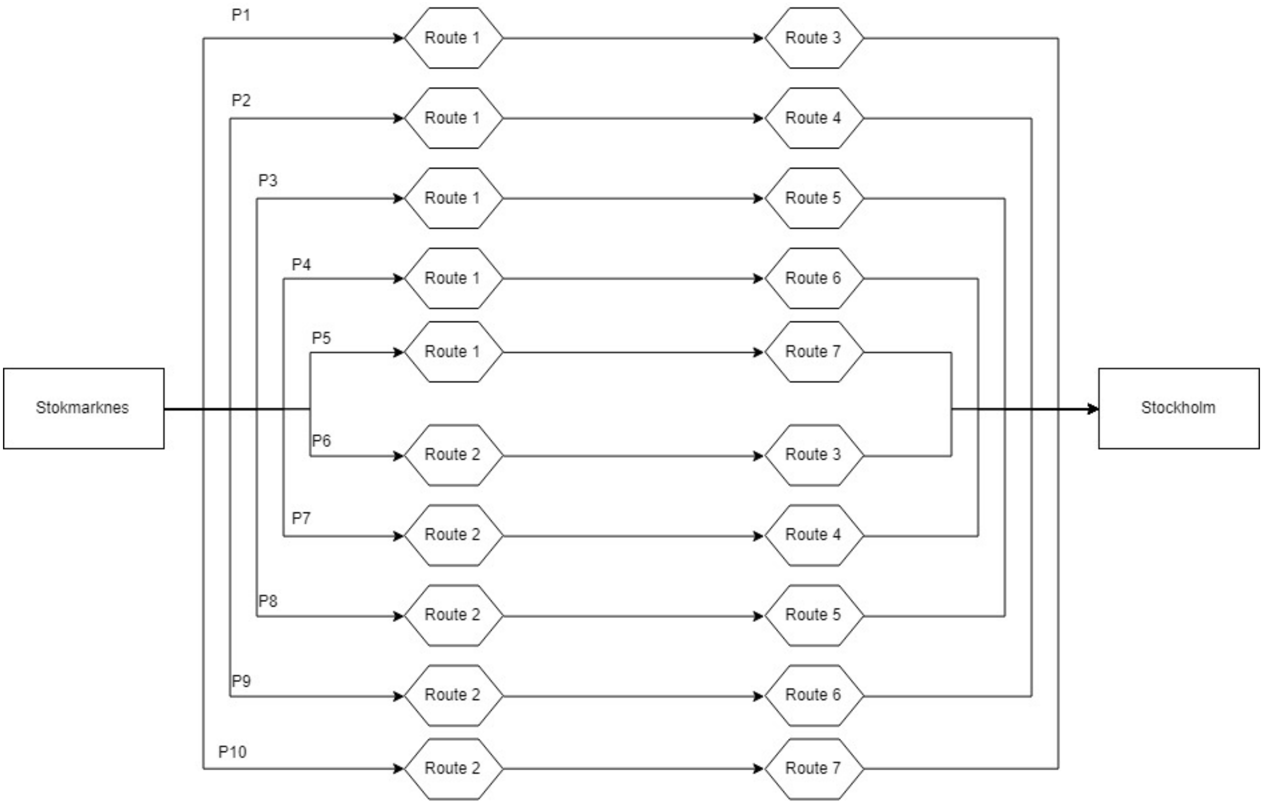

Figure 10 Route sets

The definitions for these route sets are:

- Route set (1,3): this route set takes the main route 1 from Stokmarknes and will arrive at Narvik. It will continue to main route 3 and will go through Bjørnfjell customs stations to reach Stockholm.
- Route set (1,4): this route sets takes the main route 1 from Stokmarknes and will arrive at Narvik. It will continue to alternative route 4 and will go through Bjørnfjell customs stations to reach Stockholm.
- Route set (1,5): this route set takes the main route 1 from Stokmarknes and will arrive at Narvik. It will continue to main route 5 and will go through Helligskogen customs stations to reach Stockholm.
- Route set (1,6): this route set takes the main route 1 from Stokmarknes and will arrive at Narvik. It will continue to alternative route 6 and will go through Helligskogen customs stations to reach Stockholm.
- Route set (1,7): this route set takes the main route 1 from Stokmarknes and will arrive at Narvik. In this set there is a transport mode change from truck to train at Narvik. It will continue to Stockholm on train.
- Route set (2,3): this route set takes the alternative route 2 from Stokmarknes and will arrive at Narvik. It will continue to main route 3 and will go through Bjørnfjell customs stations to reach Stockholm.
- Route set (2,4): this route set takes the alternative route 2 from Stokmarknes and will arrive at Narvik. It will continue to alternative route 4 and will go through Bjørnfjell customs stations to reach Stockholm.
- Route set (2,5): this route set takes the alternative route 2 from Stokmarknes and will arrive at Narvik. It will continue to main route 5 and will go through Helligskogen customs stations to reach Stockholm.

- Route set (2,6): this route set takes the alternative route 2 from Stokmarknes and will arrive at Narvik. It will continue to alternative route 6 and will go through Helligskogen customs stations to reach Stockholm.
- Route set (2,7): this route set takes the alternative route 2 from Stokmarknes and will arrive at Narvik. In this set there is a transport mode change from truck to train at Narvik. It will continue to Stockholm on train.

5 Analysis

In this section the analysis that has been done on the model and data to gather the required information will be explained. The assumptions that were used during these calculations are as follows:

- A uniform dispatch time has been assumed from Stokmarknes. This dispatch time is assuming that cargo trucks will leave Stokmarknes every 30 minutes starting from 00:30 until 24:00. There is a total of 48 dispatch times throughout the day.
- Effects of weather and accidents will be considered as a delay in some of the routes and transport modes. For example, in case of an intense snowstorm and blizzard bridges in route one will be temporary closed and will cause delays in case the decision maker decides to take this route.
- There are debates on whether the Bjørnfjell customs stations should be always open or not. This thesis will assume both cases for comparison.
- Routes 3, 4, 5, and 6 are assumed not to be affected by the weather effects.
- Difference in summer and winter is only due to the delay that extreme weather effects will cause. The general increase in driving time due to the normal ice and snow buildups in the roads will be neglected in this thesis.
- The time that is needed for drivers to check in at the customs stations is neglected in this thesis.
- Ferries will not be affected by extreme weather.
- Bridges are the only things that will be affected by the extreme weather conditions. Thus, route 1 will be unavailable in case of a severe weather condition.
- The weather data could not be gathered at this thesis, so the number of days that the extreme weather conditions will disrupts have been assumed 15% of the time in winter and 3% of the time in summer.
- It is assumed that the trucks will operate only in weekdays and weekends are not analyzed in the scope of this thesis (there are different timetables for both custom stations and ferries for weekends)
- For every four and a half hour driving at least 45-minute resting time is mandatory. (Vegvesen, 2019)
- It is assumed that both loading and unloading of trains will take 2 hours each.
- It is assumed that for severe weather conditions main route 1 will have a mean delay time of 8 hours and a standard deviation of 2 hours.

5.1 Estimating the baseline TTD and MTTD for each set of routes

Baseline time to delivery (TTD) is the time to delivery without any delays in the system. It denotes to the TTD with the normal operating conditions without considering the effects of weather, accidents, drivers rest and loading and unloading time for the train. This TTD has been calculated with the data from google maps (road and train timings), custom stations opening and closing times, train dispatch times, and a uniform dispatch time. Each TTD denotes to a singular dispatch time and the average of these TTD's for each route set will form the mean time to delivery for that route set. The baseline for each route set will be discussed in the following sections.

5.1.1 Route set (1,3)

These route set are the main line for delivering the cargo. The truck cargo will dispatch from Stokmarknes taking route 1 and continue with the cargo to route 3. There is no waiting time in Narvik this is applicable for all truck cargo, the only two route sets that has waiting time in Narvik is the train route (1,7) and (2,7). However, in case of arriving at Bjørnfjell in closing times the cargo needs to wait until its open. The calculations for these routes are stored in an excel sheet which will be presented in the appendix section. Time to delivery with respect to dispatch times is shown in fig. 11.

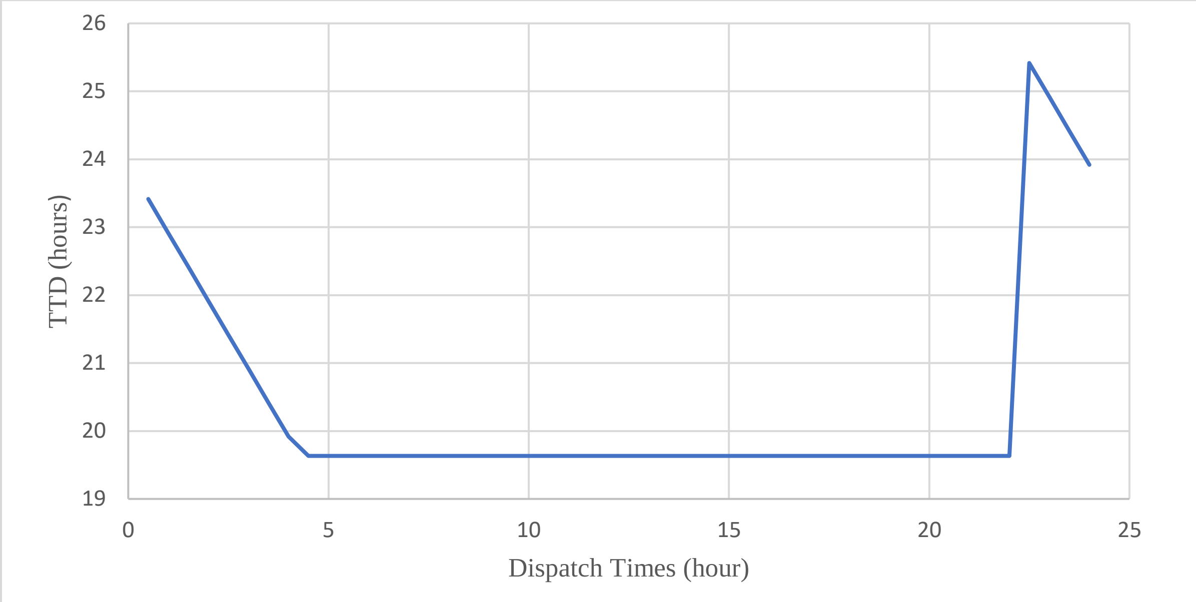

Figure 11 TTD distribution with respect to dispatch times for route set (1,3)

In this chart Y axis shows time to delivery in hours and X axis shows the dispatch times which starts from 00:30 until 24:00 each of the respective dispatch times have their own TTD. The waiting times due to Bjørnfjell closing times are apparent in this chart. For example, if the truck leaves Stokmarknes at 00:30 it will arrive at Bjørnfjell at 4:13, and it needs to wait until next morning 8:00 to leave so TTD will increase. The final mean time to delivery (MTTD) for these set of routes is **20.31** hours.

5.1.2 Route set (1,4)

This route set uses the main route 1 from Stokmarknes to Narvik and then the alternative route 4 (in case of emergency in the main route 3). Time to delivery with respect to dispatch times is shown in fig. 12. Route sets (1,3) and (1,4) have similar patterns the only difference is a 2.08 hour shift due to the road length and conditions in routes 3 and 4. The reason for considering this alternative route 4 is in case of route 3 being closed for any reason. Since the difference is not that significant (2.08 hours) any disturbances in route 3 will lead to the decision maker choosing alternative route 4. The final mean time to delivery (MTTD) for this route set is **22.47** hours.

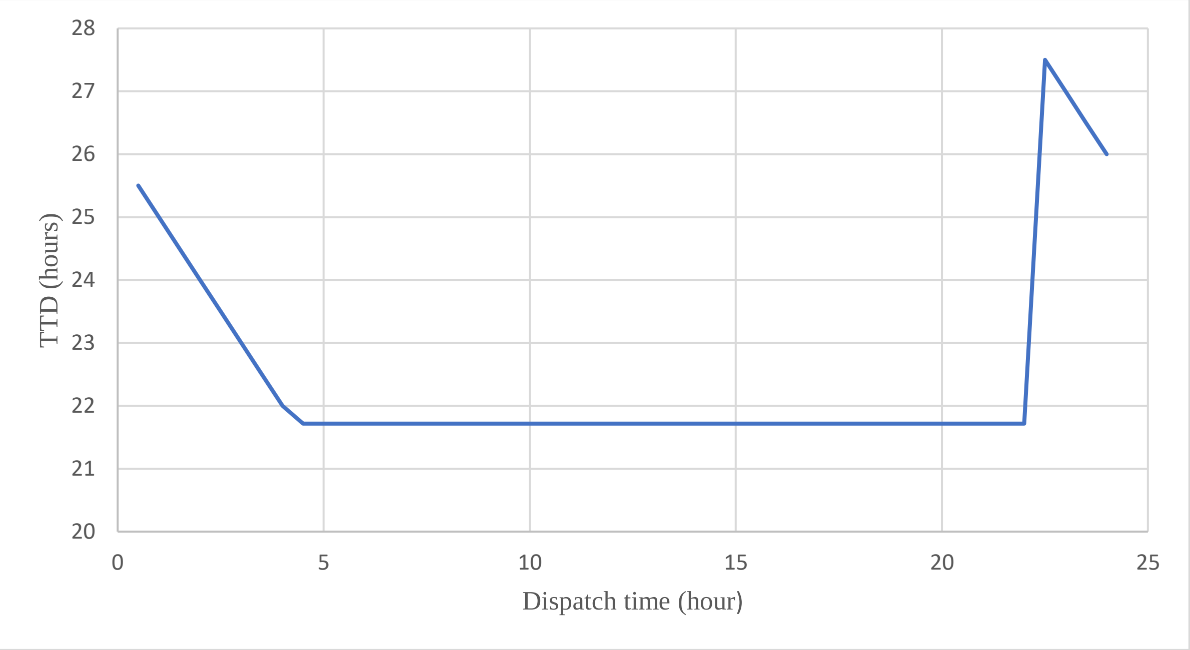

Figure 12 TTD distribution with respect to dispatch times for route set (1,4)

5.1.3 Route set (1,5)

In this route set, the truck will departure from Stokmarknes for Narvik via main route 1 and continue to Stockholm via route 5 which will use Helligskogen customs station that is always open. The benefit of this route set is the fact that there is no waiting time in Helligskogen which can lead to less TTD in some of the dispatch times. Fig. 13 shows time to delivery with respect to dispatch times. This chart shows that there is no difference in time of the day for this route set. For some dispatch times (00:30, 22:30, 23, 23:30 and 24) this route set possess the better time to delivery over the route set (1,3). The final mean time to delivery of this route set is **22.95** hours. Although these route set is the better option is some specific dispatch times the overall MTTD for them is more than both routes (1,3) and (1,4).

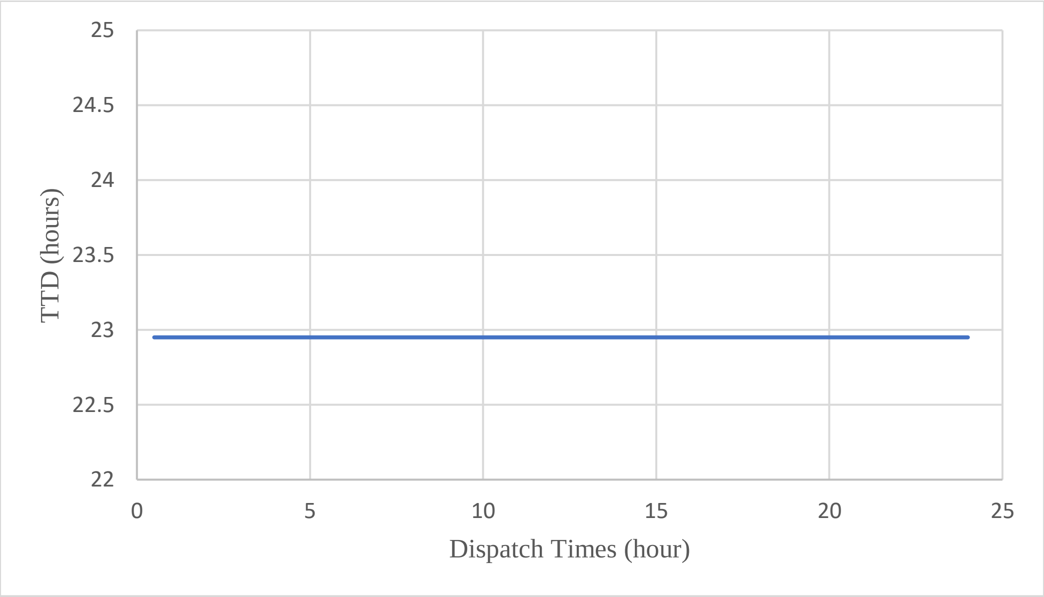

Figure 13 TTD distribution with respect to dispatch times for route set (1,5)

5.1.4 Route set (1,6)

In this route set, the truck will again take route 1 from Stokmarknes to Narvik and continue to alternate route 6 (in case of emergency in route 5) to Stockholm via Helligskogen. Time to delivery with respect to dispatch times is shown in fig. 14. The pattern between the route sets (1,5) and (1,6) is the same with a 2.32 hour difference. The final mean time to delivery for this route set is **25.27** hours.

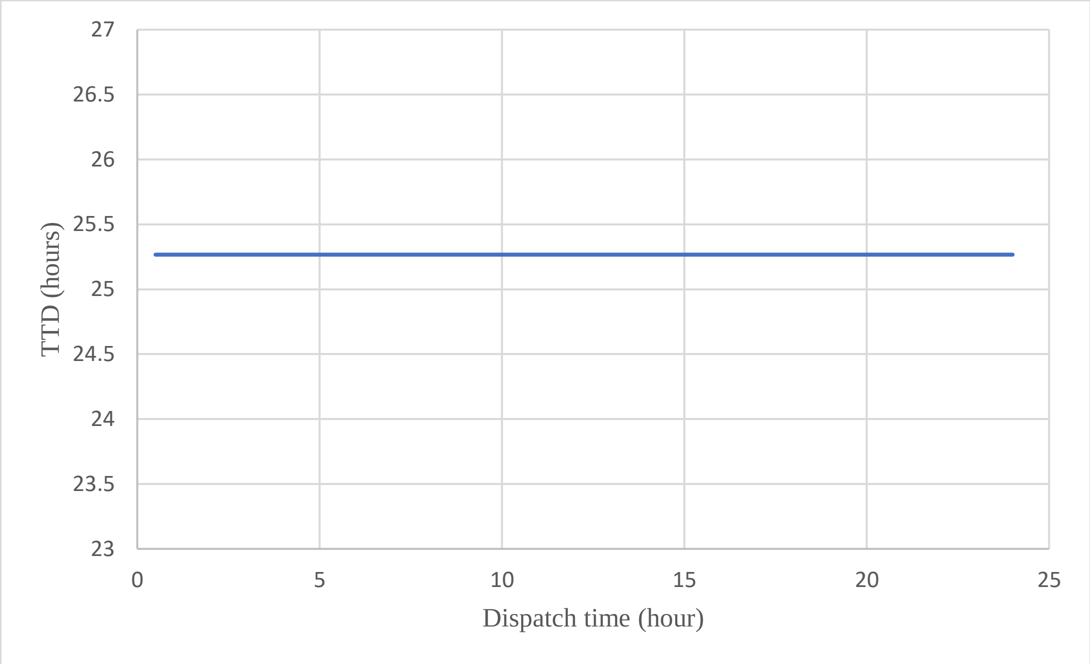

Figure 14 TTD distribution with respect to dispatch times for route set (1,6)

5.1.5 Route set (2,3)

This route set will take the alternative route from Stokmarknes to Narvik which is the route with Ferries. it will continue to Stockholm via Bjørnfjell in main route 3. The benefits of the alternative route 2 is that it is not affected by the extreme weather. Fig. 15 shows the time to delivery with respect to dispatch time. There are various parameters that are causing an increase in time to delivery in this route set. The ferry timetables in Melbu, Svolvær and Bognes these three ferries have specific times of operation and this will cause the time to delivery to increase in certain dispatch times. This is due to the waiting times at ferries. The other factor is waiting time in Bjørnfjell when arrived between 2:00 and 8:00. The final mean time to delivery for this route set is **31.86** hours.

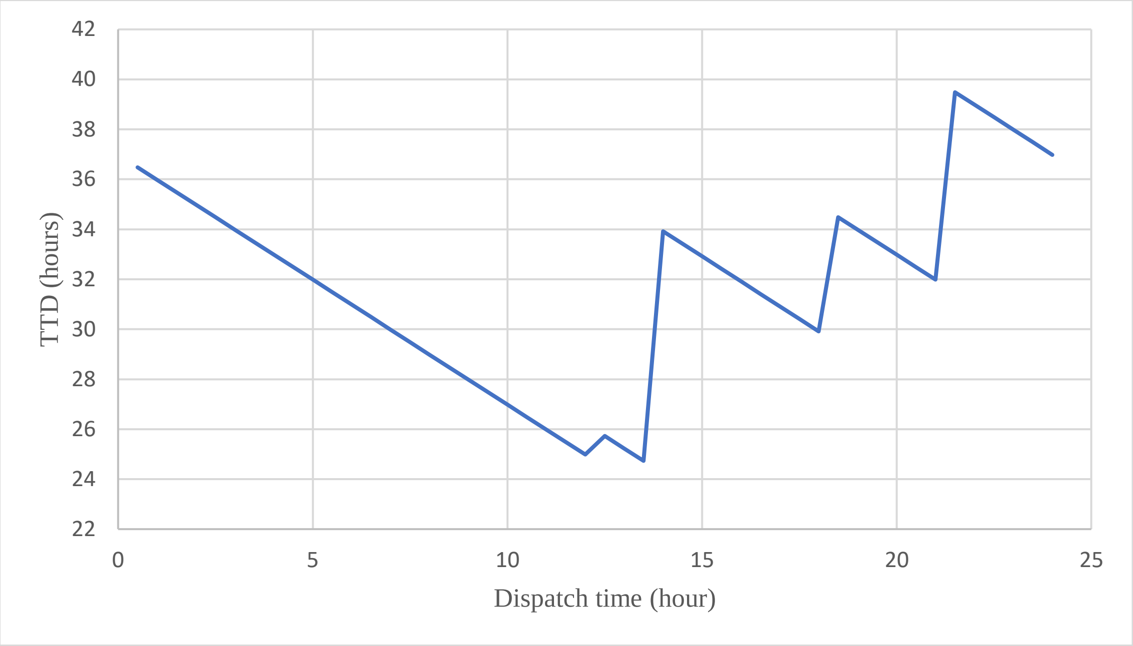

Figure 15 TTD distribution with respect to dispatch times for route set (2,3)

5.1.6 Route set (2,4)

This route set will take the alternative route from Stokmarknes to Narvik which is the route with Ferries. it will continue to Stockholm via Bjørnfjell in alternate route 4. Time to delivery with respect to dispatch time is shown in fig. 16. Again, the pattern in route sets (2,3) and (2,4) is the same the only difference is a 2.08 hour shift due to the road length and conditions in routes 3 and 4. The final mean time to delivery for this route set is **33.94** hours.

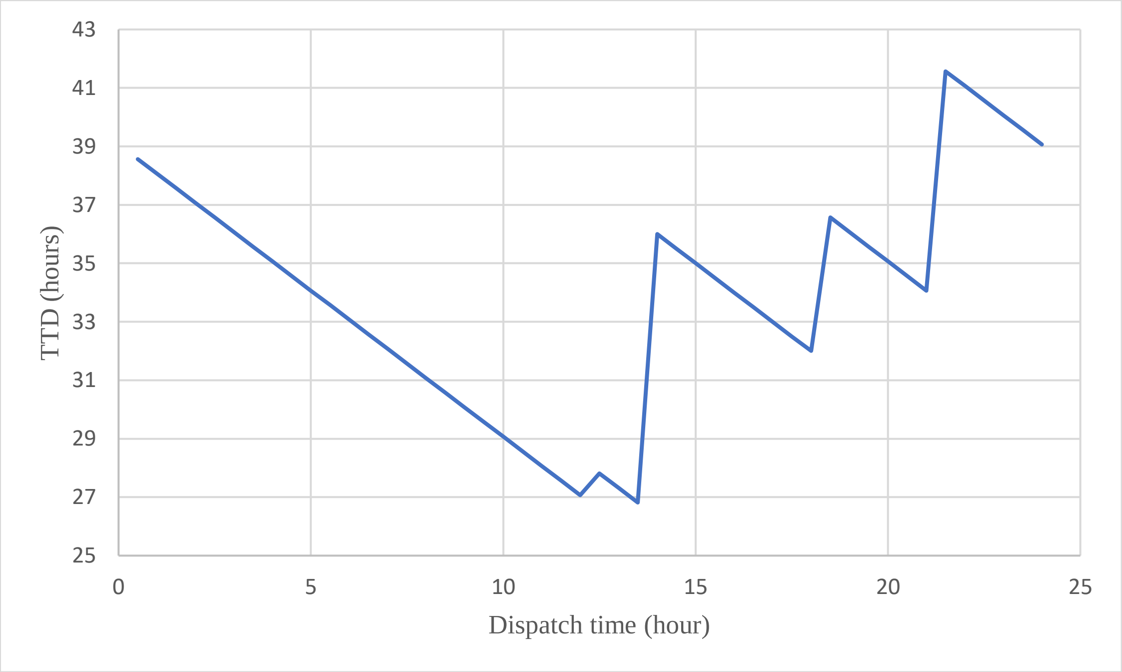

Figure 16 TTD distribution with respect to dispatch times for route set (2,4)

5.1.7 Route set (2,5)

This route set will take the alternative route from Stokmarknes to Narvik which is the route with Ferries. it will continue to Stockholm via Helligskogen in main route 5. Time to delivery with respect to dispatch time is shown in fig. 17. This route set is only affected by the ferry timetables after that there is no disturbance in the system since Helligskogen is always open. The final mean time to delivery for this route set is **34.22** hours.

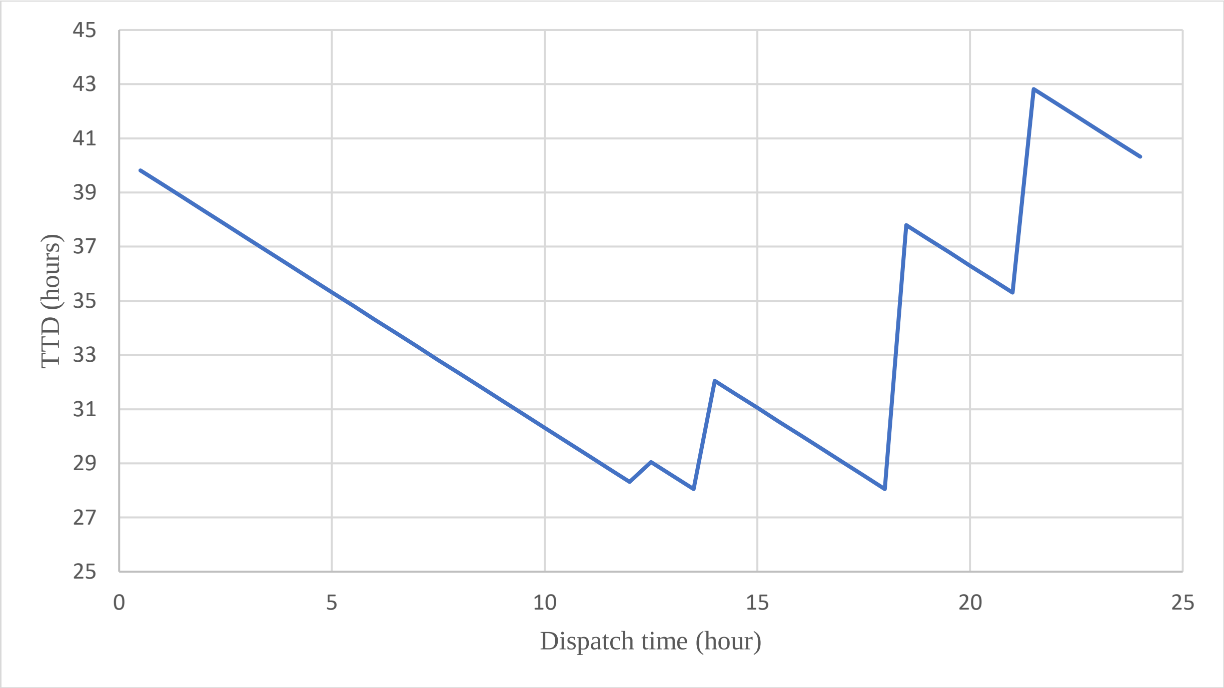

Figure 17 TTD distribution with respect to dispatch times for route set (2,5)

5.1.8 Route set (2,6)

This route set will take the alternative route from Stokmarknes to Narvik which is the route with Ferries. it will continue to Stockholm via Helligskogen in alternate route 6. Fig. 18 shows time to delivery with respect to dispatch time. the pattern in route sets (2,5) and (2,6) is the same the only difference is a 2.31 hour shift due to the road length and conditions in routes 5 and 6. The final mean time to delivery for this route set is **36.52** hours.

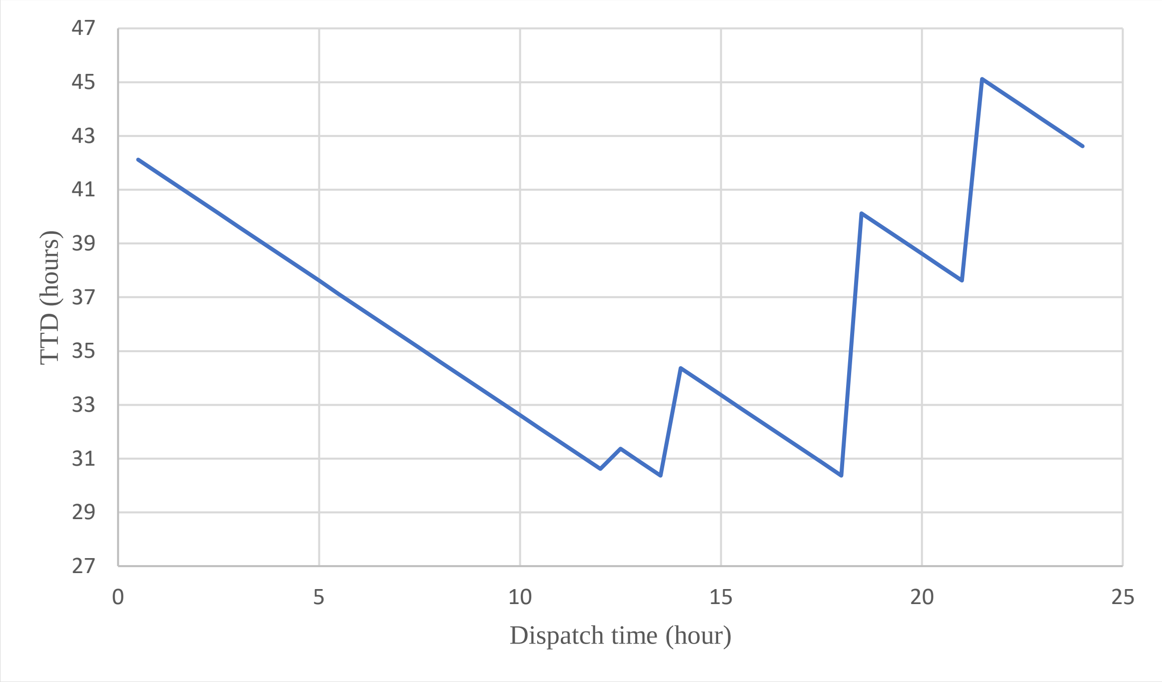

Figure 18 TTD distribution with respect to dispatch times for route set (2,6)

5.1.9 Route set (1,7)

In this route set, the truck cargo will leave Stokmarknes taking main route 1 and will arrive at Narvik. At Narvik there will be a transport mode change from truck to train (in this part of the calculations the loading and unloading time for the train is neglected.). Train will take route 7 and will continue to Stockholm. Fig. 19 shows time to delivery with respect to dispatch time. Because the train departs only once a day from Narvik cargo needs to wait for a long time in case of arriving even 20 hours after the train leaves (the huge jump in TTD is because of this factor in a 24 hour cycle). The final mean time to delivery for this route set is **34** hours.

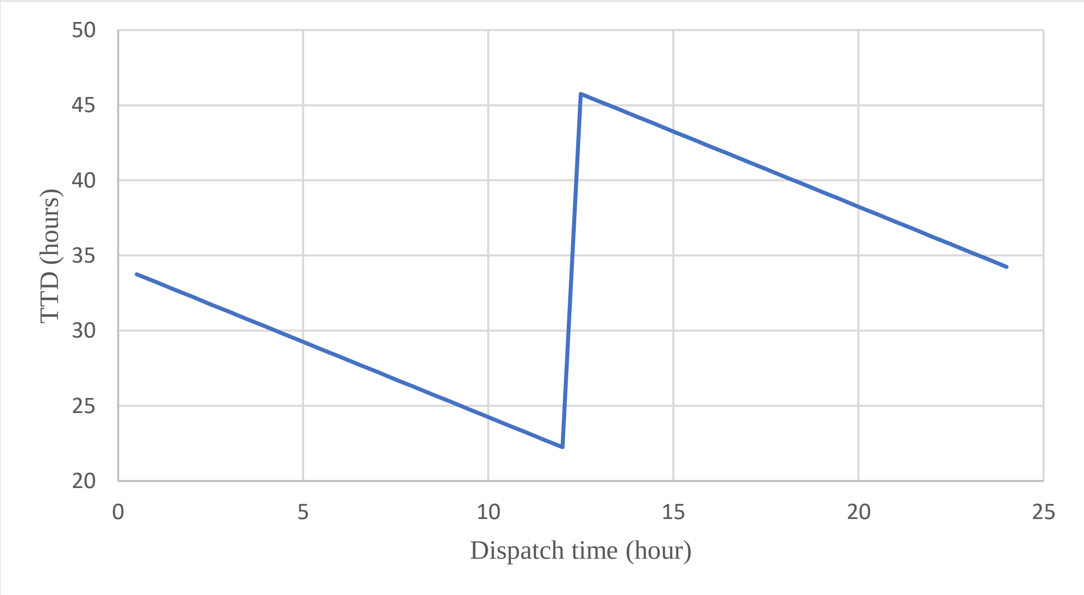

Figure 19 TTD distribution with respect to dispatch times for route set (1,7)

5.1.10 Route set (2,7)

In this route set, the truck cargo will leave Stokmarknes taking alternate route 2 (ferry route) and will arrive at Narvik. At Narvik there will be a transport mode change from truck to train (in this part of the calculations the loading and unloading time for the train is neglected.). Train will take route 7 and will continue to Stockholm. Fig. 20 shows time to delivery with respect to dispatch time. This set of routes again have the same issue with (1,7) since the train leaves only once a day. The final mean time to delivery for this route set is **49** hours.

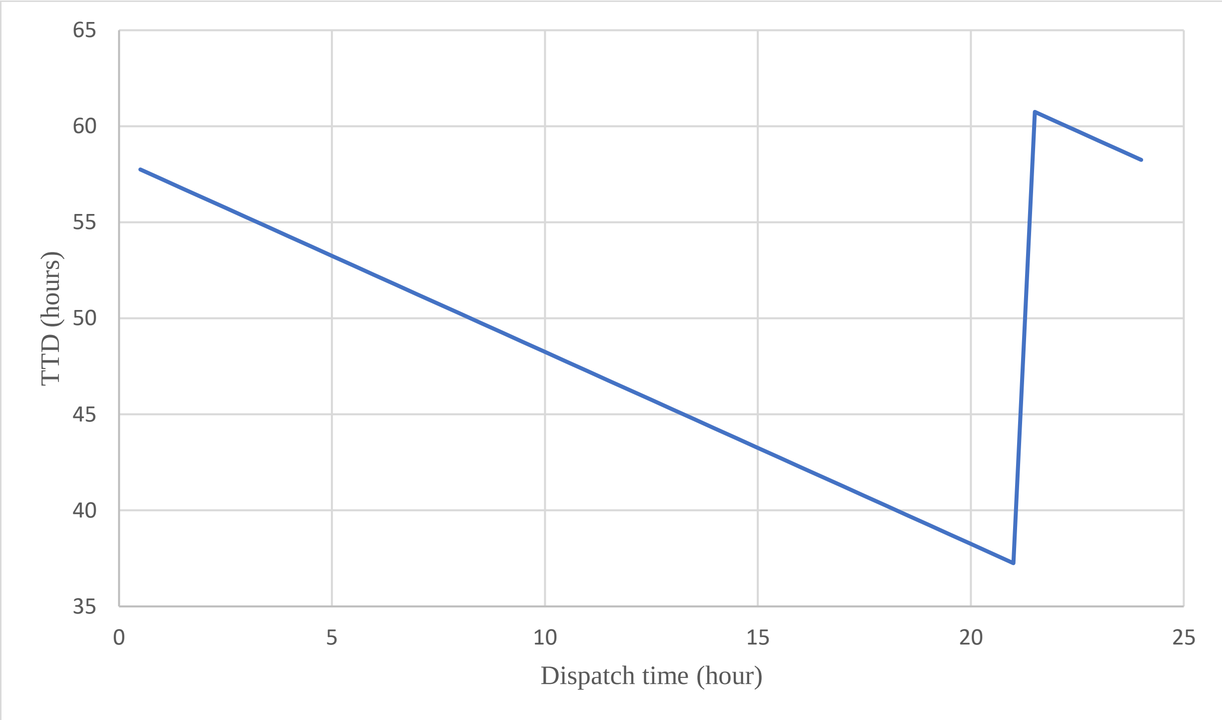

Figure 20 TTD distribution with respect to dispatch times for route set (2,7)

5.2 Comparison between the baseline TTD and MTTD of each Route set

After estimating TTD and MTTD for each route set individually and analyzing each set of data with charts, now all of them can be compared in a single chart. Fig. 21 shows all route sets and their respective TTD with respect to dispatch time. This figure will give the reader an understanding of how TTD for each specific dispatch time throughout the day will vary for each route set. There are similar patterns as discussed before between some of these sets. Sets (2,3), (2,4), (2,5) and (2,6) has a similar pattern with some time shift between them. The reason for this similarity is the fact that all these sets take the alternate route 2 (ferry route) which is a hard limit on time to delivery. This will eliminate the effect of Bjørnfjell customs station because all the trucks will arrive before 2:00 at Bjørnfjell and they can pass it without having to wait for it to be open. That’s why all these sets have a certain behavior despite them taking different routes with different limitations. Sets (1,3) and (1,4) also have a similar pattern. These sets take the same route until Bjørnfjell and after that they will take different routes the only limitation on these two sets is the Bjørnfjell customs stations waiting time which imposes. The waiting time that is between dispatch times 00:30-4:00 and 22:30-24. The trucks that dispatched with this timing will arrive at Bjørnfjell within 2:00-8:00 which will impose a waiting time on them and will cause the fluctuations in TTD. Sets (1,7) and (2,7) also have a macro pattern similarity the jumps in these two sets occur at different dispatch times but the behavior is the same. This analysis shows that for the baseline time to delivery Set (1,3) which takes the main route 1 and continue with main route 3 is the best option for dispatch times 01:00-22:00. For 00:30 and 22:30-24 however, set (1,5) which takes the main route 1 and main route 5 has the better time to delivery. Table 9 shows the baseline MTTD for all the route sets. This table shows that the baseline mean time to delivery for route set (1,3) is better than the others.

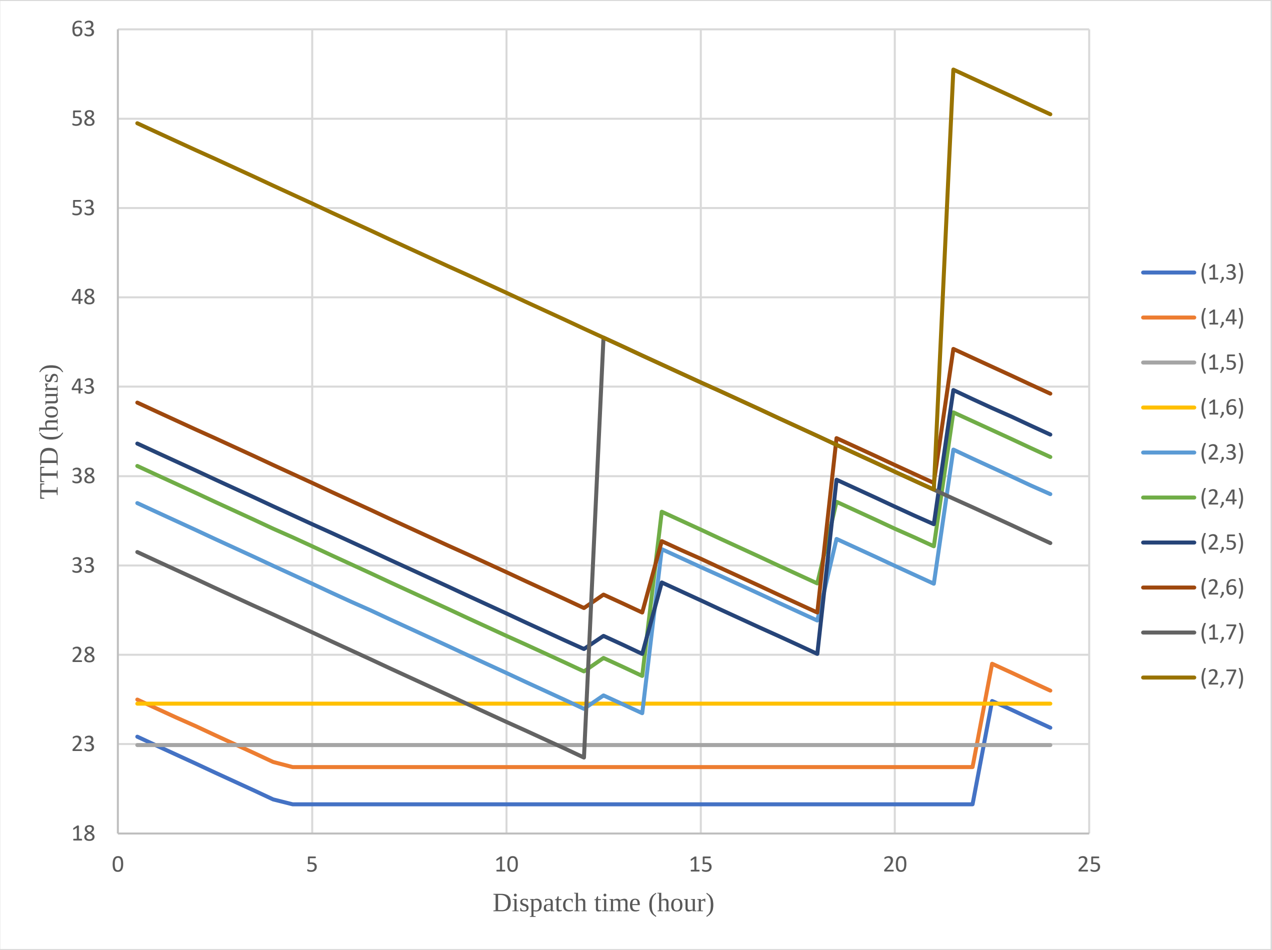

Figure 21 TTD distribution with respect to dispatch times for all route sets

Table 9 baseline MTTD for all route sets

Set of routes	Baseline MTTD (hours)
(1,3)	20.32
(1,4)	22.475
(1,5)	22.95
(1,6)	25.27
(2,3)	31.86
(2,4)	33.94
(2,5)	34.22
(2,6)	36.52
(1,7)	34
(2,7)	49

5.3 Estimating the probability using only baseline MTTD

This section will discuss estimating the probability of choosing each set for the baseline MTTD. For estimating the probability, the following formula will be used:

$$P_i = \frac{e^{U_i}}{\sum_{\forall j} e^{U_j}}$$

First there is a need to calculate the utility function:

$$U_{(i,j)} = \frac{1}{\frac{MTTD_{actual}}{500}}$$

The utility function for each set is presented in table 10, these values have been calculated using the above equation.

Table 10 Utility function for all route sets

Set of routes	Utility function
(1,3)	24.60
(1,4)	22.25
(1,5)	21.79
(1,6)	19.79
(2,3)	15.69
(2,4)	14.73
(2,5)	14.61
(2,6)	13.69
(1,7)	14.705
(2,7)	10.20

With the utility function's value for each of the sets the probability of each set can be calculated using equation 1. The probability of each set when compared to all other sets is shown in table 11.

Table 11 baseline probability for all route sets

Set of routes	Probability
(1,3)	0.8602403
(1,4)	0.0812762
(1,5)	0.0512853
(1,6)	0.0069394
(2,3)	0.0001159
(2,4)	0.000042806
(2,5)	0.0000392522
(2,6)	0.000015394
(1,7)	0.0000431443
(2,7)	0.000000478428
Sum	1

Table 11 confirms fig. 21 findings. Set of routes (1,3) has the highest probability to be chosen as the main option for delivering the cargo due to its low baseline MTTD. equation 1 can be used to calculate the probability of choosing a set among any number of sets, table 11 shows only when all the sets are used in the equation. However, the complete two by two comparison between each set is presented in the appendix (excel sheet "Baseline P 2 by 2") only the relation between set (1,3) and the other sets are presented here in table 12 for clarification. This table shows the baseline probability for when the decision maker has only set (1,3) and wants to compare it individually to each of the other sets.

Table 12 route set (1,3) probability with respect to other route sets

	(1,3)
(1,3)	1
(1,4)	0.913675196
(1,5)	0.943736811
(1,6)	0.991997696
(2,3)	0.999865342
(2,4)	0.999948528
(2,5)	0.999954373
(2,6)	0.99998182
(1,7)	0.999949849
(2,7)	0.999999444

5.4 Estimating the actual MTTD for each set

For calculating the actual MTTD for each set the equation 2 presented below will be used.

$$MTTD_{Actual} = MTTD_{Baseline} + T_{Delay} + T_{Loading} + T_{Unloading} + T_{Rest}$$

- $T_{Loading} + T_{Unloading}$ as per assumption this value will be 4 hours for trains. 2 hours for loading and 2 hours for unloading.
- T_{Rest} for each truck route set there is a need to calculate this value based on the regulations (every 4.5 driving hours requires minimum 45 minutes of rest). To calculate this value there is a need to know the gross driving time (without any wait for each set of routes) these calculations has been given in table 13. The alternate route 2 is excluded from rest calculations because the drivers can rest enough in the ferries.
- T_{Delay} in these calculations will be assumed zero and it will be implemented in the special cases which will be discussed in the following chapters.

Table 13 rest time for truck drivers

Route set	Timings (Exclude route 2) (hours)	Rest times (hours)
(1,3)	19.63	3.27
(1,4)	21.71	3.62
(1,5)	22.95	3.825
(1,6)	25.27	4.21
(2,3)	16.57	2.76
(2,4)	18.65	3.10
(2,5)	19.88	3.31
(2,6)	22.2	3.7
(1,7)	22.83	0
(2,7)	19	0

Equation 2 and its components will be summarized in the table 14. All the times in this table are in hours.

Table 14 actual MTTD and its parameters

Route set	$MTTD_{Baseline}$	$T_{Loading}$	$T_{Unloading}$	T_{Rest}	T_{Delay}	$MTTD_{Actual}$
(1,3)	20.32	0	0	3.27	0	23.59
(1,4)	22.475	0	0	3.62	0	26.09
(1,5)	22.95	0	0	3.825	0	26.775
(1,6)	25.27	0	0	4.21	0	29.48
(2,3)	31.86	0	0	2.76	0	34.62
(2,4)	33.94	0	0	3.10	0	37.05
(2,5)	34.22	0	0	3.31	0	37.53
(2,6)	36.52	0	0	3.7	0	40.22
(1,7)	34	2	2	0	0	38
(2,7)	49	2	2	0	0	53

5.5 Estimating the probability for actual MTTD without the weather effect

After finding the actual MTTD (except delay which will be discussed later), the probability can be calculated again using the new data. The procedure for calculating the probability is the same as before. The calculations will be skipped here and can be found in the appendix (excel sheet "Actual P (without delay)"). The probability for actual MTTD for the set of routes is shown in table 15. Again, set (1,3) holds the most probability and is the best choice for the decision maker. Although the probability has been decreased by 0.046 after the corrections. Two by two probabilities can be found in the appendix (Excel sheet "Actual P 2 by 2").

Table 15 actual probability (without weather effects)

Route sets	Probability
(1,3)	0.813966715
(1,4)	0.106661562
(1,5)	0.065538022
(1,6)	0.0118048
(2,3)	0.000951752
(2,4)	0.000369494
(2,5)	0.000310301
(2,6)	0.000127469
(1,7)	0.000263524
(2,7)	0.00000636117
Sum	1

5.6 Main route 1 and alternative route 2 with weather effects discussions (special case)

This case is applicable when there is a severe weather condition, which will lead to the bridges being closed in the main route 1 for some time. It is assumed that ferries can work under severe weather conditions so alternative route 2 will still be functioning under these circumstances. It is assumed that in winter 15 percent of the days these conditions will apply and in summer 3 percent.

As discussed before in section 5.5 the effect of the parameter T_{Delay} has been neglected in the estimations. For considering this effect into estimations, a uniform delay function with a mean of 8 and standard deviation of 2 has been implemented randomly throughout the day. The influence of delay will interfere with route 1 and because of it with sets (1,3), (1,4), (1,5), (1,6), (1,7). For all these sets new values for time to delivery for all the dispatch times should be estimated. The delay function is a set of 48 random numbers (for all the dispatch times) that has been generated with a normal distribution with mean of 8 and standard deviation of 2. This function will be added to all the dispatch times respectively. In these estimations, resting time of the drivers has been calculated for each dispatch time individually (which will lead to the previous estimation that the author only used MTTD for calculating the resting time of the drivers with respect to hours of driving.) and has been added to the newly found TTD for each dispatch time. Loading and unloading of trains have been implemented into (1,7) as well. Fig. 22 shows the time to delivery with respect to dispatch times for sets (1,3), (1,4), (1,5), (1,6) and (1,7), these sets are affected by the delay function since they are taking the main route 1 which had the bridges that are susceptible to being closed due to extreme weather conditions.

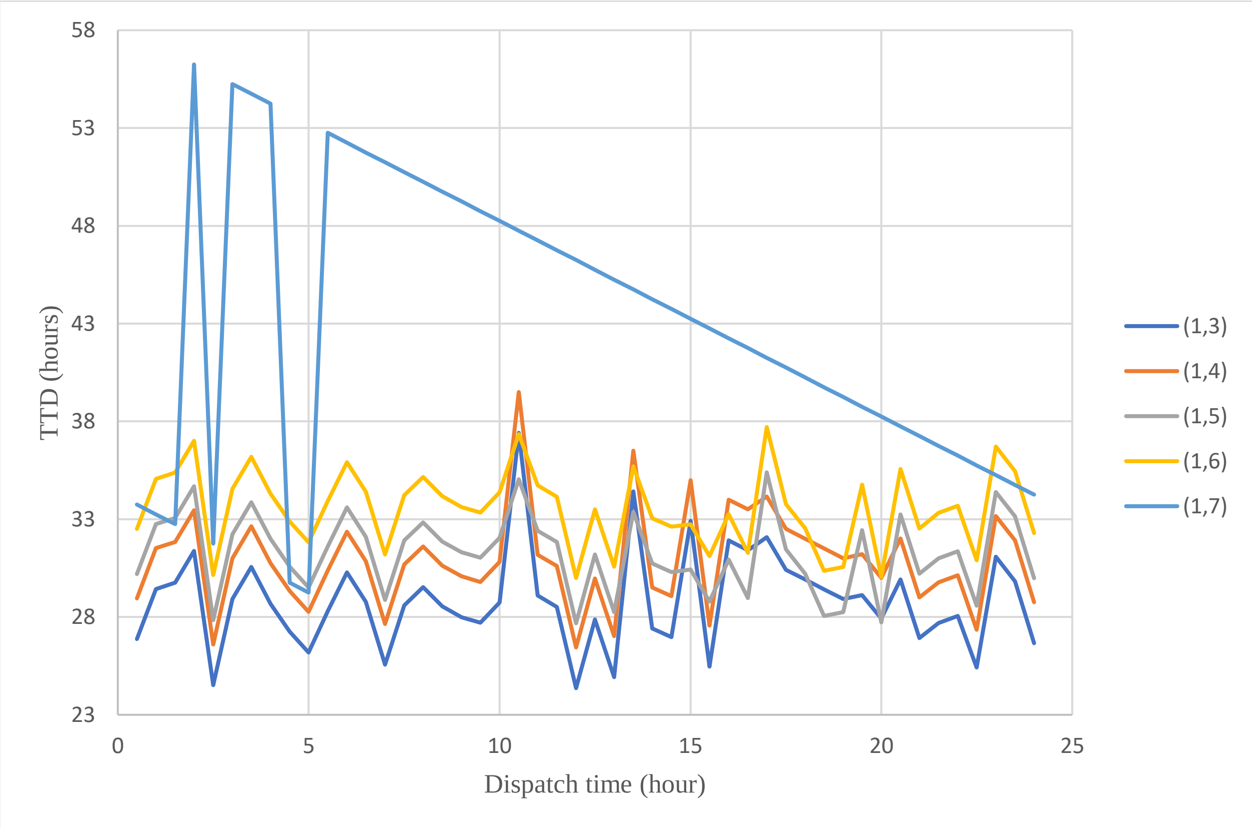

Figure 22 TTD distribution with respect to dispatch times for route sets (1,3-7) with the weather effect

Fig. 22 shows the effect of delay without considering other factors (rest, loading and unloading). Set (1,3) still holds the upper hand here with a few exceptions at dispatch times 10:30, 13:30, 15, 16, 16:30, 18:30, 19, 20 which set (1,5) will hold the better time to delivery.

Mean time to delivery for these sets of routes after applying the delay effect is shown in table 16. As expected, route (1,3) holds the best MTTD. table 16 also shows the baseline MTTD and the difference between these two which shows the effect of the delay in the system. With the normal distribution that has been used for generating the delay function it is expected for the difference to be around 8 hours which is the case.

Table 16 actual MTTD for route sets (1,3-7) with the weather effect

Set of routes	Actual MTTD (hours)	Baseline MTTD	Difference
(1,3)	28.83	20.32	8.51
(1,4)	30.91	22.475	8.435
(1,5)	31.235	22.95	8.285
(1,6)	33.55	25.27	8.28
(1,7)	43	34	9

5.7 Actual TTD and MTTD for all the added times in the system considering the special case.

Here all the effects which are resting times and weather delay effects for the truck routes and loading and unloading times for the train routes have been implemented into all time to deliveries with respect to all the dispatch times. These time to deliveries has been shown in fig. 23. With these new adjustments, all the sets that are using alternative route 2 are looking better compared to the previous estimations without delay timings.

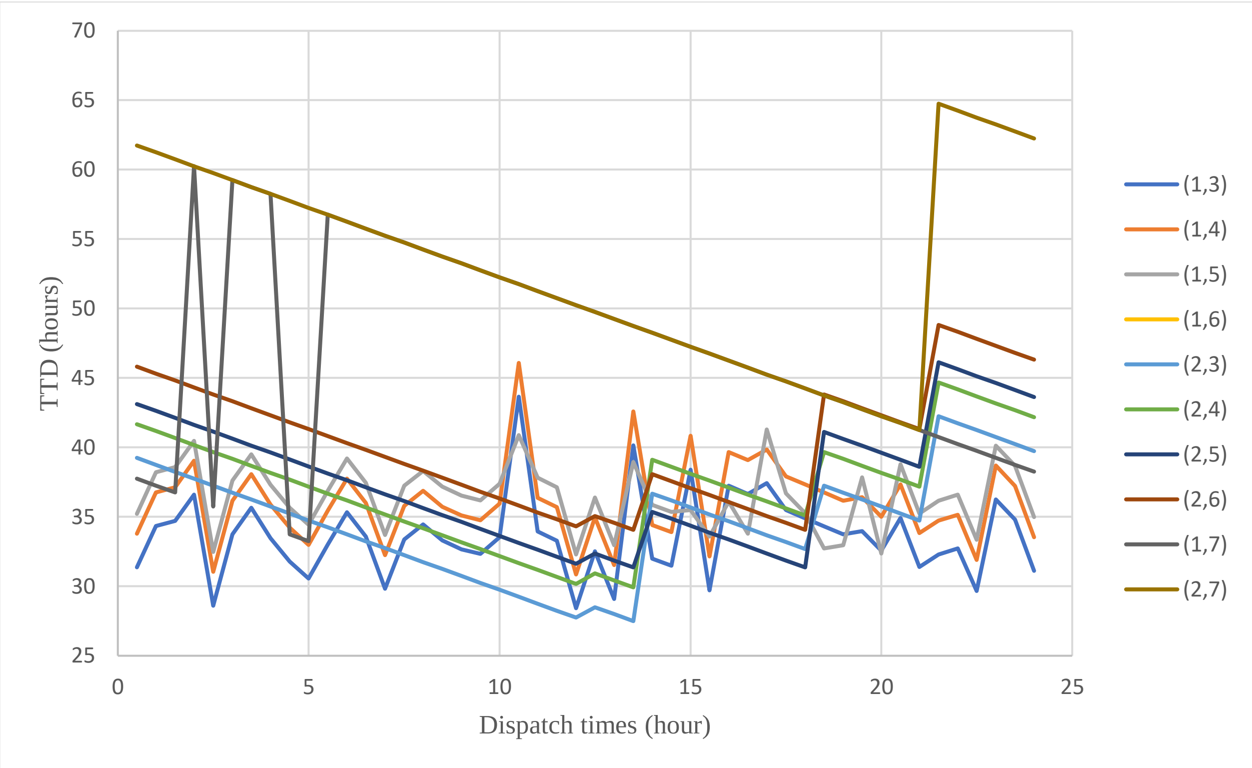

Figure 23 TTD distribution with respect to dispatch times with all the effects (special case)

Table 17 shows the actual MTTD for the special case and baseline MTTD. The difference in this case shows how dramatic the weather effect is. Although even with the weather effect delay set (1,3) still holds the best MTTD between all the sets. however, the gap between sets that take main route 1 and alternative route 2 has been decreased significantly.

Table 17 actual MTTD for all route sets with the weather effect (special case)

Set of routes	Actual MTTD (hours)	Baseline MTTD	Difference
(1,3)	33.63	20.32	13.31
(1,4)	36.06	22.475	13.585
(1,5)	36.44	22.95	13.49
(1,6)	39.14	25.27	13.87
(2,3)	34.62	31.86	2.76
(2,4)	37.05	33.94	3.11
(2,5)	37.53	34.22	3.31
(2,6)	40.22	36.52	3.7
(1,7)	47	34	13
(2,7)	53	49	4

5.8 Estimating the probability for actual MTTD with the weather effect (special case)

Now the probability for the special case that the weather effects delay is affecting the system can be estimated. The probability of the decision maker choosing each set of routes is shows in table 18 the previous probabilities have been shown in the table as well. The newly estimated probability shows that the probability of the decision maker choosing set (1,3) has highly reduced compared to the other cases. Set (1,3) is still holds the highest probability.

Table 18 actual probability with the weather effect (special case)

Set of routes	Actual P (special case)	Actual P (without delay)	Baseline P
(1,3)	0.3294726	0.813966715	0.8602403
(1,4)	0.12097631	0.106661562	0.0812762
(1,5)	0.10468973	0.065538022	0.0512853
(1,6)	0.04062853	0.0118048	0.0069394
(2,3)	0.21536501	0.000951752	0.0001159
(2,4)	0.08352051	0.000369494	0.000042806
(2,5)	0.07028024	0.000310301	0.0000392522
(2,6)	0.02883072	0.000127469	0.000015394
(1,7)	0.00479759	0.000263524	0.0000431443
(2,7)	0.00143875	0.00000636117	0.000000478428

5.9 Final estimation of probability for a whole year (for both summer and winter)

In this section, this thesis will discuss the final probability estimation considering the effects of the special case throughout some days of the year with differentiating between summer and winter. The reason for differentiating between summer and winter is the fact that weather will have different effect on the TTD in these times. In summer only 3% of the days will be affected by the weather that can close the bridges on the main route 1. In winter however these days will be up to 15%.

For estimating the final probability there is a need to develop a new formula to consider the effects of both actual MTTD (no delay) and MTTD (special case) in the calculations. To calculate the final MTTD the following equation will be used.

$$MTTD_{Final\ [s]} = \left[\frac{97 * MTTD_{Actuial(no\ delay)[s]}}{100} + \frac{3 * MTTD_{Actuial(special\ case)[s]}}{100}\right]$$

Equation 4 final MTTD for summer

$$MTTD_{Final\ [w]} = \left[\frac{85 * MTTD_{Actuial(no\ delay)[w]}}{100} + \frac{15 * MTTD_{Actuial(special\ case)[w]}}{100}\right]$$

Equation 5 final MTTD for winter

Where:

- $MTTD_{Final\ [s]}$is the final MTTD during summer.
- $MTTD_{Final\ [w]}$is the final MTTD during winter.
- $MTTD_{Actuial(no\ delay)[s]}$is the actual MTTD when there are no weather effects in the system in the summer.
- $MTTD_{Actuial(no\ delay)[w]}$ is the actual MTTD when there are no weather effects in the system in the winter.
- $MTTD_{Actuial(special\ case)[s]}$ is the actual MTTD when the weather effects are present in the system in the summer.
- $MTTD_{Actuial(special\ case)[w]}$is the actual MTTD when the weather effects are present in the system in the winter.

With the final MTTD for both summer and winter in hand the final probability can be estimated using the equations 4 and 5.

5.9.1 Final probability for summer

The final MTTD for summer can be estimated using equation 4. These values have been shown in table 19. This table will also show the actual MTTD (no delay) and actual MTTD (special case).

Table 19 final MTTD for summer

Set of routes	Actual MTTD (no delay)	Actual MTTD (special case)	Final MTTD for summer
(1,3)	23.59	33.63	23.89
(1,4)	26.09	36.06	26.39
(1,5)	26.775	36.44	27.06
(1,6)	29.48	39.14	29.77
(2,3)	34.62	34.62	34.62
(2,4)	37.05	37.05	37.05
(2,5)	37.53	37.53	37.53
(2,6)	40.22	40.22	40.22
(1,7)	38	47	38.27
(2,7)	53	53	53

With the final MTTD now the final probability for summer can be estimated. the steps are the same as section (5.3). The calculation has been conducted in the excel sheet “final probability for summer” and is presented in the appendix. Table 20 shows the final probability for all routes. The 2 by 2 probabilities for this case are shown in appendix excel sheet “final P (s) 2 by 2”.

Table 20 final probability for summer

Set of routes	Actual P (no delay)	Actual P (special case)	Final P for summer
(1,3)	0.813966715	0.3294726	0.804411
(1,4)	0.106661562	0.12097631	0.110821
(1,5)	0.065538022	0.10468973	0.06926
(1,6)	0.0118048	0.04062853	0.012919
(2,3)	0.000951752	0.21536501	0.0012919
(2,4)	0.000369494	0.08352051	0.000477
(2,5)	0.000310301	0.07028024	0.000401
(2,6)	0.000127469	0.02883072	0.000165
(1,7)	0.000263524	0.00479759	0.00031
(2,7)	0.00000636117	0.00143875	0.00000821

It is apparent that the effect of the delay throughout the year during summer is not that significant and the decision maker can choose the set of routes (1,3) as the main corridor for delivering the cargo. however, in case of a disruptive event other options can be considered.

5.9.2 Final Probability for winter

The final MTTD for winter can be estimated using equation 5. These values have been shown in table 21. This table will also show the actual MTTD (no delay) and actual MTTD (special case).

Table 21 final MTTD for winter

Set of routes	Actual MTTD (no delay)	Actual MTTD (special case)	Final MTTD for winter
(1,3)	23.59	33.63	25.10
(1,4)	26.09	36.06	27.59
(1,5)	26.775	36.44	28.22
(1,6)	29.48	39.14	30.93
(2,3)	34.62	34.62	34.62
(2,4)	37.05	37.05	37.05
(2,5)	37.53	37.53	37.53
(2,6)	40.22	40.22	40.22
(1,7)	38	47	39.35
(2,7)	53	53	53

The calculation has been conducted in the excel sheet “final probability for winter” and is presented in the appendix. Table 22 shows the final probability for all routes. The 2 by 2 probabilities for this case are shown in appendix excel sheet “final P (w) 2 by 2”.

Table 22 final probability for winter

Set of routes	Actual P (no delay)	Actual P (special case)	Final P for winter
(1,3)	0.813966715	0.3294726	0.764921
(1,4)	0.106661562	0.12097631	0.126566
(1,5)	0.065538022	0.10468973	0.084161
(1,6)	0.0118048	0.04062853	0.017874
(2,3)	0.000951752	0.21536501	0.00319
(2,4)	0.000369494	0.08352051	0.001238
(2,5)	0.000310301	0.07028024	0.00104

(2,6)	0.000127469	0.02883072	0.000427
(1,7)	0.000263524	0.00479759	0.000562
(2,7)	0.00000636117	0.00143875	0.0000213

Set (1,3) holds the best probability over other sets in this case as well all other cases. Now, for the final task, this thesis will evaluate set (1,3) in chapter (6).

6 Analysis considering Bjørnfjell customs stations being always open

After conducting analysis for multiple scenarios in chapter (5) set (1,3) was the best option in all the cases. This chapter will discuss the effects of the Bjørnfjell customs stations being always open on time to delivery and Mean time to delivery for this set. The results for this comparison are shown in fig. 24.

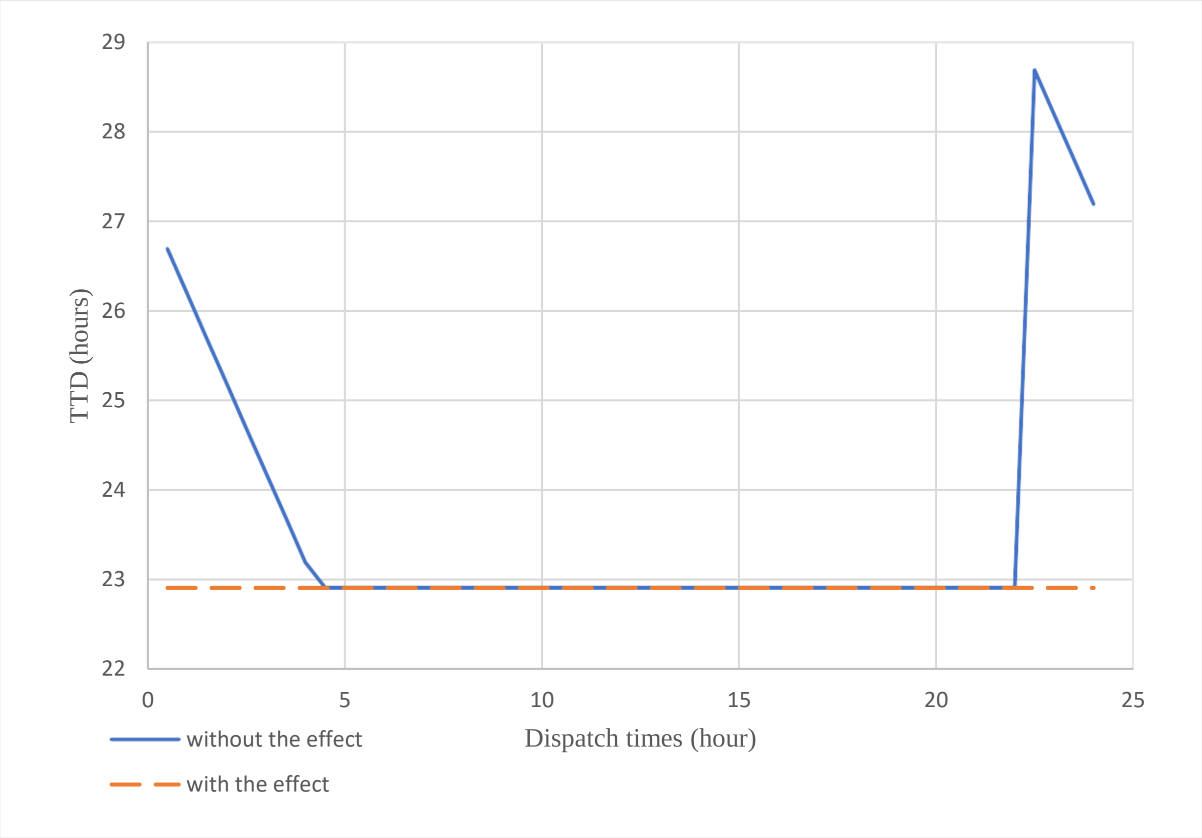

Figure 24 TTD distribution with respect to dispatch times for Bjørnfjell always open case

Fig. 24 shows that if the Bjørnfjell customs station is open all the time salmon will be delivered faster at dispatch times (00:30, 1:00, 1:30, 2:00, 2:30, 3, 3:30, 4, 22:30, 23:00, 23:30 and 24). The MTTD for these two cases is shown in table 23.

Table 23 MTTD for the Bjørnfjell always open case

Case	MTTD
With Bjørnfjell running at normal conditions	23.66
With Bjørnfjell being always open	22.905

7 Conclusion

In this thesis, effort was made to find the best corridor for transportation of salmon products from Stokmarknes to Stockholm. The section on literature review provided a good idea about the existing models in the fields of supply chain management and dynamic transportation networks. Subsequently, a new model was built on top of the previous model for the specific purpose of the problem in this thesis. The model uses multinomial logit probability and mean time to delivery to find the best corridor for transportation while considering the limitation along each corridor.

The proposed model consists of several transport routes and modes each having their own limitations. There are a total number of 7 transport routes and 2 transport modes in the model. These transport routes and modes have been identified through numerous searches and consulting with the “SINTEF” corporation professionals and by ruling out some of the other alternatives due to the cost and complications that they will bring (e.g. air transport). The model uses a set of routes and modes to get from the start to the end of the route. It considers a total of 10 combinations or “route sets” for getting from Stokmarknes to Stockholm with the admissible transport routes and modes that has been identified.

The analysis shows that route set (1,3) is the best option for transportation of salmon from Stokmarknes to Stockholm. This route set had the least mean time to delivery and probability over all the other route sets in all the scenarios that has been analyzed through the course of this thesis. There are certain dispatch times that other route sets hold the better time to delivery over route set (1,3), but overall and considering the mean time to delivery as the main parameter for choosing the best route set, route set (1,3) surpasses them all. Also, a uniform dispatch time in a whole day has been assumed for simplification throughout the calculations, which will be a disadvantage to route set (1,3) with the Bjørnfjell customs stations timetable.

The analysis shows that the usage of train for transportation of salmon by train(by assuming a uniform dispatch time throughout the day) makes the overall time to delivery much longer than truck. Thus, in the scope of this thesis, increasing the capacity of the trains and making a second railway is not going to make a significant contribution to the salmon transportation industry.

The final scenario for the thesis studied whether the Bjørnfjell custom stations should be open at all times or not. The results of the analysis showed that the Bjørnfjell being always open has little effect on the overall mean time to delivery of route set (1,3). By looking at each individual time to delivery with respect to dispatch times, it is apparent that in a normal working day’s schedule (from 8:00 to 16:00) and considering no extreme weather condition that will close the bridges in main route 1 the trucks will arrive at Bjørnfjell in time before the closing of the Bjørnfjell customs station. Thus, with the analysis of this thesis the Bjørnfjell customs station being always open will have little effect on the overall efficiency of the transport corridor.

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9 Appendix (guide for using the excel file in the attachments)

The Excel file contains the calculations conducted throughout the thesis.

There are a total number of 38 sheets in this file that shows different parts of the calculations. The description for all these sheets is presented in this guide. The guide will follow the sheets one by one from the beginning:

1. “road timings”

This sheet shows the time that each of the route will take in minutes. Cell A2 shows the main route 1. Cells A3-9 shows the parts that will build alternative route 2. Cells A10-11 shows the time that it will take for the trucks to reach each of the custom stations. Cells A12-13 shows the timing of Bjørnfjell to Stockholm via main route 3 and alternative route 4. Cells A14-15 shows the timing of Helligskogen to Stockholm via main route 5 and alternative route 6. Cell A16 shows the timing for the train route from Narvik to Stockholm.

2. “Route sets gross times”

This sheet is meant for the calculation of resting times which will be explained in the following sheets. Column A shows the route sets. Column B shows the gross time (without any delays) for these route sets. Column C shows the gross time with the exclusion of route 2 from the route sets that have route 2 in them because the drivers will rest in the ferries and there is no need for extra rest for them.

3. “Route Set (1,3)”

This sheet shows the calculation of time to delivery for route set (1,3). Column A shows the uniform dispatch time distribution. Column B shows the arrival times at Bjørnfjell with respect to the uniform dispatch time in hours. Column C shows the arrival times at Bjørnfjell with respect to the uniform dispatch time in Clock. Column D shows the arrival times at Stockholm with respect to the Bjørnfjell arrivals in hours. Column E shows the arrival times at Stockholm with respect to the Bjørnfjell arrivals in Clock. Column F shows the respective time to delivery for each of the dispatch times. The figure shows the distribution of time to delivery with respect to dispatch times which is presented in the main file as well. Different colors for the numbers show different days. Black is the 1st day (the day that each dispatch times have occurred). Red shows the 2nd day. Brown shows the 3rd day. The waiting times at Bjørnfjell due to it being closed at certain times is apparent at the calculation.

4. “Route set (1,4)”

The description for this sheet is the same as Sheet “route set (1,3)”.

5. “Route set (1,5)”

The description is the same as Sheet “Route set (1,3)” with the difference that Columns B and C shows arrival time at Helligskogen instead of Bjørnfjell.

6. “Route set (1,6)”

The description is the same as Sheet “Route set (1,3)” with the difference that Columns B and C shows arrival time at Helligskogen instead of Bjørnfjell.

7. "Route set (2,3)"

This sheet shows the calculation time for time to delivery for route set (2,3). Column A shows the uniform dispatch time distribution. Column B shows the arrival times at Narvik with respect to the uniform dispatch time in hours. Column C shows the arrival times at Narvik with respect to the uniform dispatch time in Clock. Column D shows the arrival times at Bjørnfjell with respect to the Narvik arrivals in hours. Column E shows the arrival times at Bjørnfjell with respect to the Narvik arrivals in Clock. Column F shows the arrival times at Stockholm with respect to the Bjørnfjell arrivals in hours. Column G shows the arrival times at Stockholm with respect to the Bjørnfjell arrivals in Clock. Column H shows the respective time to delivery for each of the dispatch times. Different colors for the numbers show different days. Black is the 1st day (the day that each dispatch times have occurred). Red shows the 2nd day. Brown shows the 3rd day.

8. "Route set (2,4)"

The description for this sheet is the same as Sheet "route set (2,3)".

9. "Route set (2,5)"

This sheet shows the calculation of time to delivery for route set (2,5). Column A shows the uniform dispatch time distribution. Column B shows the arrival times at Narvik with respect to the uniform dispatch time in hours. Column C shows the arrival times at Narvik with respect to the uniform dispatch time in Clock. Column D shows the arrival times at Stockholm with respect to the Narvik arrivals in hours. Column E shows the arrival times at Stockholm with respect to the Narvik arrivals in Clock. Column F shows the respective time to delivery for each of the dispatch times. The figure shows the distribution of time to delivery with respect to dispatch times which is presented in the main file as well. Different colors for the numbers show different days. Black is the 1st day (the day that each dispatch times have occurred). Red shows the 2nd day. Brown shows the 3rd day.

10. "Route set (2,6)"

The description for this sheet is the same as Sheet "route set (2,5)".

11. "Route set (1,7)"

The description for this sheet is the same as Sheet "route set (2,5)". The only difference is this is the train route. The waiting times due to the train only leaves once a day is apparent in the calculations. Different colors for the numbers show different days. Black is the 1st day (the day that each dispatch times have occurred). Red shows the 2nd day. Brown shows the 3rd day.

12. Route set (2,7)"

The description for this sheet is the same as Sheet "route set (2,5)". The only difference is this is the train route. The waiting times due to the train only leaves once a day is apparent in the calculations. Different colors for the numbers show different days. Black is the 1st day (the day that each dispatch times have occurred). Red shows the 2nd day. Brown shows the 3rd day. Blue shows the 4th day.

13. "Comparison Chart"

This sheet is for the comparison of all the time to deliveries that have been calculated in Sheets 3-12. Column A shows the uniform dispatch time distribution. Column B shows the time to delivery for route set (1,3). Column C shows the time to delivery for route set (1,4). Column D shows the time to delivery for route set (1,5). Column E shows the time to delivery for route set (1,6). Column F shows the time to delivery for route set (2,3). Column G shows the time to delivery for route set (2,4). Column H shows the time to delivery for route set (2,5). Column I shows the time to delivery for route set (2,6). Column J shows the time to delivery for route set (1,7). Column K shows the time to delivery for route set (2,7). The chart shows the distribution of time to delivery with respect to dispatch times for all route sets.

14. “Baseline P calculations”

This sheet is for the baseline probability calculations with the usage of the formulas in chapter 3. Column A shows the route sets. Column B shows the mean time to delivery for each route set. Column C shows the normalized mean time to delivery for the purpose of making the probabilities more sensible. Column D shows the utility function for each route set. Column E shows the exponential utility function. Column F shows the baseline probability (when all route sets are in the mix) for each route set.

15. “Baseline P 2 by 2”

This sheet shows the baseline probability if the decision maker wants to choose from two specific route set options. There is a Matrix in this sheet that shows each route sets probability against all the other routes when there are only these 2 options in the pool.

16. “Rest calculations”

This sheet is for the initial rest calculations with respect to only mean time to deliveries in each route set. For these calculations the timing in route 2 has been excluded since the drivers will rest in the ferries.

17. “Actual MTTD (Without Delay)”

This sheet is for calculation of actual mean time to delivery based on the baseline mean time to delivery that has been calculated previously. In this sheet the effects of weather that will cause delays in main route 1 will be neglected. Column A shows the route sets. Column B shows the baseline MTTD for each route set. Column C shows the rest timings for the truck routes. Column D and E shows the loading and unloading times for train. Column F shows the delay effect added times that in this section is neglected. Column G shows the final actual mean time to delivery for all route sets.

18. “Actual P (without delay)”

This sheet is for calculating the actual probability without the delay effect of the weather. The description is the same as Sheet “Baseline P calculation”.

19. “Actual P 2 by 2”

The description is the same as Sheet “Baseline P 2 by 2”. Only this time for the actual probability without the effect of weather.

20. “Delay function”

This sheet shows the normal distribution that have been used to generate the random numbers for the weather delay effects. The numbers are randomized around a normal distribution with a mean of 8 and standard deviation of 2.

21. “(1,3) with delay”

This sheet shows the time to delivery calculation for route set (1,3) with weather effects delay. Column A shows the uniform dispatch time distribution. Column B shows the arrival times at Bjørnfjell with respect to the uniform dispatch time in hours. Column C shows the arrival times at Bjørnfjell with respect to the uniform dispatch time in Clock. Column D shows Delay timings generated by the delay function. Column E shows the arrival times at Bjørnfjell with delay effects in hours. Column F shows the arrival times at Bjørnfjell with delay effects in Clock. Column G shows the arrival times at Stockholm with respect to the Bjørnfjell arrivals in hours. Column H shows the arrival times at Stockholm with respect to the Bjørnfjell arrivals in Clock. Column I shows the respective time to delivery for each of the dispatch times with the weather delay effect. The figure shows the distribution of time to delivery with respect to each dispatch time. Different colors for the numbers show different days. Black is the 1st day (the day that each dispatch times have occurred). Red shows the 2nd day. Brown shows the 3rd day. The waiting times at Bjørnfjell due to it being closed at certain times is apparent at the calculation.

22. "(1,4) with delay"

The description for this sheet is the same as Sheet "(1,3) with delay".

23. "(1,5) with delay"

The description of this sheet is the same as Sheet "(1,3) with delay". The only difference is in Columns B, C, E and F there is arrival times at Helligskogen instead of Bjørnfjell.

24. "(1,6) with delay"

The description of this sheet is the same as Sheet "(1,3) with delay". The only difference is in Columns B, C, E and F there is arrival times at Helligskogen instead of Bjørnfjell.

25. "(1,7) with delay"

The description of this sheet is the same as Sheet "(1,3) with delay". The only difference is in Columns B, C, E and F there is arrival times at Narvik instead of Bjørnfjell. And the transport mode will change to train.

26. "Rest calculations (new)"

This sheet shows the rest calculations after the effects of delay have been implemented in the system. In this sheet for each respective dispatch time and time to delivery a singular rest time will be calculated. Column A shows the uniform dispatch time. Column B shows the time to delivery with delay for route set (1,3). Column C shows the time to delivery with delay for route set (1,4). Column D shows the time to delivery with delay for route set (1,5). Column E shows the time to delivery with delay for route set (1,6). Column F shows the time to delivery for route set (2,3). Column G shows the time to delivery for route set (2,4). Column H shows the time to delivery for route set (2,5). Column I shows the time to delivery with delay for route set (2,6). Column J shows the resting times for each respective dispatch time and time to delivery for route set (1,3). Column K shows the resting times for each respective dispatch time and time to delivery for route set (1,4). Column L shows the resting times for each respective dispatch time and time to delivery for route set (1,5). Column M shows the resting times for each respective dispatch time and time to delivery for route set (1,6). Column N shows the resting times for each respective dispatch time and time to delivery for route set (2,3). Column O shows the resting times for each respective dispatch time and time to delivery for route set (2,4). Column P shows the resting times for each respective dispatch time and time to delivery for route set (2,5). Column Q shows the resting times for each respective dispatch time and time to delivery for route set (2,6). Column R shows the time to delivery with the resting time and weather delay effects for route set (1,3). Column S shows the time to delivery with the resting time and weather delay effects for route set (1,4). Column T shows the time to delivery with the resting time and weather delay effects for route set (1,5). Column U shows the time to delivery with the resting time and weather delay effects for route set (1,6). Column V shows the time to delivery with the resting time and weather delay effects for route set (2,3). Column W shows the time to delivery with the resting time and weather delay effects for route set (2,4). Column X shows the time to delivery with the resting time and weather delay effects for route set (2,5). Column Y shows the time to delivery with the resting time and weather delay effects for route set (2,6).

27. “TTD for the delay”

This sheet is like the “Comparison chart” sheet except for the fact that its only for the route sets that are using main route 1. To show how these route sets behave after the implementation of delay. The chart shows the distribution of time to delivery with respect to dispatch times for route sets (1,3), (1,4), (1,5), (1,6) and (1,7).

28. “TTD Special delay case”

This sheet shows all time to deliveries for all route sets after the implementation of the weather delay effect, resting times, and loading and unloading times into time to deliveries. The description of this sheet is the same as Sheet “Comparison Chart”.

29. “P estimations (Special case)”

This sheet is for calculating the probability in when the weather effect is present in the system. (which is 15% of the days in winter and 3% of the days in summer). The description is the same as Sheet “Baseline P calculations”

30. “Special case P 2 by 2”

The description of this sheet is the same as Sheet “Baseline P 2 by 2”. Only for the special weather delay case.

31. “Summer final MTTD”

This sheet is for the calculation of the final mean time to delivery for summer which is based on the equation in section 5.9. Column A shows the route sets. Column B shows the actual mean time to delivery without the weather delay effect. Column C shows the actual mean time to delivery with the weather delay effect. Column D shows the Final mean time to delivery for summer.

32. “Winter final MTTD”

The description of this sheet is the same as Sheet “Summer final MTTD”. only needs to change the summer with winter!

33. “Final Probability for Summer”

The description of this sheet is the same as Sheet “baseline P calculations”. The only difference is here instead of the baseline mean time to delivery, the Final mean time to delivery for summer has been used.

34. “Final P (S) 2 by 2”

The name of this sheet means final probability for summer 2 by 2. The description for this sheet is the same as Sheet “Baseline P 2 by 2”.

35. “Final Probability for Winter”

The description of this sheet is the same as Sheet “Baseline P calculations”. The only difference is here instead of the baseline mean time to delivery, the Final mean time to delivery for Winter has been used.

36. “Final P (W) 2 by 2”

The name of this sheet means final probability for winter 2 by 2. The description for this sheet is the same as Sheet “Baseline P 2 by 2”.

37. “Effects of Bjørnfjell (no rest)”

This sheet wants the examine the effects of the Bjørnfjell custom stations being closed all the time against its normal operating conditions on route set (1,3). The weather delay effects will be neglected here. The resting times have not been considered in this sheet. Column A shows the uniform dispatch time distribution. Column B shows the arrival times at Bjørnfjell with respect to the uniform dispatch time in hours. Column C shows the arrival times at Bjørnfjell with respect to the uniform dispatch time in Clock. Column D shows the arrival times at Stockholm with respect to the Bjørnfjell arrivals in hours when the Bjørnfjell is at its normal operating conditions. Column E shows the arrival times at Stockholm with respect to the Bjørnfjell arrivals in Clock when the Bjørnfjell is at its normal operating conditions. Column F shows the time to delivery with respect to dispatch times when Bjørnfjell is at its normal operating conditions. Column G shows the arrival times at Stockholm with respect to the Bjørnfjell arrivals in hours when the Bjørnfjell is always open. Column H shows the arrival times at Stockholm with respect to the Bjørnfjell arrivals in Clock when the Bjørnfjell is always open.

38. “Effects of Bjørnfjell (rest)”

This sheet shows the effects of Bjørnfjell customs station being always open with the rest timings added. Column A shows the uniform dispatch time distribution. Column B shows the time to delivery for each respective dispatch time with Bjørnfjell at its normal operations without rest timings. Column C shows the time to delivery for each respective dispatch time with Bjørnfjell at its normal operations with rest timings. Column D shows the time to delivery for each respective dispatch time with Bjørnfjell always being open without rest timings. Column E shows the time to delivery for each respective dispatch time with Bjørnfjell Being always open with rest timings. The chart shows the distribution of time to delivery with respect to dispatch times for the Bjørnfjell at normal operation with rest timings and Bjørnfjell being always open with rest timings.