Master's thesis

NTNU
Norwegian University of Science and Technology
Faculty of Engineering
Department of Civil and Environmental Engineering

Marie Husum Malvik

# Intermodal Freight Transport in Norway

## A Study of Terminals and Railway Performance Time

Master's thesis in Railway Engineering
Supervisor: Albert Lau
Co-supervisor: Christine Handstanger
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TBA4955 - Railway Engineering, Master's Thesis

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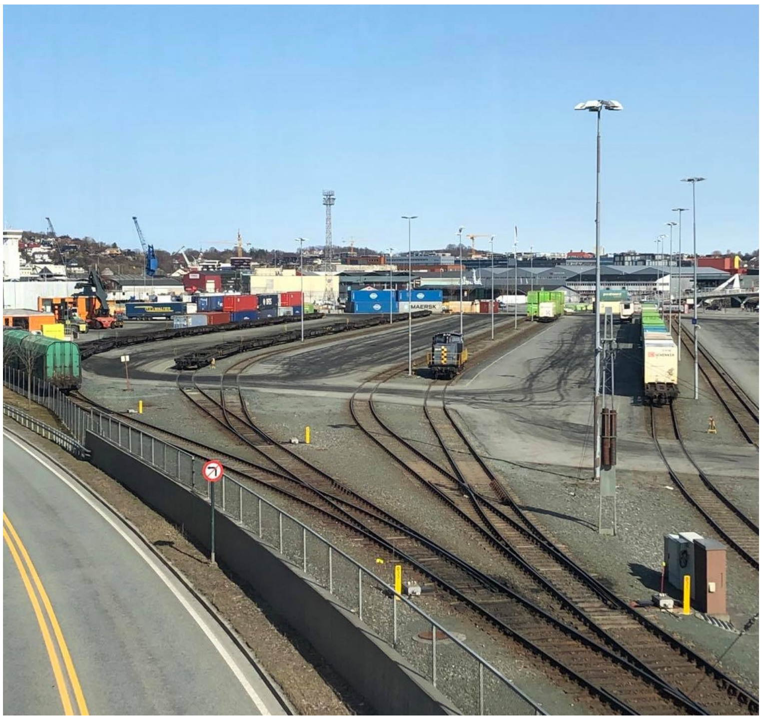

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*Date:* June 11th, 2021

# Abstract

This thesis considers the planning and operation of intermodal freight transport and road-rail terminals, which is a highly present, interesting, and discussed topic. The passenger and freight transport in Norway has been predicted to grow considerably towards 2050, and to meet this growth the capacity of both new and existing infrastructure must be utilized in the best possible way. The main and overall goal of the thesis has been to increase the knowledge of how railway freight transport can be improved and utilized to a higher degree.

The thesis consists of two main parts. First, a broad approach was taken to map current challenges with a specific focus on terminals. Here it was established that terminals and lines are so closely connected that they have to be considered together. One of the main challenges was identified as prioritization in timetabling, and this was chosen to be studied further. Second, a detailed study of how performance time will influence the demand for railway freight transport was analyzed. Performance time is a parameter used to represent prioritization, and to evaluate this different average travel speeds were used to estimate demand for the years 2018, 2030, and 2050.

Terminals are of interest to be studied, as these represent places where transshipment between rail wagons and trucks can happen and have previously been pointed out as one of the major bottlenecks for further development and growth in the railway freight market. They are also one of the main reasons why rail is often deprioritized in favor of other transport modes. Performance time is an important factor for the demand for railway freight transport, and therefore also interesting to study. With the current trends and ambitions to increase the frequencies of passenger trains, this can become an increasing challenge in the future.

A literature review was conducted to establish a foundation for the study, and further both in-depth interviews and simulation in the national freight model, NGM, were used to approach the thesis goals and to answer the research questions. The interviews were used to map out the main challenges for the current situation and to collect suggestions for measures and improvements from experienced people with a variety of perspectives. One of the main challenges was identified as prioritization in timetabling, which was further studied in detail. Simulations in NGM were used to study how performance time, and hence prioritization, will influence the demand for railway freight transport. This can again be used to evaluate the attractiveness and competitiveness of railway compared to other transport modes.

The results from the study showed that freight transport on railways currently faces many challenges related to infrastructure, operation, organization, knowledge, and economy. To meet these challenges different measures were proposed. A change where freight trains are prioritized higher would reduce their travel time, and could hence help transfer more freight towards more environmentally friendly modes. The effects of performance time were found to be present for most freight markets, especially general cargo. The impact was most prominent at stretches where there is a high competition between road and railway.

**Keywords:** Railway freight transport, Intermodal transport, Intermodal terminals,
Performance time, Prioritization in timetabling

# Sammendrag

Denne oppgaven omhandler planlegging og drift av godstransport og terminaler for omlasting mellom veg og jernbane, et dagsaktuelt og interessant tema. Det er forventet en økning i person- og godstransporten frem mot 2050 og for å møte denne veksten og utviklingen vil det være behov for å utnytte ny og eksisterende infrastruktur på best mulig måte. Formålet med oppgaven har vært å øke kunnskapen om hvordan godstransport på jernbane kan forbedres og benyttes i større grad enn i dag.

Oppgaven består av to hoveddeler. For det første ble det gjennomført en bred kartlegging av dagens største utfordringer med et spesifikt fokus på terminaler. Her ble det funnet at terminaler og linjer er så sammenknyttet at det er nødvendig å vurdere dem sammen. En av dagens hovedutfordringer ble funnet til å være prioritering mellom person- og godstog, og dette ble valgt å studere videre. For det andre ble en detaljert studie av hvordan fremføringstid vil påvirke etterspørselen etter godstransport på jernbane. Fremføringstid er en parameter brukt for å beskrive prioritering, og for å evaluere dette ble ulike gjennomsnittlige kjørehastigheter brukt for å estimere etterspørselen for årene 2018, 2030 og 2050.

Terminaler er interssante å studere da disse representerer plasser der overføring mellom jernbanevogner og lastebiler kan skje, og fordi disse har blitt pekt på som en av dagens største flaskehalser for videre utvilking og vekst innen godstransport på markedet. Utfordringer her en av hovedårsakene til hvorfor jernbanen ofte blir nedprioritert til fordel for andre transportmåter. Fremføringstid er en viktig faktor for etterspørselen etter godstransport på jernbane, og er derfor også interessante å studere. Med de pågående trendene og ambisjonene med å øke frekvensen for passasjertog vil dette potensielt bli enda mer utfordrende i fremtiden enn hva det er i dag.

Et litteraturstudie ble gjennomført for å etablere et grunnlag for oppgaven, og videre ble dybdeintervjuer og simuleringer i NGM brukt for å besvare oppgavens problemstilling og forskningsspørsmål. Dybdeintervjuer ble brukt for å kartlegge dagens største utfordringer, samt å samle forslag til endringer og forbedringer fra erfarne fagfolk med ulike perspektiver. Fremføringstid og prioritering i ruteplanlegging ble funnet som en av de største utfordringene, og dette ble valgt å analysere videre i detalj. Simuleringer i NGM ble brukt til å undersøke hvordan fremføringstid påvirker etterspørsel etter godstransport på jernbane, og dermed attraktiviteten og konkurranseevnen sammenlignet med andre transportmåter.

Resultatene fra studien viste at godstransport på jernbane står i en vanskelig situasjon i dag med flere utfordringer, både når det gjelder infrastruktur, drift, organisering, kunnskap, og økonomi. Tilnærminger og tiltak for å møte disse utfordringene ble foreslått. Fremføringstiden for et godstog ble funnet å ha innflytelse og påvirkning for de fleste markeder, spesielt for stykkgods. Innflytelsen viste seg å være mest markant for strekninger der det er høy konkurranse mellom veg og jernbane.



**Nøkkelord:** Godstransport på jernbane, Intermodal godstransport, Intermodale terminaler, Fremføringstid, Prioritering i ruteplanlegging

# Preface

This document is written by Marie Husum Malvik and is the concluding work for a master's thesis in Civil and Environmental Engineering at the Norwegian University of Science and Technology (NTNU). It is written during the spring semester of 2021 for the course "TBA4955 Railway Engineering, Master's Thesis" and counts for 30 credits. In the autumn semester of 2020, a pre-project was done including a first literature review and development of a problem statement and research questions.

I would like to thank my supervisor at NTNU, Albert Lau, for advice and guidance during the work, as well as my co-supervisor Christine Handastanger at Infraplan AS for discussions, ideas, and feedback.

Ellen Heffer Flaata, PhD candidate at NTNU, gave great support with the national freight model and running of scenarios, which has been crucial for the execution of the project. A great thank you also to Paul Røvik at Bane NOR for showing me around at Brattøra terminal and for answering questions, as well as everyone who agreed to be interviewed for the project.

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# Definitions

| | |
|---|---|
| Transport performance | Measurement for volume of freight transport, in tonnes-kilometres. |
| Performance time | The time it takes for a freight train to travel from the departure terminal to the arrival terminal. |
| Residual capacity | Capacity of a freight train which is not used. |
| Transshipment | The operation where goods are moved from one transport mode to another. Happens at terminals. |
| Simultaneous entries | Procedure where two trains enter a passing section in opposite ends at the same time. Requires a technical system which is programmed to make it impossible for one train to enter into the track of the other train, as well as an extended safety zone. |
| Overlong crossings | Procedure where the freight train uses the main track and the passenger train uses the passing track. |
| Co-modality | Efficient and optimal use of different transport modes in combination. |
| Modal shift | A change from one transport mode to another.<br>Here understood as the transfer from road to railway/maritime. |
| Forwarders/shippers | Organizer of freight transport from the producer/sender to the receiver, and have the power to choose between different transport modes and options. |
| Railway undertakings | Companies which operate on railway lines and who provide transport of passengers or goods. |

# Abbreviations

| | |
|---|---|
| **TEU** | Twenty feet Equivalent Unit |
| **UIC** | The International Union of Railways |
| **ITU** | Intermodal Transport Units |
| **ERTMS** | European Rail Traffic Management System |
| **TKM** | Tonne-kilometre, unit of measurement of freight transport which represents the transport of one tonne of goods over a distance of one kilometre |
| **SSB** | *Statistisk sentralbyrå*, Statistics Norway |
| **TØI** | *Transportøkonomisk institutt*, Institute of transport economics |
| **NSD** | *Norsk senter for forskningsdata*, Norwegian center for research data |
| **NGM** | *Nasjonal Godsmodell*, Norwegian national freight model |
| **PWC** | Producer-warehouse-consumer |
| **ADA** | Aggregated-Disaggregated-Aggregated |

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# 1 Introduction

This chapter will introduce the background for this thesis, as well as the problem statement, research questions, and scope.

## 1.1 Background

The subject for this thesis is intermodal freight transport and how the railway can be utilized to a higher degree than today. Intermodal freight transport can be defined as the transport of goods that utilizes more than one mode of transportation from the sender to the receiver. This can be many different modes, but in this project the use of road and railway will be considered where the main part of the transport is conducted by rail. When utilizing multiple transport modes, the need for good connection points and transfer opportunities between them is of high importance and will be a decisive factor to whether or not transport operators will choose to use the railway. Another important factor for railway freight transport is the time it takes for the goods to travel from their departure destination to their arrival destination, namely their performance time. This will be especially relevant for goods that have a high time value.

There is and has been for a long time a political goal to transfer more freight from roads to sea and railway. This is a present goal for both Norway and the EU. In the European Mobility Strategy, it is stated that a 50% increase in high-speed rail traffic is expected by 2030 and a 50% increase is expected for rail freight traffic within 2050 (European Commission, 2020). The main goal of the strategy is to form a smart, competitive, sustainable, and safe transportation sector, where emissions are low and mobility is high. Railway is considered to be the greenest form of traffic, and could therefore have a pivotal role in achieving the goals of this strategy. The $CO_2$ emissions from rail freight transport have been measured to be 6.5 g/TKM, whereas for road transport the emissions were 2 500 g/TKM for light vehicles and just below 90 g/TKM for heavy vehicles (Engedal et al., 2020). The numbers for light vehicles might be unreasonably high as this also includes other purposes than freight, but there is still a huge difference between the modes. According to the ECA, the $CO_2$ emissions from rail transport is 3.5 times lower per TKM compared to road transport (European Court of Auditors, 2016). Higher utilization of railway could hence help provide a more environmentally friendly transport sector.

The demand for transport is expected to increase towards 2050, both for freight and passengers. Freight transport from roads, railway, and sea at Norwegian territories was measured to be 511 million tonnes in 2015, which corresponds to a transport performance of 144 billion tonnes-kilometres (Mld. St. 33 (2016-2017), 2017). For transport over 300 km about 8 % of the transport performance in Norway was conducted by railways, where the largest advantages for railway are present for long distances and large volumes. A single freight train will be able to transport the same amount as a number of road trucks. A 600 m long freight train will correspond to 32 road trucks, while a 450 m long freight train corresponds to 21 road trucks (Skauge, 2021). Here, the scale of economics from using rail are clear. In Norway, there is a present goal that transport of goods between the different regions should be managed by either sea or railway. This goal has been approached by the use of both direct and indirect measures such as heavy restrictions for goods carried by road and regulation of taxes (Marskar and Askildsen, 2015), but the desired change has still not been realized.

Intermodal transport aims at exploiting the scales of economics and the environmental benefits of railway, in addition to the flexibility and reach of road transport. Railway transport is an environmentally friendly transport mode, which utilizes electric power to a high degree. The electric power is produced mainly using hydropower, which is a renewable power source (Jernbaneverket, 2012). However, development within road vehicle technology, a transition from gasoline to diesel, and more use of alternative fuels for road transport have lowered the emissions from road transport (Fedoryshy, 2017). Moving forward it is hence of interest to make the different transport modes function well together, and create a good foundation for co-modality. In such a system where multiple transport modes are used in combination the need for good connection and transfer between them are important, and this is where terminals play a crucial role. Most costs related to intermodal transport are connected to loading and unloading of goods, transshipment of transport units, and distribution to and from the terminals (Jernbanedirektoratet, 2019). Hence, creating efficient and attractive terminals is of high interest to make intermodal transport the desired way of moving goods. Increasing the knowledge about rail-road terminals has been the first main aspect of this thesis.

The other main aspect has been how performance time will influence the demand and use of the railway for freight transport. The performance time of railway freight trains has been increasing over time, as more and more passenger trains have been introduced in the timetables. As the regulations and rules are today, passenger trains will be prioritized over freight trains when conflict arises (Jernbaneforskriften, 2017). These rules are applied for all times during the day, both daytime and nighttime, even if the demand for passenger and freight transport has a large variance throughout the day. Freight are mainly transported during the night when passenger demand is at its lowest. Possibilities for changing and adjusting these prioritization rules throughout the day have been examined (Samferdselsdepartementet, 2015), but there still exists a need to research this further and establish how large the effects of such possible changes can be. Further, it would also be of interest to research how this could be implemented and what changes are realistic to accomplish.

For freight trains, the extended performance times could limit the attractiveness and competitiveness (Voldsund, 2020), and potentially push more freight towards other less environmentally friendly transport modes. From the goals stated in national strategies this is not desired. A study was conducted to evaluate how much forwarders are willing to change their current operation, and this found that forwarders have a significant willingness to pay for improved performance time (Halse and Killi, 2012). Such findings are interesting, and quantifying how much the demand can change depending on this would hence improve the platform of knowledge for future decisions. This will be approached in this thesis.

## 1.2 Problem statement and research questions

To evaluate these subjects with an academic approach a problem statement was developed and studied using academic research methods such as literature review, in-depth interviews, and scenario analysis. The aim of the project was to gain increased knowledge about the current challenges and possibilities for intermodal transport in Norway, as well as a better understanding of factors that have a large influence on freight transport on railways. The focus has especially been towards terminals, as well as timetable prioritization and performance time. A set of research questions were formulated, as listed below.

1. What are the current main challenges for planning and operation of railway terminals and railway freight transport, and how can these be met?
2. How does performance time affect the demand for railway freight transport?
3. How will the different markets/market segments be influenced by a change in performance time, and how are the effects for different stretches in Norway?

The first question was stated in order to get a grip of the state-of-the-art for intermodal freight transport today, where the goal was to understand the factors that are limiting the utilization of railway as the desired mode for transport of goods. Terminals were chosen as a focus area as these have been found from previous literature to be challenging and to have large potential for upgrade and development. A lot of time and effort has been used in recent years to achieve the essential development of terminals, but the significant changes which is necessary to meet predicted and desired future demands have still not occurred fully. The author wanted to broaden the knowledge related to why it is so difficult to make the necessary changes and why this is taking such a long time. The second part of the research question aims at identifying different approaches which could be taken in order to limit or reduce the challenges. The goal was to form a solution or set of proposals for how more freight transport can use railways. This is an ambitious goal and a lot of different directions are possible. The objective has been to gain a broad overview of possible solutions as well as filling part of the current knowledge gap.

The second and third question was developed through the work with the thesis. Prioritization in timetabling was found as one of the main challenges related to railway freight transport, and a limiting factor for the transfer of freight towards railways. The author wanted to approach this in a detailed way, hoping to create a basis for knowing how much the effects of prioritization and performance time are. In the coming years, there are a lot of ambitions for the railway sector, including higher frequencies for passenger trains. Being able to know how these ambitions might influence and limit the possibilities for freight transport on railways was found to be an interesting subject. Evaluating how changes in performance time will affect different markets/market segments for different stretches in Norway will help make a better basis for precise and goal oriented measures to reach the national goals. Each stretch might not have the same needs, and finding the right measures should be based on the largest possible knowledge and information.

## 1.3 Scope

The time frame of the project is set to one semester, and hence not all aspects could be studied in detail and choices had to be made. The focus for the thesis have been towards terminals and railway performance time, as these were found to be the most interesting and necessary to study. An overall mapping of current challenges gave many possible subjects to study further, such as infrastructure capacity, organization, knowledge and economy. These aspects are very interesting, but have not been approached in major detail here.

The chosen methodology set a certain frame work, which is explained in detail in Chapter 3. The thesis has been conducted in a year that has been highly influenced by restrictions related to the Covid-19 pandemic and these introduced needs for digital rather than physical solutions. This was however not a major challenge for the execution of the different activities as many digital tools are available today, but set some requirements for planning.

## 1.4 Structure of the report

This report includes six chapters in total. First, an introduction to the project, the background, and the problem statement is introduced. The second chapter will introduce relevant theory and research which was collected during a literature review. The methodology and the results are presented in the third and the fourth chapters, and comments on the results are given. The fifth chapter elaborates on the findings and discusses the results and the methodology. Last, a conclusion and some suggestions for further research are given.

A set of appendices are attached to the thesis including; Scientific abstract (A), Interview guide (B ), Statement of consent for interview respondents (C), Terminal visit at Brattøra (D), and Results from NGM (E).

# 2 Literature review

To achieve knowledge and insight into the subjects of freight transport and intermodal terminals, a literature review was conducted. Much of the work with the literature review was done during the pre-project in the autumn of 2020, and much of what will be explained in the first chapters were developed through this (Malvik, 2020).

## 2.1 Method for literature review

The literature review was done in order to get an overview of how freight transport is functioning and how terminals are planned and operated, as well as different approaches used within the branch. Aspects such as layout, functions, equipment, coordination between lines and terminals, and planning tools were studied. The research started broad with evaluating both Norwegian and international literature, but during the master's thesis most of the studied literature have been from Norway.

The literature review was performed by the use of different search engines available at the university. The main engines used were Oria and Google Scholar, where Oria is a collective of many different databases including 44 databases for science and technology, and Google Scholar is an open search engine for academic literature. Additionally, previous work at NTNU has been found through the use of "NTNU Open" where a variety of academic works from the university are available, such as master's theses, doctoral theses, and articles. The university library was also explored in order to find books and handbooks about the subjects, as well as information about different academic methodologies such as quantitative and qualitative research. Through the research words such as "railway terminal", "freight terminal", "intermodal transport" and "performance time" combined with "capacity", "efficiency", and "punctuality" were used. Norwegian search words such as "godstransport", "fremføringstid", "godsterminal", and "intermodal terminal" were also used.

Both forward and backward snowballing technique were applied. Forward snowballing means a process where the references of an article or other document are explored, whereas backward snowballing is a process where the citations of an article or a document are traced back to the primary source. This gave a lot of results, and the most relevant were chosen and studied in detail.

## 2.2 Intermodal freight transport

Intermodal freight transport is transport of goods that utilizes more than one mode of transportation from the sender to the receiver. It is defined by the United Nations Economic Commission for Europe as *"multimodal transport of goods, in one and the same intermodal transport unit by successive modes of transport without handling of the goods themselves when changing modes"* (UNECE, 2019). This could be a combination of transport modes such as road, railway, maritime, inland waterways, and aircraft. Different types of transport units can be used, such as containers, swap bodies, or semi-trailers. Multimodal freight transport is understood as the transport of goods by at least two different modes of transport, whereas intermodal transport is a particular type of multimodal transport (UNECE, 2019). Usually, the goods are compacted together and placed in an intermodal transport unit, shortened ITU, which is then brought through the network as one unit.

The use of ITUs reduces the risk of damage to the cargo along the way, as all the different individual goods are compacted together. This is called the principle of unit loads (Woxenius, 1998), defined as *"If possible, goods should be kept together in form of a transport unit adapted to all present vehicles and handling equipment. This transport unit should be formed as early as possible in the material flow, preferably at the consignor's, and be broken as late as possible, preferably at the consignee's"*. Hence, the use of ITUs opens up for a more efficient transshipment, meaning the operation where goods are moved from one transport mode to another, compared to the handling of many different types of cargo. The type of ITU used is a choice from the operators or the forwarders.

### 2.2.1 Types of intermodal transport units

The most common types of intermodal transport units for freight transport are containers, swap-bodies, and semi-trailers (Lavoll, 2016).

#### Containers

Containers are rectangular boxes usually made of steel, which are used a lot in combined transport and especially for transport including maritime. They have various sizes, whereas the most common is 20, 40, and 45 feet (Rcontainer, 2021). Some standardizes sizes exist, such as ISO-containers and CEN-containers. A 20 feet container will often be called one TEU, a twenty feet equivalent unit, illustrated in Figure 1.

Figure 1: Twenty feet container, photo from Rcontainer (2021).

#### Swap-bodies

Swap-bodies are transport units adapted to trucks, as these can be moved and transferred between trucks and railway wagons. They are equipped with legs making it possible to transfer between two trucks without being lifted. This gives possibilities to use a ro-ro technique, which is a type of horizontal transshipment. An illustration is shown in Figure 2.


Figure 2: Swap-body, photo from Sicom Containers (2021).

#### Semi-trailers

Semi-trailers are the most common transport unit for trucks. They have wheels connected to the transport unit, making it possible to drag it around. It is possible to transport them on railway wagons, whereas this might have some challenges due to the dimensions of the semi-trailer and the possibilities to use different lifting equipment for transshipment. An illustration of a semi-trailer is shown in Figure 3, but it is important to note that these can have different shapes.


Figure 3: Semi-trailer, photo from Shcmitz cargobull (2021).

### 2.2.2 Transshipment equipment

Transshipment methods can be categorized as vertical or horizontal. Vertical transshipment is normally done by gantry cranes, forklifts, or reach stackers. The gantry cranes can either be moved according to rails or by the use of rubber tires, respectively called rail mounted gantry crane (RMG) and rubber tyre gantry crane (RTG). For reach stackers, the lifting could be done either as a top lift or a bottom lift, based on how the equipment and the transport units are designed. Lavoll (2016) found that bottom lift was the most efficient method and that lifting of semi-trailers definitively was the most time consuming. Horizontal transshipment can be performed by the use of a ro-ro technique, which stands for roll on roll of. It is most common to use vertical transshipment in Norway, whereas the introduction of horizontal transshipment is relevant especially for small and medium size terminals.

## 2.3 Management levels for rail transportation planning

The different management levels for planning can be divided into strategic, tactical, and operational (Prince, 2015), where strategic is the most overall and operational is the most detailed. An illustration of the management levels is shown in Figure 4.

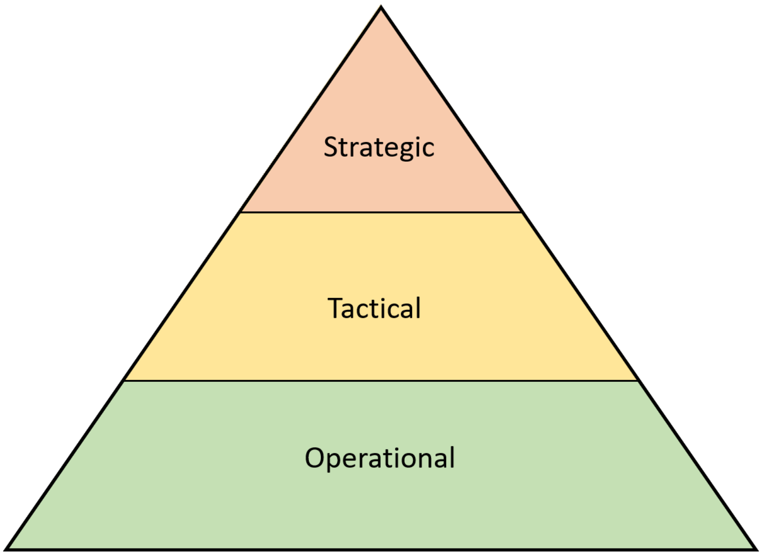


Figure 4: Management levels for rail transportation planning.

### Strategic

The strategic management level has a long term perspective. It involves changes in the structure of a company and investments for new infrastructure, system capacity, technology, and resources. Decisions are influenced by surroundings such as market and economic forces, policies, industry regulations, society, and the environment. The time frame for decisions is usually 10 to 20 years (Prince, 2015).

### Tactical

The tactical management level has a medium term perspective where the aim is to utilize the existing resources in the best possible way, with a time frame of weeks, months, or a few years. Important parameters to evaluate is congestion, capacity and system performance (Prince, 2015). Activities for tactical management are scheduling of personnel and vehicles, and hence creating a timetable. The final timetable might not be able to fulfill all the wishes of the different operators, as there is often a limited capacity. This must be coordinated by the infrastructure manager in order to solve conflicts where multiple operators want the same time slots. If congestion arises there is a need to prioritize between different trains, and in such a case passenger trains are often prioritized over freight trains.

The final timetable will be presented as a train graph or train diagram where the paths are illustrated with locations for different times. An example of this is shown in Figure 5. In the diagram, steeper lines indicate trains with higher speeds. Horizontal lines represent a complete stop in motion, which usually will be happening at stations and passing tracks. The different colors are used to represent different train categories.

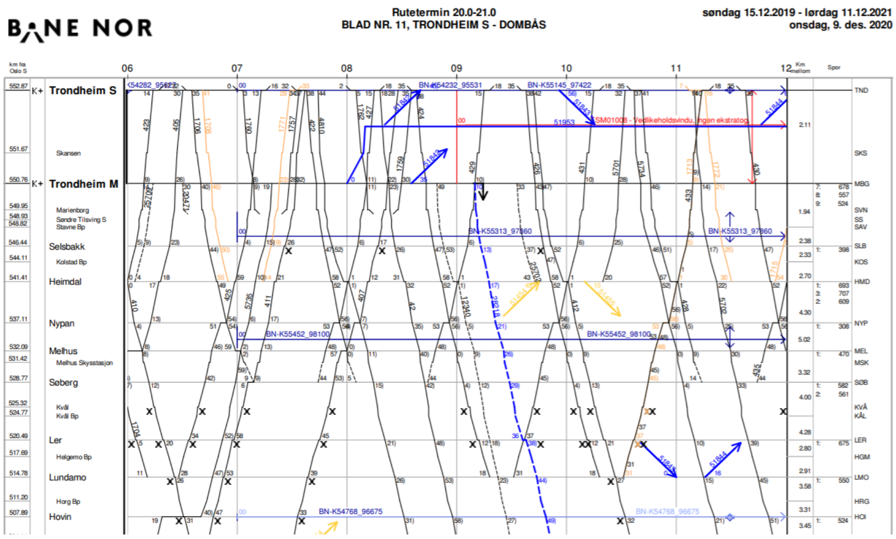


Figure 5: Example of a graphical timetable, from Bane NOR (2020*a*).

*"At this level, the terminal owner makes decisions regarding the capacity levels of the terminal´s superstructure capacity, while the terminal operator plans labor and equipment capacity, and redesigns operational routines and layouts"* (Prince, 2015).

### Operational

The operational level has the shortest time perspective and considers the day-to-day operation and activities, as well as changes in the tactical plan according to current conditions. The aim is to ensure that the customers are handled in a safe and reliable manner.

Train dispatchers or traffic controllers are important stakeholders at this level, as they are responsible for making real-time decisions for a complex system. Their main tasks are listed below (Prince, 2015).

- Monitor and coordinate train movement.

- Initiate and stop train movements by controlling signals and switches, and communicating with the staff along the tracks.
- Manage the situation during unplanned events and emergencies. For example cases with unscheduled delays.
- Train rescheduling. Involves forecasting possible traffic conflicts and resolving them before they occur.

### 2.3.1 Strategic planning in Norway

The national transport plan can be said to have a strategic perspective, and enhances different measures for improving the competitiveness for railway freight transport, such as terminal measures, passing tracks, triangle tracks, and electrification (Mld. St. 33 (2016-2017), 2017). Triangle tracks, or "tilsvinger" in Norwegian, are tracks where a train can run between two branches in a Y-cross without going through the station. With the use of this, a lot of time is saved considering shunting movements. An illustration is shown in Figure 6.

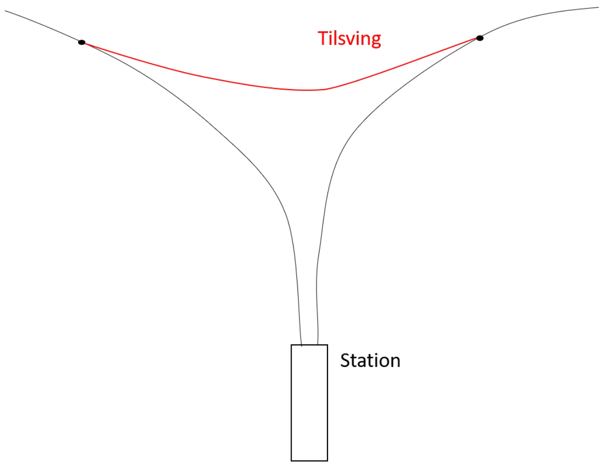


Figure 6: Triangle track/"tilsving".

#### Freight transport strategy

Jernbaneverket developed a strategy for freight transport on railways in 2016 named "Godsstrategi for jernbanen 2016-2029". In 2017, the company of Jernbaneverket was dissolved and split into multiple different units as a result of the railway reform, and the strategy is now a part of the Norwegian railway directorate ("Jernbanedirektoratet") who has the overall responsibility for management and coordination of the railway sector. They function as the organ responsible for the long term planning, hence strategic management.

The freight strategy aims at enabling an efficient, reliable, secure, and environmentally friendly freight transport (Jernbaneverket, 2016). In order to achieve this, four main areas have been detected and chosen as focus points for development.

1. A reliable and punctual railway
2. Capacity and efficiency of performance time
3. Accessible and effective terminals
4. An extended and connected network

The first focus point is one of the main advantages for railway and a prerequisite in order to be competitive. It consists of three main categories of measures to focus on; improved maintenance and renewal of infrastructure, planning and control of traffic, and preparedness and processing of deviations. First, improved maintenance and renewal of the infrastructure in order to operate the system as smoothly as possible and minimize downtime. Maintenance will be more important moving forward as the system grows more complex and existing infrastructure ages, as well as climate change inducing more unpredictable and extreme conditions. These measures will be aimed at both passenger and freight transport. Second, planning and control of traffic to make sure trains arrive on time. The challenges with punctuality are increased when the distance and stakeholders of the supply chain are increased, which is influenced by the operations on both the lines and the terminals in the network. Third, preparedness and processing of deviations in order to handle situations where processes do not go as planned, which there will always be a risk for. This includes situations where the line is out of order, and there need to be alternative ways to come through or around.

The second focus point aims at facilitating a system that utilizes the advantages of volume, hence the scale of economics, so that rolling stock and personnel are used as efficiently and profitable as possible. The three main categories for measures here are passing tracks and double tracks, longer trains, and optimized routes for freight. First, passing tracks and double tracks open up for a better operation including both passenger and freight transport. Passing tracks makes it possible for two trains to meet or overtake at several locations, and hence leads to increased capacity and flexibility in the network. Second, longer trains increase the advantage of volume as even more goods can be transported per train. As freight trains are operated at low speeds compared to passenger trains, they will occupy the sections for a longer time and hence it is favorable that each train contains as much load as possible. Third, optimized routes for freight aims at reducing the performance time and utilizing the existing infrastructure in the best possible way. This includes working with timetables, where minimized dwell time and increased average travel speed are important factors.

The third focus point concerns terminals as nodes in the network, and challenges related to structure, efficiency, stable operations, and capacity. Both considering new and existing market segments are important. Three main categories for measures have been stated as terminal structure, terminal capacity, and efficient terminal operation. First, the terminal structure aims at creating simple, cost efficient, and robust solutions, where realistic demands are considered. Standardization of operation systems and processes for terminals with similar functionalities are important, as well as facilitating the possibilities for multi-functional terminals at locations where several types of businesses are present. Second, terminal capacity aims at increasing the capacity at existing terminals, according to the objective of increasing growth of 75% for combined transport towards 2029. Third, efficient terminal operation consider reducing the unit costs related to terminals, and hence raising the competitiveness. The operation is influenced by factors such as organization, management and leadership, physical structure and layout, and how much volume can be handled.

The fourth focus point aims at removing bottlenecks, increasing the flow, and releasing capacity. This will make the railway a more attractive and efficient mode of transport, and more accessible for new users. The three main categories for measures here are stated as new line connections, electrification, and port, side and industrial tracks. First, new line connections will make room for new driving patterns and increased flexibility. Measures like triangle tracks, shown in Figure 6, will open up for more direct running without having to stop at stations and perform shunting operations. For freight transport this is favorable, as there often is little need to stop in between terminals. Second, the electrification of non-electrified lines creates a more standardized system and better flow within the system. This could alternatively be achieved by the use of new engine technologies and alternative fuels. Third, port, side, and industrial tracks will connect stakeholders within freight operation to the existing network of railway lines and make it easier to choose railway as a mode of transport for their goods.

An analysis for the national transport strategy found that the transfer potential for freight from roads is 5-7 million tonnes and that it is realistic to transfer about 30-50% of this by increasing the competitiveness of sea and railway (Jernbaneverket, 2016). To achieve this the measures mentioned above need to be realized.

### 2.3.2 Tactical planning in Norway

Prioritization and timetabling are important terms in rail transportation planning, especially for tactical planning. The network of railway tracks function as a closed system which requires a lot of management and regulation. In this system, both passenger trains and freight trains need to be operated together, and issues regarding which trains should be prioritized in different situations need to be settled and determined before operation can begin. Reasons for this are to avoid conflicts as much as possible and to have clear rules to be followed during operation, and hence ensure safety and security for the passengers and the goods.

A timetable is a plan or a schedule of how trains should move through a network. This plan will include the stopping points along the way, the time for stops, and the running speed which is to be used during operation. The timetable will be of high importance for the utilization of capacity and for how the operation is functioning. The steps of developing a timetable can be summarized as stated below (Abril et al., 2007) (Marinova et al., 2013).

1. Calculation of demand.
2. Modelling the actual infrastructure; layout of tracks, lines and nodes, average transit times, and signaling system. Using a macroscopic or microscopic approach.

3. Dividing the line into sections, and calculate running times as a function of section length and speed.
4. Determining the required headway; the time distance between two consecutive trains on the same line with the same direction.
5. Calculating the scheduled time for each train, corresponding to the time between arrival and departure.
6. Creating timetable; first trains with high priority and then fit in trains with lower priority afterward.

The current prioritization rules in Norway can be found in "Forskrift om jernbanevirksomhet, serviceanlegg, avgifter og fordeling av infrastrukturkapasitet mv. (jernbaneforskriften)" (Jernbaneforskriften, 2017). These are to be followed in cases where the infrastructure is congested and the demand is higher than the possible supply. In the regulations, the prioritization criteria are as stated below, where these are translated from Norwegian by the author and might differentiate a bit in wording.

1. Services which are included in contracts with the state concerning public services (passenger trains)
2. National and international freight transport
3. Certain types of traffic at lines mentioned in § 8-8 second term
4. Other passenger traffic

From these regulations passenger trains as mentioned in point 1), are to be prioritized before freight trains as mentioned in point 2). § 8-8 concern railway infrastructure for special purposes, such as tourism. Always favoring passenger trains is a challenge for freight trains, and with political goals aiming at increasing the frequency for passenger trains the situation for freight trains will be even more demanding. A study on prioritization of freight trains indicates that few socio-economic assessments have been done to evaluate these rules and that such changes could potentially have a considerable impact (Voldsund, 2020). Trials and analyzes to favor freight trains from 6 pm to 5 am was ordered by the government in 2015 (Samferdselsdepartementet, 2015), whereas the rules are still the same.

### 2.3.3 Operative planning in Norway

The operative planning in Norway is managed by Bane NOR, using traffic centers for coordination and control. These are responsible for information about traffic, distribution of capacity at stations, distribution of residual capacity, and management of the catenary system. There are three centers throughout the country, placed in Oslo, Bergen, and Trondheim, and these each has their specific region and lines to cover (Bane NOR, 2016). Operative management includes signaling system, traffic management, communication management, and surveillance automatic systems (Bane NOR, 2020*b*).

## 2.4 Stakeholders

The freight transport sector consists of many stakeholders, and Figure 7 show an overview of the main stakeholders involved in moving goods from one destination to another (European Court of Auditors, 2016). Shippers or forwarders are the ones who have the power to decide which transport modes they want to use, and this decision is usually based on an overall evaluation of the most favorable and convenient solution for their needs. The railway undertakings or operators are companies that are licensed to operate vehicles in the railway network, and these will be competing in an open market to attract the shippers. Infrastructure managers own the infrastructure and have the overall authority and management responsibilities.

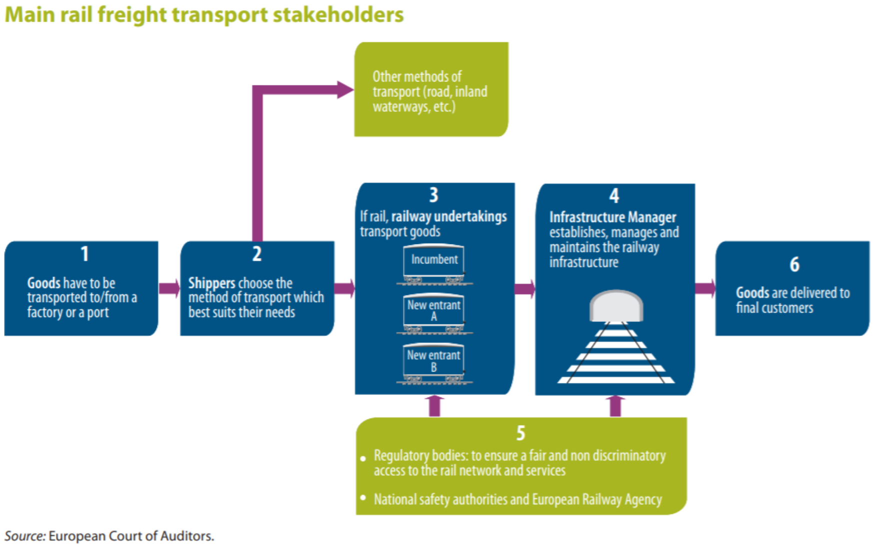


Figure 7: Main rail freight stakeholders, from European Court of Auditors (2016).

## 2.5 Railway freight terminals

Railway terminals are nodes in a network of railway lines. They work as meeting points for different modes of transport and are placed at a location where transferring and distribution of goods happen. A key element for terminals is to ensure a safe and efficient interchange. In Norway, a variety of terminals exist throughout the country, whereas in this project the focus will be on road-rail terminals. Railway freight terminals are usually owned by an infrastructure manager who hires an operating company to do the day-to-day work or a private company that does the day-to-day work themselves.

### 2.5.1 Components of a railway terminal

As terminals vary in size and design according to what type of goods they are to handle and the volume of this, they will consist of different components. There can however be found similarities between most terminals, which are listed below (Ballis and Golias, 2002). In order to make the system work efficiently, there is a need to make these components function well together, and that the amounts and capacity of the different components are adjusted to each other.

1. Rail sidings for train/wagon storage, marshalling, and inspection purposes
2. Transshipment tracks (also called loading tracks) for the train loading/unloading operations
3. Storage or buffer lanes for ITUs
4. Loading and driving lanes for the trucks
5. Gates, and internal road network

### 2.5.2 Functions of railway terminals

Figure 8 show a set of basic functions for a railway terminal, where the ones on top are the most basic and the ones at the bottom are more additional services (DIOMIS, 2007). The basic functions are requirements for any intermodal terminal to be able to operate, while additional services will vary depending on the local demand.

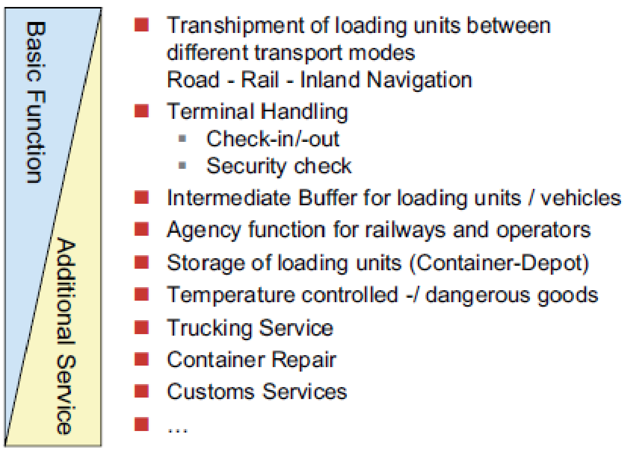


Figure 8: Basic functions and additional services at terminals, from DIOMIS (2007).

Principles for a common understanding of terminals are listed below according to DIOMIS (2007). These principles are set in order to create a system where all operators are to be competing according to the same terms and conditions, and is especially relevant for terminals where the ownership of infrastructure and the operation and management are split between different stakeholders.

- Principle of non-discriminative access to terminals, at least for those that have received public funding

- Rail-side access for all licensed railway undertakings
- Road-side access for all operators
- Transparent capacity allocation and pricing
- Bundling of different cargoes (maritime container, continental cargoes), and market segments (international and domestic relations) and thus improved capacity utilization.

### 2.5.3 Structure and layout of networks

5 different ways to structure terminals or create traffic patterns are stated by Woxenius (1998) to be direct, corridor, hub and spoke, fixed routes, and flexible routes. These are visualized in Figure 9 and further explained below.

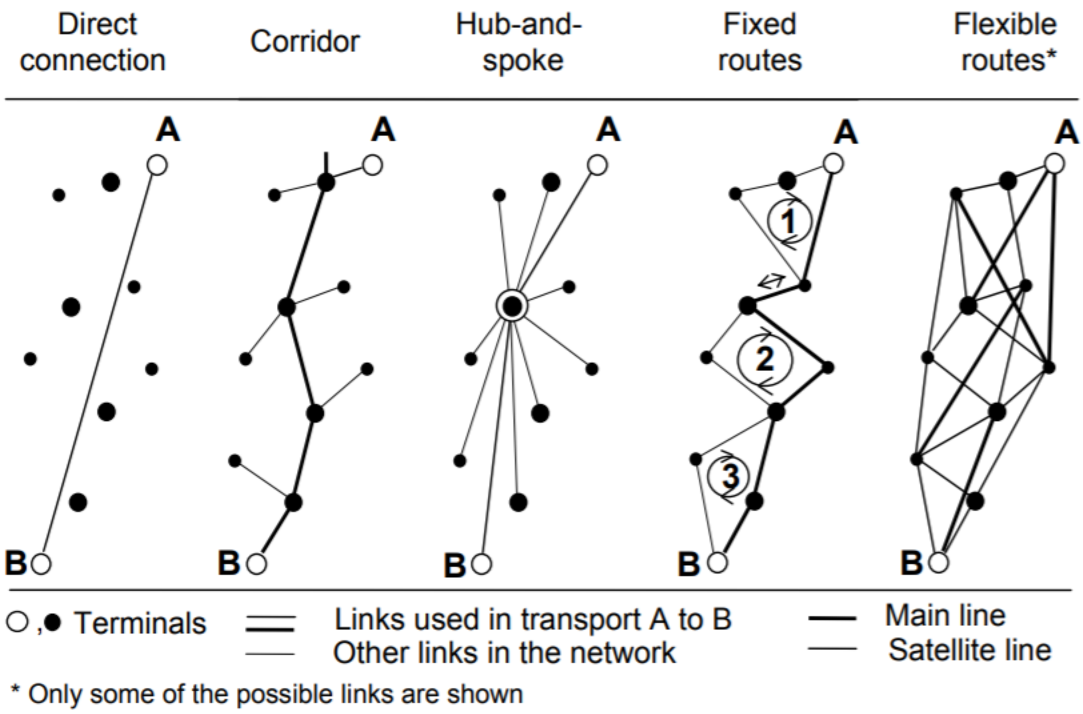


Figure 9: Different traffic patterns, from Woxenius (1998).

#### Direct connection

Transport goes directly between two terminals without stopping, as the name indicates. By using this method one is able to provide the customer with exactly what they need, as long as there is enough capacity in the network. Timetabling does not depend on other transport assignments. The advantages are that there is a high degree of flexibility and that the freight volume passing each terminal is limited and hence reduced need for capacity at each terminal (Woxenius, 1998).

**Corridor**

There is a frequent connection along the main path, called corridor, with short feeder services. Here there are main terminals along the corridor, and satellite terminals connected to the feeder route. As the goods are to be handled at several terminals, the transfer time of each terminal needs to be as low as possible.

**Hub and spoke**

In this alternative there is a main terminal or hub where all transport passes through. This solution requires an effective hub terminal and good utilization of vehicles to make up for a longer transport distance, as well as enough storage space at the hub.

**Fixed routes**

The operator has decided on specific routes to be used, with a fixed schedule, and connections to other routes at fixed terminals. Loading of goods is happening at multiple terminals, and organization of pick up/delivery between terminals can be done. For this alternative, the loading plan is crucial, as too much load means that there is a need for extra vehicles/trains/ships.

Advantages are that frequency and capacity can be adapted to the amount of goods in each area and that wagons that are emptied along the way can be decoupled. However, if delays or cancellations are to happen this could influence the plans ahead and have a domino effect through the network.

**Flexible routes**

The alternative with flexible routes is the most complex, with the highest degree of freedom as well as the highest demand for planning. Routes are allocated in real time based on actual demand, and the operator is free to use any wanted route. If enough goods are to be transported, one can have direct connections between all terminals. However, this traffic pattern has strict timetables which can induce challenges.

The most common traffic pattern for railway in Norway is the hub and spoke according to Lavoll (2016) and Woxenius (1998), where the terminal in Oslo, Alnabru, function as the hub.

### 2.5.4 Layout of terminals

Terminals can either be shaped like a sack terminal or a run through terminal depending on how they are connected to the main line. Figure 10 show a simplified sketch of a sack terminal where the connection to the main line is solemnly in one end of the terminal, while Figure 11 shows a run through terminal where there are connections to the main line in both ends of the terminal. A run through solution gives a lot more flexibility and redundancy to the system, and is easier to operate. It is however difficult to adjust existing sack terminals to run through terminals due to existing infrastructure and other developments in the surrounding areas.

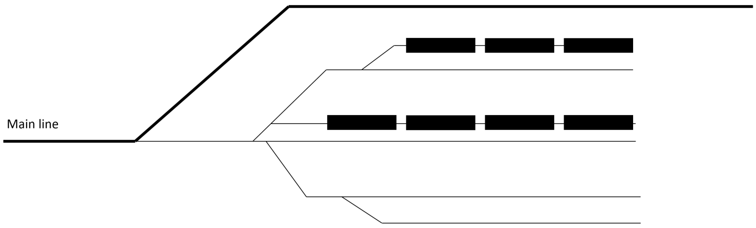


Figure 10: Simplified illustration of a sack terminal.

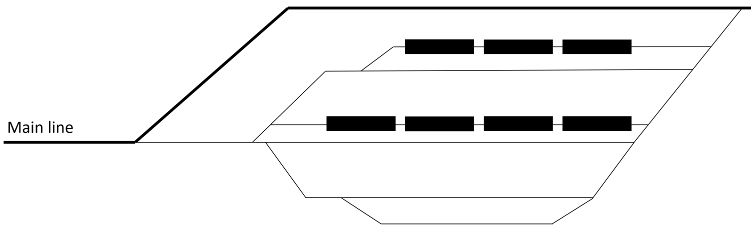


Figure 11: Simplified illustration of a run through terminal.

## 2.6 Cost factors

There are a variety of factors related to intermodal freight transport, and these are related to last mile activities, terminal activities, performance time costs, and time value for the cargo. Terminal activities and transshipment stand for a significant amount of the costs related to intermodal freight transport. Lavoll (2016) found that 1/3 of the costs for rail-road combined transport were related to terminals and that it is hence a lot to gain from making processes here as efficient and smooth as possible. The most important factors related to freight transport on railway lines have been identified by Jernbanedirektoratet to be transport efficiency (amount of goods per train), performance time, distance, and rolling stock plan (Jernbanedirektoratet, 2019). Here it was also found that terminal related activities stood for the largest contribution.

### Transport efficiency

Transport efficiency refers to the amount of goods per train, and thus larger this amount is the lower will the unit costs be. Economics of scale can be achieved by increasing the transport efficiency, either by running longer trains, loading to a higher degree per wagon, or increasing the possible axle load. Such an alternative will make it possible to operate the same amount of goods with fewer trains, which is an advantage for the operators as this gives less maintenance and lower costs related to leasing of rolling stock (Jernbanedirektoratet, 2019).

### Performance time

Performance time is the time it takes for a train to travel from a starting point to an ending point. This is not a significant part of the costs related to railway freight transport, but can possibly affect the choice of transport mode and the competitiveness towards other transport modes. Technical performance time is the theoretical minimum time a train needs to move between two points (Nielsen, 2017), while the term performance time usually also include the time spent for waiting, running with a lower speed than allowed, and other delay related factors. The actual or practical performance time is most relevant for decision processes, as this is the time that will actually be available for operators.

### Distance

Distance is of course an important factor and refers to the length between the start point and the endpoint. The longer the distance is the more favorable is the use of the railway for freight transport, and the shorter the distance is the harder is the competition towards road transport.

### Rolling stock plan

Utilization of rolling stock and rolling stock planning will influence the costs related to intermodal freight transport. This is related to how much time the rolling stock is used, and how much time is spent on standing still and not operate. If vehicles and rolling stock have a lot of still standing, it would be negative for the costs related to the operation.

## 2.7 Elasticity in transport demand

To be able to evaluate the response from a system given certain changes it is common to use the concept of elasticity. This term is perhaps more commonly used for passenger transport than for freight transport, but could theoretically be used to describe the change in demand for any system. Elasticity can be described as a measure for the sensitivity in demand depending on the changes in supply (Oslo Economics, 2016). This sensitivity will influence operators who offer transport. A common definition of elasticity is shown in Equation 1, for an example where the change in demand Y is measured relative to the change in price P.

$$\epsilon^P = \frac{\delta Y}{Y} / \frac{\delta P}{P} \tag{1}$$

For passenger transport the prices are commonly represented as tickets or travel time, but these could also rather be represented as generalized costs. Generalized cost is a concept used to describe the total costs of travel, including multiple factors such as prices, travel time, and others. A study on generalized costs in intermodal freight transport found that factors influencing the mode choice are (1) handling costs at terminals, (2) total transport distance, (3) pre- and post haulage costs, (4) distance dependent marginal generalized costs for the long-haul, (5) the distance dependent marginal generalized costs for truck and (6) resting costs for truck drivers (Hanssen et al., 2012).

The demand can change both with respect to costs and quality. A reduced cost will normally induce an increased demand, and a reduced quality will normally induce a reduced demand. This is illustrated in Figure 12. Here a more vertical curve will indicate a more inelastic demand, where the costs have little influence on the demand. A more horizontal curve will indicate a more elastic demand, where the costs have a larger influence on the demand.

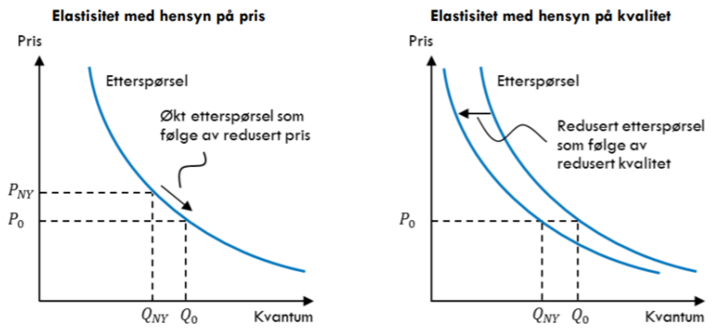


Figure 12: Change in demand for changes in costs and quality, from Oslo Economics (2016).

Freight traffic has commonly been assumed to be price inelastic or at least to a higher degree than passenger transport, which has however been found to be false (Graham and Glaister, 2004). Modeled elasticity will depend on the type of data used, the level and definition of commodity group aggregation, market coverage, and demand definitions. There will hence be different results depending on what type of model one uses.

An analysis done by Oslo Economics (2015) showed that intermodal transport between Oslo and Trondheim would be sensitive to prices, performance time, transshipment time, and deliverance precision. Factors used to describe this was that there is a significant competition towards road transport, overexerted capacity for some periods of the day, and disruptions in some periods.

## 2.8 Capacity

The term capacity refers to the maximum traffic flow which can be handled by a piece of infrastructure under specified operating conditions, and for railway lines, this would mean the number of trains per unit time (Pachl, 2018). For railway terminals, this could hence be explained as the number of trains which could be managed per time, the amount of goods which can be managed per time, or the amount of goods which can be stored per time. The available capacity should reflect the demand, and the inbound and outbound flow from terminals should be corresponding in an ideal situation.

Capacity planning examines how to create the most cost efficient and feasible method for meeting demand and requirements. From a strategic point of view, it can be expressed as *"the potential output of a system that may be produced in a specific time, determined by the size, scale and configuration of the system´s transportation inputs"*. From an operational point of view, it can be expressed as *"the maximum level of value-added activity over a period of time that a process can achieve under normal operating conditions"*. Railways are complex systems with many inter-related sub-systems, complex track layout, and a large amount of terminology, and hence a common definition of capacity for all situations is difficult to decide (Prince, 2015).

For railways the capacity of lines and terminals are evaluated differently. The capacity consumption on railway lines depends on both the infrastructure and the timetable (Landex et al., 2006). For railway terminals, the most common approach is to use queuing theory to evaluate the capacity, where all sub systems are evaluated as a queue and the total system will be a set of serial queues.

Capacity can be divided into theoretical capacity and practical capacity. Whereas theoretical capacity is a function of the fixed resources such as infrastructure and equipment, while practical capacity is mostly depending on how these resources are used. The use of resources is again depending on coordination between different stakeholders at all levels, and the use of coordination and communication tools (Prince, 2015).

### 2.8.1 Methods for evaluating capacity

There exists a variety of methods for evaluating the capacity of railway lines, but fewer methods for evaluating the capacity of terminals. For both categories, these can be classified as analytical methods, simulation methods, or optimization methods (Abril et al., 2007).

#### Analytical

Analytical methods are the simplest and aims at determining the preliminary solution, as well as referencing and comparison. They use mathematical formulae or algebraic expressions to determine the theoretical capacity, and then determine the practical capacity from a utilization factor.

### Optimization

Optimization methods are used to evaluate railway capacity based on obtaining optimal saturated timetables. The capacity is obtained by scheduling a maximum number of additional train services in a timetable. These tools are often used for tactical planning.

### Simulation

Simulation methods are used to represent a real-world operation with dynamic behavior, with the aim of validating a given timetable. As terminals function as a set of queues, most methods use queuing theory for determining the capacity of a terminal.

## 2.8.2 Line capacity - Theoretical and practical

Abril et al. (2007) distinguishes between theoretical and practical capacity, as well as used and available capacity. Here, used capacity refers to the actual traffic volume occurring on the network and available capacity refers to the difference between practical capacity and used capacity.

### Minimum headway time

Minimum headway time, $t_{s,min}$, is the minimum required time between the fronts of two consecutive trains in order to operate safely under ideal conditions, meaning that all traffic is homogeneous (same speed, weight, length, etc.), no time delays and no interference between vehicles. Also assuming minimum running times and minimum blocking distances (Prince, 2015). This will be the same as the interval between two subsequent trains.

### Theoretical capacity

The theoretical capacity is the maximum possible capacity of a railway line/interlocking/terminal under ideal conditions. When calculating the theoretical capacity one is assuming that the system is working without disturbances, as well as being able to operate all trains with the minimum headway time. This capacity does not reflect reality, but is useful to establish in order to set an upper theoretical limit. The theoretical capacity for a railway line can be calculated using Equation 2, where T represents the number of trains and $t_{s,min}$ represents the minimum headway time.

$$K_{theoretical} = \frac{T}{t_{s,min}} \tag{2}$$

### Practical capacity

The practical capacity is a more realistic measure for the operation of a railway system. When calculating the practical capacity one takes into account both the minimum headway time and a buffer time, where the buffer time is included for safety reasons, delays, and the effects related to trains not always have an actual running time equal to the minimum running time. The buffer time is defined as *"the difference between the actual headway and the minimum allowed headway"* (Landex et al., 2006), and can be calculated using Equation 3 where $t_b$ is the buffer time.

$$K_{practical} = \frac{T}{t_{s,min} + t_b} \tag{3}$$

The practical capacity can also be calculated using a utilization factor, u, as shown in Equation 4. This indicates the relationship between the actual operation and the ideal situation.

$$K_{practical} = u \cdot K_{theoretical} \tag{4}$$

UIC 406 has recommended limits for the utilization of a railway line, which is given as a percentage of the theoretical capacity. These values will correspond with the utilization factor in Equation 4 and is set to avoid delays accumulating in the network, and are given in Table 1 (UIC, 2013).

Table 1: Recommended values for capacity utilization from UIC 406.

| **Type of line** | **Peak hour** | **Daily period** |
|---|---|---|
| Dedicated suburban passenger traffic | 85% | 70% |
| Dedicated high-speed lane | 75% | 60% |
| Mixed traffic | 75% | 60% |

Reliability is a term that is used to describe the quality of service for a railway network, and high reliability indicates that few disturbances and failures can be expected. In order to achieve a desired level of reliability, one uses a proper amount of buffer time giving an actual headway time rather than a minimum headway time. The actual headway time during operation is set to achieve an acceptable level of reliability, based on the actual timetable, traffic mix, and running times. It is required that enough buffer time is used so that the amount of unscheduled delay does not exceed a certain amount. The relation between capacity and reliability is shown in Figure 13.

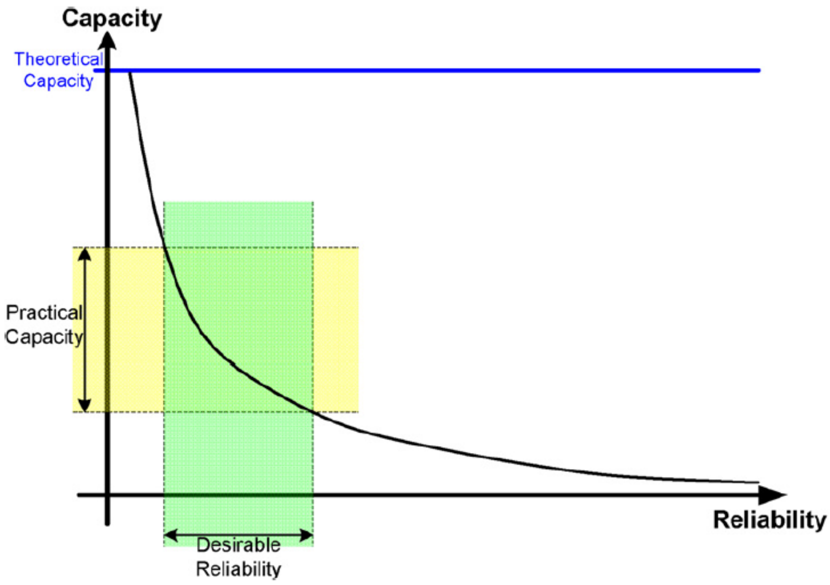


Figure 13: Relation between capacity and reliability, from Abril et al. (2007).

**Bottleneck approach**

The capacity for a line will be limited by one section, which can be described as the bottleneck. The bottleneck approach is then used to evaluate the overall capacity of the line, where the most constrained line section is determining.

### 2.8.3 Terminal capacity - Queuing theory

The most common approach to evaluate terminal capacity is the use of queuing theory. Terminals function as a set of queues, where one wants to identify the location of the bottle neck. Queues normally consist of customers and servers, and for terminals the customers will be the transport units and the servers will be the transshipment equipment.

Little's Law is a theory which estimates the average waiting time and the average number of waiting items in a queue (John D. C. Little and Stephen C. Graves, 2008), and is a common approach. The theory is simply explained as items arriving into the system, being handled through the system, and then departing from the system. During their time inside the system the items might experience a queue or not depending on whether or not there are other items in the system as well, and how many items can be handled simultaneously. The items will also be exposed to some sort of service, which can for example be containers at a terminal being lifted and transported to a storage location. In this way the theory is relevant for railway terminals, as well as for manufacturing industries and everyday life decisions. The theory assumes a stationary stochastic process. From their article John D. C. Little and Stephen C. Graves write that *"The average waiting time and the average number of items waiting for a service in a service system are important measurements for a manager. Little's Law relates these two metrics via the average rate of arrivals to the system. This fundamental law has* *found numerous uses in operations management and managerial decision making"* (John D. C. Little and Stephen C. Graves, 2008).

Items in a queue might receive service according to the FIFO concept (first in, first out), but this is not necessarily always present. Other versions for giving service can be random or last in first out.

Little's law can be expressed as Equation 5 which is quite simple, but also very effective. If you do know two of the terms, it is easy to estimate the third. Here $\lambda$ is a measure for the arrival rate, L is the average queue length, and W is the average waiting time.

$$L = \lambda \cdot W \tag{5}$$

where,
L = average number of items in the queuing system
W = average waiting time in the system for an item
$\lambda$ = average number of items arriving per unit time

In this formula some end effects will occur, meaning effects from items entering before the measure period starts and items leaving after the measuring period ends. As these items will be present in the system during the measurement period, they will influence the queue length and the waiting time. However, these effects will be smaller and smaller as the measurement period increases and can hence be neglected.

## 2.9 Trends within railway freight transportation

A dialog between Norway and EU has stated goals for reduced emissions with 40% for the sector not covered by the European emission trading system (ETS) within 2030 (Mld. St. 33 (2016-2017), 2017). As the transport sector is responsible for about 60% of the emissions for this group in Norway, this sector will need to reduce their emission in order to meet the objective. A variety of trends are present which will have an influence, and the most important are summarized here.

### 2.9.1 Aging and outdated infrastructure

An important trend within infrastructure is the aging and increasing maintenance gap of existing infrastructure. A study on the state of the current infrastructure and systems are have been done by Rådgivende ingeniørers forening, and this found that most of the current infrastructure is outdated and does not fulfill today's standard (RIF, 2021). On a scale from 1 to 5, the score for railways was set to 2. The costs of upgrading from score 2 to score 4 were estimated to be 600 billion NOK.

### 2.9.2 Technology

Improvement in technology will vary between different modes of transport when it comes to form, scope, and pace for implementation. This could potentially lead to reduced costs, increased efficiency, increased safety, reduced emissions, and other environmental concerns. The current development opens up for better engines and less fuel consumption, which is especially attractive for road transport using large trucks. Also within sea transport new and improved engine technology is on the agenda, as well as better navigation systems. For railways, the development of a standardized signaling system in Europe (ERTMS) and more efficient terminal operations are important factors.

With improved technology for engine and fuel, railway might not have the same environmentally friendly advantage as it has had in the past. The introduction and implementation of new technology for road vehicles can happen at a high tempo because these vehicles are changed quite frequently. Numbers from the national transport plan show that the vehicles used for freight transport are quite new. For large trucks, 60% are newer than 5 years old and 90% are newer than 10 years old. For all vehicles, 30% are newer than 5 years old, including passenger cars and small trucks (Mld. St. 33 (2016-2017), 2017). Newer vehicles will hence have lower fuel consumption and improved competitiveness with respect to environmental concerns.

The national transport plan lists these technological changes as factors that are expected to influence freight transport:

- Environmentally friendly vehicle technology and alternative fuels (electric, hydrogen, biofuels, hybrid).
- Improved efficiency of road transport leading to reduced costs and fuel consumption.
- Development and interconnection of more and improved driver assistance systems.
- ERTMS, development of a common signaling system for railway in Europe.
- New and better navigation systems for sea transport, as well as improved engine technology. More automation and autonomy will potentially help increase safe, cost efficient, and environmentally friendly sea transport.
- Digitization, further development of logistics systems. Examples of this are tracking services, optimization of travel routes, improved utilization of capacity, and reduced risks related to delivery.
- More efficient terminal operations.
- Technological development in the production of goods and services.

In Norway the long distances in combination with scattered production and settlement pattern induces some particular challenges. This opens up for increased transport costs compared to other competing countries and might influence the choice of transport mode. A solution to these challenges has been pointed out, which is more focus on co-modality rather than modal shift. Co-modality is a concept where the aim is to make the different transport modes function well together, whereas modal shift is a concept of transferring as much goods as possible from one mode to another.

### 2.9.3 Automation and digitization

Important trends within transport are the introduction of automation and digitization, and the implementation and utilization of new technologies as described above. An example of this in the railway sector is the implementation of two new systems, TOS (Terminaloperajsonssystem) and GOS (Gateoperasjonssystem), at the Alnabru terminal (Bane NOR, 2021*b*). These systems aim at increasing the efficiency of operation at the terminal by utilizing new systems and reducing the need for manual registration of vehicles. Hence, increasing the competitiveness of intermodal transport and railway freight transport. In 2021 these systems are also planned to be implemented at other terminals in Norway, both at Brattøra in Trondheim and at Ganddal in Sandnes. Compared to 2018 the systems will be able to handle $300$ more trains, reduce the hours of lifting for terminal equipment by $700$, release $25\%$ of the storage areas, and reduce the costs for using the terminal by $30\%$, per year (Bane NOR, 2021*b*).

An automated multimodal mobility will open up for greater interoperability between different sectors, and allow seamless transshipment of freight (European Commission, 2020). Relevant projects for this are the implementation of ERTMS (European Rail Traffic Management System), and the development of TEN-T (Trans-European Transport Network).

### 2.9.4 E-commerce

E-commerce has had a significant increase in the recent years, introducing a change in consumption patterns (European Commission, 2020). This trend will set new demands and requirements for the freight supply system, with smaller and more specific deliveries. The reach and scale of this is not fully known yet, but through time the transportation sector will need to adapt itself to this.

### 2.9.5 Bi-modal locomotives

Use of locomotives with different sources of energy and possibilities of driving at both electrified and non-electrified lines are up and coming. Last mile solutions for terminals have been tested in Norway, which will reduce the need for shunting effort at terminals (Jernbanedirektoratet, 2019). The use of such locomotives might reduce the need for investments in new infrastructure. Bi-modal locomotives could use power sources such as electrical power, diesel, or hydrogen in combination.

# 3 Methodology

This chapter will introduce and explain the methodology which has been used for the project. Much of the information in this chapter was developed in the pre-study for the master's thesis, where the main decisions for which approaches to use were decided (Malvik, 2020).

The thesis aims at developing knowledge about what the largest challenges for operation and planning of freight transport on railways are today and what the effect of these challenges can be, as well as finding solutions and proposals for how to improve the situation. One factor, performance time, was chosen to be studied in detail. The key working principles applied for the project have been literature review, qualitative in-depth interviews, and simulations/analysis in the Norwegian national freight model, NGM. In this chapter, the procedure for qualitative interviews is explained and simulations in NGM are introduced briefly. The method for literature review was explained in Section 2.1.

## 3.1 Interviews

A series of 10 interviews was conducted in order to answer the research questions. In-depth interviews were the chosen approach, as this allows the interviewer an opportunity to ask open questions and to ask follow-up questions if necessary. When studying the subject from broad and different perspectives this was found to be most useful. The interviews serve as a qualitative data collection, where the aim was to collect knowledge and information from experienced people within the railway industry.

The largest advantage with this method is that the respondent can introduce and comment on other subjects than planned, and hence show their experience and knowledge as much as possible. This is more difficult with quantitative questionnaires, as the answers will be locked to predefined questions. The disadvantages are that the interview situation requires a lot of focus, and there might also be necessary to ask follow-up questions at later times. As the respondents have different backgrounds and perspectives there might also be difficult to compare the results, and this required some interpretation and reflection from the author.

Interviews open up for the possibility to gain knowledge which is not written down, as well as a very up to date perspective. Supplemented with the literature review, this approach aimed at identifying the challenges with today's methods for operation and planning, as well as how this can be improved. The results of this could help to optimize the utilization of capacity by identifying where the largest needs are, and what type of measures are possible and realistic to implement. Also, the answers from the industry would help make an impression of what measures have been tried and what is and what is not working.

### 3.1.1 Election and recruitment of respondents

The aim was to have a total of 5-10 respondents from people with different perspectives in the freight sector, where both the strategic planning, the tactical planning, and the day-to-day operation were considered. Through the project, a total of 10 interviews were conducted, whereas most of the respondents had perspectives from overall management and planning, and a few had a background from day-to-day operation. Many of the respondents from overall management and planning have previous experience and knowledge from the day-to-day operation which was helpful to gain insight and knowledge. In this way, a broad and overall perspective could be achieved. Many of the respondents were contacted through the supervisor's network, but some were also found through different websites of organizations within the railway sector and then contacted by mail.

### 3.1.2 Design of interviews

The interviews aimed at being open in order to give the respondent room and possibility to bring their own experience and thoughts, as well as including some more specific questions and subjects. An in-depth semi-structured interview design is characterized by open questions where the actual interview is similar to a dialogue, with some concrete questions and some more open questions. In this design, the interviewer prepared a set of topics and questions which was sent to the respondents in advance, and these were discussed. Inputs and other aspects from the respondents were very welcome, as this would broaden the knowledge further.

Preparation and use of an interview guide were useful in order to keep track of which subjects had been discussed, and to keep a certain structure during interviews. This guide is attached in Appendix B.

The platform "Teams" was used to conduct the interviews. In the planning phase, it was considered that physical interviews where one could meet in person might be difficult to carry out due to the Covid-19 pandemic. Physical interviews could have felt more personal and might have given a better impression of the interviewer and the respondent, but the digital solution was found to be functioning well. A digital solution would open up the possibility to have an audio recording, which would make it easier to remember what was discussed. This was however evaluated not to be necessary, as taking notes during the interview and the possibility to prepare the notes with the interview guide was good enough. This also made the application process through Norsk senter for forskningsdata (NSD) easier and more efficient, as further explained in Section 3.1.4. The notes were written down to the computer during the interview and later rewritten as a summary. This required a lot of focus and multitasking from the interviewer at the time, and would also include a risk that some information was not noted. As all of the respondents worked within the Norwegian railway industry, it was natural that the interviews and summaries were done in Norwegian. In this way, quite a bit of translation work had to be done.

### 3.1.3 Processing of data

After the interviews were performed, a summary was written to describe what was discussed. The respondents got the chance to review and approve the summaries in order to avoid any misunderstandings or large mistakes, as well as giving approval to whether or not the summary could be attached as a part of the master's thesis. Most of the respondents agreed to this, but it was however decided not to attach the summaries as all of the relevant information is explained and included in Chapter 4.

### 3.1.4 Privacy

Through the work with the interviews it was necessary to handle personal information such as names, mail addresses, and phone numbers, as well as information that might be sensitive to businesses. It was therefore necessary to apply to Norsk senter for forskningsdata (NSD) to get the project approved, as a result of the General Data Protection Regulation (GDPR) which was introduced in 2018. The personal information was stored on the author's private computer, introducing a risk of information getting out of hand. Therefore the names of the respondents were replaced with a code, which was kept in separate documents. The likeliness of information coming out of hand was however evaluated to be unlikely, a conclusion which was approved by NSD as well.

Before the interviews started an interview guide and a consent form was sent to the respondents, in order to inform them about the project, how their answers would be treated, and to give them the possibility to prepare for the interviews. These are attached in Appendix B and Appendix C.

## 3.2 Simulation in the national freight model, NGM

Through the in-depth interviews a set of current challenges for railway freight transport was mapped, and one of these challenges was further analyzed using the Norwegian national freight model, NGM. The challenge which was chosen was the effect of performance time for the demand of railway freight. As a result of increasing frequencies for passenger trains, desires for longer freight trains, and low priority in timetabling processes, this was established as a major concern for railway freight transportation in the coming years. The effects were studied by adjusting the average travel speed for freight trains on domestic railway lines, and the development of transport performance was analyzed. A short introduction to NGM will be given here.

### 3.2.1 Model introduction

NGM is a static and deterministic model developed to analyze the distribution of all freight transport within and to/from Norway, based on the different modes of railway, road, aircraft, maritime, and inland waterways. The model also differentiates for types of goods, vehicle types, and transport units. The model consists of a set of base matrices related to flows of goods, cost functions, transport networks, and a logistical module, as well as the equilibrium model PINGO (Hansen et al., 2017).

In a simplified manner, modeling of freight transport can be said to occur in four steps as indicated in Figure 14. These have similarities to the modeling of passenger transport, but follow a more sequential order. The model in NGM follows such a methodology. The four step method uses a principle called ADA (Aggregated-Disaggragated-Aggregated), where the two first steps are aggregated, the third is disaggregated and the fourth is again aggregated. A more comprehensive description of the model system can be found from Homleid et al. (2016), whereas the three main components are described here.

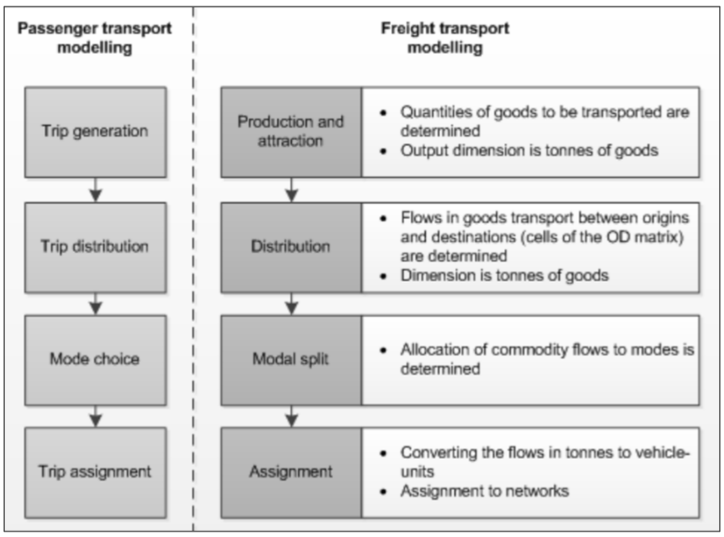


Figure 14: Four step methodology in transport modeling, from Brümmerstedt et al. (2015).

## PINGO

PINGO is a model developed by the Institute of transport economics, TØI, and is used to produce matrices called producer-warehouse-consumer (PWC) for different years, which include data about freight volumes in different regions in the country and for different types of goods. A total of 39 types of goods are used, which can be aggregated into 7 groups. The model is used to forecast demand for freight transport in the future, and the forecasts are further used to establish basic matrices for freight volumes in the coming years (Vold and Jean-Hansen, 2007). The estimates are mainly based on predicted population growth from Statistics Norway, SSB, and the actual freight volumes will probably differentiate a bit from the modeled values. Other uncertainties that need to be mentioned are that the forecasts are based on a development of the current structure and placement of businesses, and new establishments in other areas can not be predicted and included in the model. Route choices in the model are based on optimizing each shipment based on costs, which includes transshipment costs.

The types of goods used in NGM are shown in Figure 15, and translated in Table 2.

| Nr | 39 Varegrupper | Aggregert varegruppe |
|---|---|---|
| 1 | Jordbruksvarer | Tørrbulk |
| 2 | Frukt, grønt, blomster og planter | Termovarer |
| 3 | Levende dyr | Stykkgods |
| 4 | Innsatsvarer termo | Termovarer |
| 5 | Fersk fisk og sjømat | Fisk |
| 6 | Fryst fisk og sjømat | Fisk |
| 7 | Termovarer, konsum | Termovarer |
| 8 | Matvarer konsum | Stykkgods |
| 9 | Drikkevarer | Stykkgods |
| 10 | Dyrefôr | Tørrbulk |
| 11 | Organiske råvarer | Industrivarer |
| 12 | Andre råvarer | Industrivarer |
| 13 | Jern og stål | Industrivarer |
| 14 | Andre metaller | Industrivarer |
| 15 | Metallvarer | Industrivarer |
| 16 | Kjemiske produkter | Våtbulk |
| 17 | Plast og gummi | Industrivarer |
| 18 | Tømmer og produkter fra skogbruk | Tømmer |
| 19 | Trelast og trevarer | Stykkgods |
| 20 | Flis og tremasse | Industrivarer |
| 21 | Papir | Industrivarer |
| 22 | Trykksaker, programvarer og filmproduksjoner | Stykkgods |
| 23 | Kull, torv og malm | Tørrbulk |
| 24 | Stein, sand, grus, pukk, leire | Tørrbulk |
| 25 | Mineraler | Tørrbulk |
| 26 | Maskiner og verktøy | Industrivarer |
| 27 | Elektrisk utstyr | Industrivarer |
| 28 | Byggevarer | Stykkgods |
| 29 | Sement og betong | Tørrbulk |
| 30 | Forbruksvarer | Stykkgods |
| 31 | Høyverdivarer | Stykkgods |
| 32 | Transportmidler | Industrivarer |
| 33 | Petroleum uraffinert | Våtbulk |
| 34 | Naturgass | Våtbulk |
| 35 | Raffinerte petroleumsprodukter | Våtbulk |
| 36 | Bitumen | Våtbulk |
| 37 | Avfall og gjenvinning | Tørrbulk |
| 38 | Bearbeidet fisk | Fisk |
| 39 | Gjødsel | Tørrbulk |

Figure 15: Types of goods used in NGM, from Madslien et al. (2015).

Table 2: Types of goods, translated to English.

| **Aggregated type of cargo** | **Specific type of cargo** |
|---|---|
| Dry bulk | Agricultural products (1); animal feed (10); coal, peat, and ore (23); rock, sand, gravel, crushed rock, and clay (24); minerals (25); cement and concrete (29); waste and recycling (37); and fertilizer (39) |
| General cargo | Alive animals (3); consumption food (8); beverages (9); lumber and woodwork (19); print supplies, software, and film production (22); building materials (28); consumer goods (30); and high value goods (31) |
| Fish | Fresh fish and sea food (5); frozen fish and sea food (6); and manufactured fish (38) |
| Thermal | Fruit, vegetables, flowers, and plants (2); thermal intermediate goods (4); and thermal consumption goods (7) |
| Industrial cargo | Organic raw materials (11); other raw materials (12); iron and steel (13); other metals (14); metal products (15); plastic and rubber (17); chipwood and wood pulp (20); paper (21); machines and equipment (26); electrical equipment (27); and vehicles (32) |
| Timber | Timber and products from forestry (18) |
| Wet bulk | Chemical products (16); unrefined petroleum (33); natural gas (34); refined petroleum products (35); and bitumen (36) |

#### Cost module

The cost functions in NGM are used to prepare input to the logistical module and form a basis for the modal split. The factors included are transportation costs, terminal costs, storage costs, time costs for the goods, and eventual degradation costs for goods during transport. These calculations are produced as text files, which are further used in the logistical module.

#### Logistical module

The logistical module is used to distribute the freight volumes in the network, deciding the amount and type of goods for each link in the network. It is run sequentially for each of the 39 different types of goods, where the best possible route choice is found for each. The best possible route choice can either be based on the fastest or the shortest route, where types of goods with high time values choose the fastest route and types of goods with low time values choose the shortest route. The logistical module does not consider maximum infrastructure capacity in the network, but rather a theoretical flow of goods with no upper limit. The output could hence show a demand which is larger than what the current infrastructure is able manage.

### 3.2.2 Input parameters

The input parameter which is changed for this analysis is the average travel speed for domestic railway lines, and the default value used in NGM is 65 km/h. Evaluation of the default average speed compared to current graphical route tables was found necessary, in order to evaluate if the modeled speed was realistic according to the current timetable and operation.

To evaluate the credibility of the input a set of calculations of current average travel speed was done based on the graphical timetables from Bane NOR for the year of 2021 (Bane NOR, 2021*a*). It was chosen to evaluate four freight lines in Norway; Bergensbanen, Sørlandsbanen, Dovrebanen, and Nordlandsbanen. A selection of freight trains was found from the graphical timetables, and the average travel speed was then calculated based on this. Figure 16 shows the used distances for each of the stretches, which was read from the graphical timetables as well. Figure 17 to Figure 25 shows the calculated speed values based on the current timetable for R21, which indicates that the current average travel speed is somewhat lower than 65 km/h for most stretches. There is a variation between different lines and regions in Norway, as well as a slight difference depending on the direction of travel. For the stretch Heimdal-Alnabru at Dovrebanen and for Sørlandsbanen the value of 65 km/h seems to be most fitting. For further evaluation and analysis of the results, this needs to be considered.

| | |
|---|---|
| DOVREBANEN | |
| Distance Trondheim-Alnabru [km] | 546 |
| Distance Heimdal-Alnabru [km] | 534 |
| BERGENSBANEN | |
| Distance Bergen/Nygårdstangen-Alnabru [km] | 471 |
| NORDLANDSBANEN | |
| Distance Trondheim-Bodø [km] | 729 |
| SØRLANDSBANEN | |
| Orstad-Hokksund [km] | 507 |

Figure 16: Distances for railway freight stretches in Norway.

#### Bergensbanen

BERGENSBANEN

| From | To | Train number | Departure | Arrival | Performance time |
|---|---|---|---|---|---|
| Bergen | Alnabru | 5512 | 22:20 | 05:46 | 07:26 |
| Bergen | Alnabru | 5510 | 19:58 | 03:30 | 07:54 |
| Bergen | Alnabru | 5522 | 19:58 | 03:30 | 07:32 |
| Bergen | Alnabru | 5508 | 17:08 | 01:06 | 07:58 |
| Bergen | Alnabru | 4844 | 19:13 | 03:01 | 07:48 |
| | | | | | |
| Average performance time | | | | | 07:43 |
| Average travel speed [km/h] | | | | | 61.0 |

Figure 17: Average travel speed for Bergen-Alnabru, at Bergensbanen.

BERGENSBANEN

| From | To | Train number | Departure | Arrival | Performance time |
|---|---|---|---|---|---|
| Alnabru | Bergen | 5527 | 14:02 | 21:49 | 07:47 |
| Alnabru | Bergen | 5507 | 12:43 | 20:37 | 07:54 |
| Gulskogen | Bergen | 4845 | 14:12 | 21:24 | |
| Average performance time | | | | | 07:50 |
| Average travel speed [km/h] | | | | | 60.1 |

Figure 18: Average travel speed for Alnabru-Bergen, at Bergensbanen.

### Sørlandsbanen

SØRLANDSBANEN

| From | To | Train number | Departure | Arrival | Performance time |
|---|---|---|---|---|---|
| Orstad | Hokksund | 4862 | 09:37 | 17:26 | 07:49 |
| Orstad | Hokksund | 5802 | 10:26 | 18:39 | 08:13 |
| Orstad | Hokksund | 4866 | 11:08 | 18:20 | 07:12 |
| Orstad | Hokksund | 5814/5820 | 18:38 | 03:00 | 08:22 |
| Orstad | Hokksund | 5806 | 20:25 | 04:44 | 08:19 |
| Average performance time | | | | | 07:59 |
| Average travel speed [km/h] | | | | | 63.6 |

Figure 19: Average travel speed for Orstad-Hokksund, at Sørlandsbanen.

SØRLANDSBANEN

| From | To | Train number | Departure | Arrival | Performance time |
|---|---|---|---|---|---|
| Hokksund | Orstad | 5821 | 18:12 | 01:49 | 07:37 |
| Hokksund | Orstad | 4867 | 19:19 | 02:50 | 07:31 |
| Hokksund | Orstad | 4863 | 21:26 | 04:18 | 06:52 |
| Hokksund | Orstad | 5811 | 22:11 | 05:26 | 07:15 |
| Hokksund | Orstad | 5801 | 10:33 | 18:29 | 07:56 |
| Average performance time | | | | | 07:26 |
| Average travel speed [km/h] | | | | | 68.3 |

Figure 20: Average travel speed for Hokksund-Orstad, at Sørlandsbanen.

### Dovrebanen

DOVREBANEN

| From | To | Train number | Departure | Arrival | Performance time |
|---|---|---|---|---|---|
| Alnabru | Trondheim | 5737 | 16:12 | 00:35 | 08:23 |
| Alnabru | Trondheim | 5707 | 17:12 | 02:38 | 09:26 |
| Alnabru | Trondheim | 4811 | 18:12 | 03:19 | 09:07 |
| Alnabru | Trondheim | 4813 | 20:42 | 05:18 | 08:36 |
| Alnabru | Trondheim | 5709 | 21:12 | 06:17 | 09:05 |
| Alnabru | Trondheim | 5735 | 22:42 | 07:15 | 08:33 |
| Alnabru | Trondheim | 5731 | 09:42 | 18:33 | 08:51 |
| Alnabru | Trondheim | 5711 | 10:27 | 19:17 | 08:50 |
| Average performance time | | | | | 08:51 |
| Average travel speed [km/h] | | | | | 61.7 |

Figure 21: Average travel speed for Alnabru-Trondheim, at Dovrebanen.

DOVREBANEN

| From | To | Train number | Departure | Arrival | Performance time |
|---|---|---|---|---|---|
| Heimdal | Alnabru | 4812 | 19:17 | 03:35 | 08:18 |
| Heimdal | Alnabru | 5708 | 21:24 | 05:18 | 07:54 |
| | | | | | |
| Average performance time | | | | | 08:06 |
| Average travel speed [km/h] | | | | | 65.9 |

Figure 22: Average travel speed for Heimdal-Alnabru, at Dovrebanen.

DOVREBANEN

| From | To | Train numbe | Departure | Arrival | Performance time |
|---|---|---|---|---|---|
| Trondheim | Alnabru | 4810 | 07:39 | 16:37 | 08:58 |
| Trondheim | Alnabru | 5738 | 06:38 | 14:37 | 07:59 |
| Trondheim | Alnabru | 5736 | 11:07 | 19:37 | 08:30 |
| Trondheim | Alnabru | 4814 | 08:44 | 17:37 | 08:53 |
| Trondheim | Alnabru | 5702 | 09:02 | 18:37 | 09:35 |
| Trondheim | Alnabru | 5704 | 17:18 | 02:25 | 09:07 |
| Trondheim | Alnabru | 5730 | 23:32 | 08:07 | 08:35 |
| Trondheim | Alnabru | 5714 | 21:35 | 07:12 | 09:47 |
| | | | | | |
| Average performance time | | | | | 08:55 |
| Average travel speed [km/h] | | | | | 61.2 |

Figure 23: Average travel speed for Trondheim-Alnabru, at Dovrebanen.

### Nordlandsbanen

NORDLANDSBANEN

| From | To | Train number | Departure | Arrival | Performance time |
|---|---|---|---|---|---|
| Leangen | Bodø | 5793 | 16:35 | 04:30 | |
| | | | | | |
| Trondheim | Bodø | 5791 | 19:41 | 07:20 | 11:39 |
| Trondheim | Bodø | 5797 | 08:11 | 19:36 | 11:25 |
| Trondheim | Bodø | 5795 | 08:11 | 20:04 | 11:53 |
| Trondheim | Bodø | 5799 | 08:11 | 20:04 | 11:53 |
| | | | | | |
| Average performance time | | | | | 11:42 |
| Average travel speed [km/h] | | | | | 62.3 |

Figure 24: Average travel speed for Trondheim-Bodø, at Nordlandsbanen.

NORDLANDSBANEN

| From | To | Train number | Departure | Arrival | Performance time |
|---|---|---|---|---|---|
| Bodø | Trondheim | 5790 | 09:20 | 21:48 | 12:28 |
| Bodø | Trondheim | 5798 | 18:00 | 05:42 | 11:42 |
| Bodø | Trondheim | 5794 | 22:11 | 10:17 | 12:16 |
| | | | | | |
| Bodø | Mo i Rana | 5796 | 14:17 | 20:04 | |
| | | | | | |
| Average performance time | | | | | 12:08 |
| Average travel speed [km/h] | | | | | 60.1 |

Figure 25: Average travel speed for Bodø-Trondheim, at Nordlandsbanen.

### 3.2.3 Output files

A lot of output files were created from the model, but the one used for this analysis is called *transportarbeid_tog.txt*. This is an output that gives transport performance based on 10 railway stretches in Norway, given in Table 3. All outputs were studied, but for the final result, 8 stretches were chosen excluding the ones named Rest-Sverige and Rest-Oslo.

Table 3: Railway stretches used in NGM.

| Number | Name |
|---|---|
| 1 | Oslo-Finse |
| 2 | Hokksund-Stavanger |
| 3 | Oslo-Støren |
| 4 | Røros-Solør |
| 5 | Ofotbanen |
| 6 | Rest-Sverige |
| 7 | Rest-Oslo |
| 8 | Bergen-Finse |
| 9 | Støren-Tronhjem |
| 10 | Bodø-Trondhjem |

The 7 different transport modes used are given in Table 4. For the output files on railway stretches, the sum of electric and diesel trains are used. The other transport modes have not been studied in this project.

Table 4: Transport modes in NGM.

| Code in NGM | Transport mode |
|---|---|
| BIL | Truck |
| MVT | Large trucks (modulvogntog) |
| SKIP | Maritime |
| TOG | Electric train |
| TOG DIESEL | Diesel train |
| FERGE | Inland waterway |
| FLY | Aircraft |

### 3.2.4 User interface CUBE

In the user interface CUBE there are six different applications which can be used; 1 Scenario preparations, 2 Network editing, 3 Editing of input parameters, 4 Model calculations, 5 Making plot of differences, and 6 Selected link (Madslien et al., 2015). The newest version of the model was accessed, but this did not include the second module "2 Network editing" which was found necessary to edit the average travel speed for different links. Because of this, an older version of the program was used instead.

The first application consists of preparations for each scenario and is used when a new alternative scenario is created. The second application is used to make changes to the network. The third application can be used to make changes to the input parameters, both to cost related parameters and terminal parameters. The fourth application does the calculations and distribution between the different transport modes. The fifth and sixth applications are used to evaluate and analyze changes between different scenarios. In this project the first, the second and the fourth application was used, and the output was closely evaluated using Excel.

### 3.2.5 Creating scenarios

#### Reference scenarios

The model comes with a set of reference scenarios for different years, and for this project it was chosen to use 2018 as a base for today as this was the closest available year. Further, reference scenarios for 2030 and 2050 were used to simulate future situations. These scenarios were used in order to have a basis to compare new changes towards.

#### Changes in the model

As it was decided to focus on effects related to performance time, it was natural to include both increased and reduced time compared to the current situation. Longer freight trains will not be able to utilize all existing passing tracks as it does today, reduced flexibility and more difficult operation are likely to occur. It is believed that the performance time will be affected by this, and that some forwarders will choose other modes of transport instead. Hence it is of interest to analyze for what travel speed one will lose and gain demands.

To evaluate the effects of performance time the attribute "SPEED" was varied. The average speed for freight trains has a default value of 65 km/h for lines within Norway and 50 km/h for lines outside of Norway (Madslien et al., 2015). An evaluation of this was given in Section 3.2.2. In this project, only the lines within Norway were changed. Table 5 shows a summary of what changes were made in the model, and these scenarios were then run for the years 2018, 2030, and 2050.

Table 5: Alternative scenarios in NGM.

| **Scenario** | **Changes in NGM** |
|---|---|
| Reducing speed | Reduction of the average travel speed for domestic railway links to 60 km/h, 55 km/h, 50 km/h and 40 km/h. |
| Increasing speed | Increase of the average travel speed for domestic railway links to 70 km/h, 80 km/h, 90 km/h and 100 km/h. |

## 3.3 Limitations to the methodology

The use of interviews required being able to get in touch with enough and relevant respondents to interview which showed to be more challenging than assumed. Some groups of respondents were more difficult to get in touch with, especially the ones working with day-to-day operations. The aim to get a broad overview required respondents with varied and different perspectives, and not all stakeholder groups have been represented equally which might influence the results.

A limitation for the modeling part of the study is that it does not consider new establishments in new areas or the fact that there are capacity limitations in the infrastructure network. The model will calculate the maximum potential demand given that the system can handle any increase, which is not completely realistic as there will be capacity constraints in the network. The software has a high complexity, and there are possibilities to utilize it for a lot of different analysis. The author has however been a beginner, and hence some aspects of the model might not have been utilized to its full potential.

# 4 Results

In this chapter the results are presented and commented, and these are further discussed in Chapter 5.

## 4.1 Interviews

To identify current challenges for freight transport and terminals, a set of 10 in-depth interviews were conducted. This resulted in many interesting findings, with a broad variety. Since the respondents came from different parts of the industry and had different perspectives, they would also focus on different aspects related to planning and operation. The respondents can be categorized into planners, infrastructure owners, and operators. Operators are here understood as railway undertakings, which are responsible for the operation of rolling stock and cargo at railway lines and terminals. Table 6 shows an overview of the respondents. Some of the respondents have a current position in one of the groups, but also have previous experience from other groups and were therefore considered to have insight into several perspectives. The results from interviews are based on the interview guide given in Appendix B, and the following sub chapters correspond to the topics from this guide.

Table 6: Interview respondents.

| Respondent group | Number of respondents |
|---|---|
| Planners | 6 |
| Infrastructure owners | 2 |
| Operators/Railway undertakings | 2 |

### 4.1.1 Main challenges for railway freight transport today

First the main challenges were mapped in order to get a broad overview of the current situation, and a summary of the findings is shown in Table 8. The challenges have been divided into subgroups which are further explained below. The thesis was mainly focused on the challenges related to terminals and how to improve these as connection points between road and railway, but through the interviews it became clear that the capacity on lines and terminals are so closely related that they have to be considered together. The results will therefore be related both to terminals and the lines in between.

#### Infrastructure

Both planners, infrastructure owners, and operators introduced and revealed the lack of capacity in infrastructure as a major challenge. Much of the existing infrastructure is very old, and in many regions there is a major need for renewals and major upgrades. For a long period, large maintenance procedures and upgrades were not prioritized, which lead to a lack which can be observed today. During the last couple of decades, there has been an increasing investment in railway infrastructure, but most of this has been aimed towards passenger transport. The improvements will also be a positive contribution towards railway freight transport, but to a somewhat limited extent.

The lack of capacity in infrastructure is especially present around the big cities in Norway and most prominent around Oslo. There exist plans and goals to increase the frequency of passenger trains, and such an increase will lead to a higher occupancy of capacity for the lines, leaving less space for freight trains. Planners and infrastructure owners are concerned that this will influence the operation of freight transport negatively, and limit the time frames where it is possible to operate. Goods have their desired times during the day when it is most favorable to arrive/depart from a location, just like passengers. Limiting the possible arrival and departure times is likely to reduce the attractiveness of the railway as a transport mode for freight, and hence forwarders might be lost. Another consequence could be that the maximum supply of freight transport is utilized and further demand will have to be rejected, a case which has already been occurring.

The layout of terminals today is a result of a long history. Earlier, freight trains were a lot shorter than they are today, and terminals were designed to fit the old design. With the introduction of longer and longer freight trains a need for splitting each train into several parts increased, and hence more shunting effort occurred. Therefore the operation of terminals today often includes running the train all the way into the terminal, uncoupling some wagons, run back, and then enter again in another track. As the terminal tracks have varying lengths, it is a need to make detailed plans for which wagons are to be placed were, and how the coupling and uncoupling are to be organized. Operators described this process as a continuously changing puzzle. Figure 26 shows a simplified example of how a train must be split in a terminal. Imagine a train consisting of ten wagons entering the terminal, which needs to be split into three parts to fit inside. As the loading/unloading tracks are too short to fit the entire train, splits and shunting are necessary and time consuming processes.

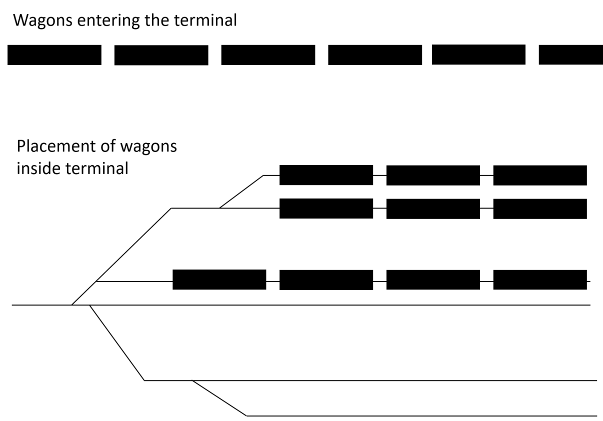


Figure 26: A simplified example of splitting a freight train at a terminal.

The layout also has challenges related to the placement of depot areas relative to the loading/unloading tracks. Many terminals have depot areas a far distance from the tracks, meaning that trucks and reach stackers must drive a relatively long way between each loading/unloading. This is not efficient and results in a longer time required for loading and unloading of trains.

The last found challenge related to infrastructure is the amount of investments. Both roads and railways are important parts of the transport network and will have to be prioritized towards each other. In the past years, there has been a relatively larger investment in road infrastructure compared to railway infrastructure, and hence the competition between the two has been in favor of road transport.

Limiting factors were also mapped through interviews, and related to infrastructure it was found that this will vary from place to place. It was mentioned several times that a train length of 600-650 m would be desirable to meet future demands, and Table 7 shows mentioned factors that limit the possibilities for this. Line capacity is of high importance, and especially with an increasing demand for transport, the system must be capable of handling this. The amount and length of passing tracks are especially important at single line tracks, where there are no other possibilities to meet or pass another train. Within the terminal factors such as track length, depot area, and gate system have been found to be limiting.

Table 7: Limiting parameters for infrastructure.

| **Parameter group** | |
|---|---|
| Passing tracks | Length<br>Total number<br>Position along the line |
| Load capacity | Load capacity for each train<br>Load capacity for each wagon |
| Terminal tracks | Length<br>Total number<br>Layout |
| Depot area | Storage space at terminals<br>Placement of storage space inside terminal area |
| Truck related parameters | Number of gates<br>Parking inside terminal area<br>Road system to/from terminal |

**Operation**

Operation of railways includes all activities related to the day-to-day management, as explained in Section 2.3. Challenges related to operation are related to flexibility, prioritization, punctuality, and varying demand during the day, the week, and the year.

Railways have lower flexibility compared to other transport modes and especially compared to road transport which is the largest competitor at many stretches. Rail transport requires transshipment at terminals in both ends, and hence the flexibility is a lot lower. Road transport has become cheaper and cheaper as a result of higher customer demands related to travel time and flexibility. Road transport is more flexible, requires less planning, and requires a smaller freight volume per trip. The safety requirements for road transport are also lower compared to railway transport. Resulting in a hard competition for railway operators to win the freight customers and forwarders.

Prioritization between passenger and freight trains was mentioned by almost all of the interview respondents as a major factor for operation. The current prioritization rules are explained in Section 2.3.2. With the increasing demand for both passenger and freight transport these prioritization rules will be in favor of passenger trains always, and hence creating less and less space in the timetables for freight trains. Prioritization was established by operators to be the most influencing factor towards their day-to-day activities. Considering costs and benefits, it does in their opinion not make sense that freight trains are always deprioritized. For some times during the day, it would be favorable if freight transport could be prioritized.

Similar to passenger transport, freight transport also has varying demand through the day, the week, and the year. The peak period for loading of freight transport is in the afternoon, the peak period for running is at nighttime, and the peak period for unloading is in the early morning hours. These demands are related to the operation and needs of freight customers and especially for container transport which is used for the supply of stores that need refills in the morning. These peak hours sometimes tend to be in conflict with passenger trains, for example freight trains which should desirably leave Alnabru at around 5 pm will be in conflict with the rush hours for passengers. No easy way to solve this conflict has been found yet, but a change in prioritization could possibly help.

Stability within punctuality and regularity is of the utmost importance to attract and keep freight customers. This research indicates that predictability is one of the main factors for freight customers and forwarders. Most companies operate with a well developed running pattern where being able to know future conditions are decisive. Some companies operate with a more ad-hoc based planning system making it less important to have a lot of detailed information beforehand, such as smaller freight companies. For these predictability might be of less importance.

The last challenge related to operation was found to be late announcements of residual capacity. This is done so late that it makes it almost impossible for other operators to utilize this, and especially for smaller companies operating with an ad-hoc method.

#### Organization

The organization of the freight sector is complex with many different stakeholders, as explained in Section 2.4. The current organization is designed so that multiple operators are present at the same terminal, and these all have their own areas and equipment. Challenges related to the utilization of areas and equipment will hence be very individual, and common planning for the entire terminal can be difficult. A possible consequence of this is that equipment use and planning are not optimized and that the necessary tools are physically existing, but not available because they belong to someone else.

The current organization will also open up for challenges when it comes to national vs. local politics. A freight terminal is something that will have a positive function and impact for a large area or an entire region, whereas the downsides will mainly be related to the one municipality where the terminal is placed. Very few municipalities are eager to establish large terminals within their own areas and hence planning and decisions for new terminals are extremely time consuming. These establishments are also very large, and will be difficult to move when they are built.

Regulations were found to be another challenge related to the organization. Planners and infrastructure managers missed a set of laws and guidelines for minimum requirements at terminals. The possibility of having a standardized set of rules to follow would make it easier to rule out projects which are not doable at an early stage. It was desired that such guidelines should include a set of construction and operation conditions, which makes it possible to establish smaller terminals closer to customers and users of transport.

**Knowledge**

Competence and knowledge are important aspects when creating a well functioning system. There exists a lot of competence and knowledge within the industry, but there is a need to pass this information on to politicians, decision makers, and civilians for the society as a whole to have a better understanding of the role freight transport has for communities. The supply of goods can be said to be a critical part of the well being of a community, as almost all of the necessary tools, equipment, and provisions need to be transported from somewhere.

The importance of goods supply might not be understood to a sufficiently high degree when it comes to making decisions. Planners often meet decision makers who have a lack of competence about how important it is to create good supply systems, and what role goods supply has for a city or a region. As decision makers are the ones who decide whether or not something should be prioritized and which projects to focus on, the need for sufficient knowledge is important.

Most terminals today are placed within cities and are considered to be area consuming and environmentally damaging, and are hence a huge source for conflicts and challenges. Questions related to what a city is and what it should be, as well as what functions are necessary to create a "good city" is relevant. This is already up for debate, but more debate around these subjects are welcomed by planner and infrastructure managers. Moving terminals outside of the city where it will be less visible might induce larger costs for the customers, but might also open up for other use of attractive areas within the city. Such a solution could be said to "hide" the problem, and it is uncertain whether or not it will solve the problem. New challenges related to last mile transport will also occur if terminals are placed further away.

In a competitive business sector sharing of data is difficult. Without enough data, it is difficult to make good plans which utilize the advantages to the highest possible degree. Also, innovation within digitization is limited by the skepticism to share data. This will hence create problems with establishing and developing good and accurate models for planning.

**Economy and financing**

All of the respondents emphasized economy and financing as huge challenges. There are a lot of possible projects and measures which could help the situation for freight trains, both regarding maintenance and improvement of existing infrastructure, as well as renewals and establishment of new lines, triangle tracks, passing tracks, and terminals. In order to defend large investments in rail infrastructure, it is necessary to have a certain demand for transport and to prove that the projects will contribute in a good way. Compared to other countries Norway has a relatively low demand for freight transport on railways, and hence the argumentation to invest in more infrastructure might be found weaker. Other solutions for road transport have proven to be up and coming and it is not impossible that such solutions might be able to handle the future needs and demands. This however induces challenges related to congestion and increased traffic load for roads, and issues regarding traffic safety, which needs to be mapped further in order to get a sufficient foundation for decisions and further planning.

Establishment of new terminals and new infrastructure is extremely costly. Infrastructure managers compare the costs in Norway to similar projects in Sweden and find that there is a huge difference even though the terrain and topography are quite similar. This is interesting, and looking into reasons why it is so much more costly in Norway is necessary. This has not been done in this project, but would for sure be interesting for future projects.

Planners say that up until around 2010 there was a very long period with low investments in railway, which has lead to a large maintenance lag where upgrades are necessary. There are already large challenges and demands for maintaining existing infrastructure, but little resources have been given to improve and approach this. The long processing time in order to get projects planned, approved, and realized does not help the situation and was a concern for all respondent groups.

Planners find that a terminal as an isolated component is not useful, and that the benefits are only present as long as there are less costs during transport and that the total costs are lower. Hence, the costs related to transshipment need to be compensated by low enough costs during running. The current situation is not promising to be fulfilling such a case in the future.

A summary of all the mapped challenges is listed in Table 8.

Table 8: Main challenges today.

| | |
|---|---|
| Infrastructure | • Existing infrastructure is old, and the layout of terminals is not optimal.<br>• Terminal and line capacity needs to be corresponding, and upgraded.<br>• Bottlenecks around the large cities in Norway.<br>• Time consuming to establish new terminals and lines.<br>• Large competition about investments toward road infrastructure. |
| Operation | • Low flexibility.<br>• Prioritization between freight and passenger transport.<br>• Residual capacity is announced very late, making it difficult to utilize.<br>• Variation in demand during the day, with large loads for peak hours.<br>• Punctuality and regularity. |
| Organization | • Many different stakeholders involved, leading to a high complexity.<br>• National vs. local politics.<br>• Simple guidelines for establishment of new terminals. |
| Knowledge | • Lack of knowledge in decision processes.<br>• Concerns towards sharing information and data. |
| Economy and financing | • Very costly to invest in and maintain infrastructure.<br>• Lack of financing for freight projects for a long time.<br>• Relatively low demands make it difficult to defend large investments.<br>• Limited resources for research activities. |

## How to meet these challenges?

After that the main challenges had been mapped, the next step was to identify ways to improve the situation. The respondents had a variety of suggestions which will be explained here, and these are also summarized in Table 9.

### Improvement and development of infrastructure

Both terminals and lines need an upgrade. Most terminals today are shaped as sack terminals with short tracks where splitting up and shunting are necessary, as illustrated in Figure 27. One way of approaching this is by changing the layout so that it is possible to enter/exit the terminal in both ends using a run through terminal, and creating a much more flexible operation. Such changes will however require large investments and resources, and there are uncertainties if this something that will be prioritized in financing. Surrounding establishments will also need to be taken into consideration. There are some examples for terminals with possibilities for entering/exiting in both ends, such as Alnabru, Mo i Rana and Fauske.

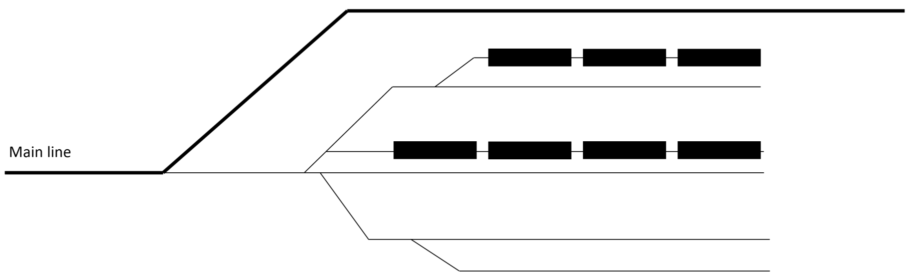


Figure 27: Illustration of a sack terminal.

A major part of the Norwegian railway network consists of single track lines, which typically can operate between 60 and 80 trains per day. This will have constraints for how many freight trains it is possible to squeeze into the timetable, considering that there is a high amount of passenger trains as well. An upgrade to double track typically gives the possibility to run as many as 300 to 400 trains per day, as there is less need to pass opposing trains. Such a change will hence make a considerable effect.

An approach at lines is the establishment of longer passing sections and triangle tracks. Also the establishment of longer sections with double track would have a positive effect. These are perhaps obvious, but sometimes the solution does not need to be very advanced in order to solve the problems.

### Change of prioritization

Change of prioritization was mentioned several times by the respondents, and means the choices of which trains should wait and which should run when conflicts arise. Today the regulations almost always prioritize passenger trains over freight trains, and a lot of effort is necessary in order to make changes to this system. A solution where freight trains have priority for some time slots or periods during the day could potentially improve the situation considerably without any new infrastructure or too large consequences for passengers. As several respondents pointed out, freight trains have their largest demand during evening and night time where the demand for passenger trains is lower. Hence, giving priority to freight trains during these periods might not have such large negative consequences regarding increased travel time for passengers.

Two possible ways to approach different prioritization rules are to use simultaneous entries or overlong crossings. Simultaneous entries are a procedure where two trains are allowed to enter a station or a passing section at opposite ends at the same time. This approach would require a change in the current signaling system, as well as security that one train is not able to enter into the track of the other train. Such changes might be complicated and expensive to implement, but are definitely possible. Overlong crossings are an approach where the passenger train will use the passing track, while the freight train will use the main track. The freight train will enter the main track in the passing section and wait there. When the passenger train enters the passing track, the freight train can go ahead again. This procedure will induce a larger loss in travel time for the passenger train, compared to simultaneous entries. It is however not as complicated, expensive and area consuming, and could be a favorable solution. As passenger trains usually are shorter compared to freight trains, this would mean that existing passing tracks can be used without being extended as well as possibilities for longer freight trains at the same time. Hence, it would be a solution that does not require such large changes in the current infrastructure.

Another aspect which was discussed was the possibilities to regulate rail transport compared to road transport. It was found possible to adjust the market shares with the use of taxes and other means based on political ambitions, but that this alone would not make rail a more competitive solution. The ideal aim would be to make rail such an attractive choice on its own that forwarders would use this anyway.

**Introduction and implementation of new technologies**

Many of the respondents pointed towards technology and innovation as important areas for solving today's challenges. For the terminal in Oslo (Alnabru) and Trondheim (Brattøra) there are ongoing projects to introduce an automatic gate system, GOS - Gateoperasjonssystem. This is a system that will register the incoming trucks through automatic cameras and photos, and send information directly to the operational systems at the terminal. The need for manual operations at the gate will then be reduced, and efficiency of operation will increase. There is also an ongoing project to develop an operating system for terminals, TOS - terminaloperasjonssytem. This system aims at improving the logistics for the placement of transport units within the terminal area so that all driving internally at the terminal is minimized. In this way a more efficient and optimized operation can be achieved.

The introduction and change towards zero emission vehicles at terminals is an important factor for the transition towards a more environmentally friendly operation. The respondents believe that this will get an even larger impact and influence on choices and attractiveness in the future, and that this will be beneficial for the railway. Use of the railway is already considered to be quite environmentally friendly, but there is still room for further improvement.

#### Financing

Financing is of the utmost importance to take plans and projects from ideas to realization. The power of what projects should be prioritized and not are in the hands of politicians and authorities, and hence it is of utmost importance to provide sufficient and relevant information for them.

#### Communication and information

In order to increase the knowledge and competence one needs to have good communication of how projects will contribute and what role supply of goods have for a city. To achieve such a solution there is a need for an educational and pedagogical approach towards decision makers and the public. To achieve this there is a possibility to use new and creative approaches, for example the use of exhibitions and interactive learning. An example mentioned by respondents was to use a container made of glass, where the cargo inside is very visible for visitors. Here, the goal is that it becomes more obvious that the supplies each person needs in their life has to be transported.

Table 9: Summary of measures to improve freight transport on railways.

| **Measure** | |
|---|---|
| Infrastructure improvements | Creating a competitive alternative.<br>Increasing the amount and length of passing sections.<br>Modernization of terminals, and adjusted layout for current and future demand. |
| Change of prioritization | Higher prioritization of freight trains in timetabling and in conflict situations.<br>Varying prioritization during the day.<br>Simultaneous entries and overlong crossings. |
| New technology | Automation and digitization.<br>Gate operation system and terminal operation system.<br>Introduction of zero emission vehicles for terminal operations. |
| Financing of projects | Prioritization of freight measures in national plans.<br>Opening up for private investments in railway infrastructure. |
| Communication | Improved communication towards the public, using a pedagogic and understandable approach.<br>More dialog and collaboration between planners, owners, operators, and society.<br>There is a need for enthusiastic and engaged people promoting railway freight. |

### 4.1.2 Communication and collaboration between stakeholders

Communication and collaboration were found to be interesting aspects to study, as there are many stakeholders involved and a high degree of competition and dependability between them. Through the interviews, the candidates were asked how they experienced the collaboration between different stakeholders and if there was anything that should be done differently than to today. The overall impression was that communication and collaboration were functioning well internally in the industry, and that there are usually well established and long time relations with well developed patterns and systems. The largest challenges for railway freight transportation were said to be related to other aspects such as infrastructure, prioritization, technology, and economy.

Planners, operators, and infrastructure managers emphasized that the sector has limited resources, and that economy and other means need to be prioritized thoroughly. This makes it difficult to start up and spend time on a lot of activities that might not give a positive outcome right away, and which will require some time. Such activities can for example be research that will have a positive effect in a long term perspective.

Operators told that in an industry with open competition there would of course be competitive relationships, but that a lot of common interests were also present. These common interests would be related to upgrading and development of the current infrastructure, as well as financing of projects aimed at increasing the competitiveness for railway freight transport. The areas with potential for improved communication were said to be towards the authorities and the public. From an operating perspective, the need for further increased knowledge of how terminals are operated with a holistic view is necessary. As the infrastructure manager Bane NOR took over the ownership for the terminals not too long ago there is still a need for adjustment and development, but it was believed that this would be improved through time.

A challenge mentioned by operators was the managing of space within a terminal area. Terminals have a limited amount of space and with the increasing number of operators at each terminal, the need for coordination between them is also increasing. Each operator has their own space and equipment, and sharing between them was found to be uncommon. One way of meeting this challenge is the use of an independent third party that could be in charge of the operation at the terminal, and the current operators/railway undertakings which run trains could buy services from this independent company. This would open up for more efficient and united use of the space and equipment which is available, but would also decrease the communication towards the forwarders. Terminals are usually the place where freight operators and forwarders meet, and important relations are built and maintained here. To lose this contact would have some consequences, and could potentially lead to a worsened trust towards each other.

As the process of being approved as a railway undertaking for freight on railways is complicated, there is a limited number of operators and the ones we have are large or operate within niche markets. This creates a very professional industry, where the operators are serious.

Planners and infrastructure managers emphasized that there is a huge difference between large and small operators. Whereas large operators have very planned and regular departures, smaller operators use more ad hoc planning. There are challenges occurring when residual capacity is made available very last minute, making it almost impossible for smaller operators to utilize this. As a result, wagons are transported empty, which is not favorable in an overall perspective.

Planners and infrastructure managers were also concerned that the competitive terms of the industry are an obstacle towards creating good and precise models for transport. With the competitive terms, there is a limited trust to share data about the operation, such as; the amount of goods which is transported; when, from where and to where it is transported; how this is loaded and unloaded; how storage is handled through the chain; and if the goods have any restrictions related to temperature, contact with other types of goods, etc. A better system for this would help the planning process a lot, especially considering the mapping of demands and the development of models and plans. As a result of more sharing of data, one would be able to plan and decide on routes that are more optimized. This is area is found very interesting for further studies.

The last communication challenge which was found was related to planning processes and public processes. As also mentioned in Section 4.1.1 these take a lot of time and need to be more efficient in order to realize the planned projects sooner. If projects are planned today and realized in 12 years there is a high probability that they do not fit the demands at that time. The railway is highly desired and needed right now, and hence the need is now and not in 12 years. One way of approaching this is through more private capital and investment, but there are uncertainties as to whether or not someone would be interested in investing in projects which might not be profitable. There are also uncertainties to whether or not society would want to increase the amount of private capital within the industry.

### 4.1.3 Current methods and tools for planning and operation

The current methods and tools used for planning and operation were studied, and the respondents were asked what kind of methods they use, how they experience these methods, and their suitability, as well as possible changes which should be introduced and developed further.

The procedure used when planning operation for railway freight transport consists of many steps. In the early phase and strategic planning, planners and infrastructure managers use methods such as a collection of OD-matrix, transport modeling, and prediction modeling, as well as cost-benefit analyses which eventually determine whether a project is continued or not. Planners and infrastructure managers find it ideal to have a model or method for an "optimal" terminal where there is a set of requirements that needs to be fulfilled, such as geometry, layout, and functions. If these requirements are not met, it would be easier to determine not to continue the projects at an early stage and hence avoid spending a lot of time and resources on projects which do not continue. Such a model or method could be said to exist to some degree, but there is a need to further develop this. The planning phase is described as a non-high tech process, based on well known procedures and experience, and was also said to be a conservative process. The involvement of operators earlier in the planning process could be a positive influence, as these have the knowledge and competence of how the operation is done most efficiently.

When planning for an operation in a tactical time frame the first step is for all operators to apply and be approved to run trains on Norwegian lines. When this is completed there is a yearly round of applications for routes. There is then a comprehensive process to coordinate and assign routes for all operators, both freight and passenger trains. This does usually not fulfill all wishes and demands, but is the best possible solution with the given infrastructure and restrictions. When the assignments have been done, all information is put into a computer system where the operators each have their own system. This was found to be a bit of a challenge when it comes to coordination between different operators as there are limitations related to the coordination between these systems. However, there is an ongoing process to develop a common system for this, TOS, as explained in Section 4.1.1. With an increasing number of operators within a relatively small area, this will be even more important moving forward.

Most of the tools used by planners and infrastructure managers are self developed. Typically, the market is mapped, and one makes a survey of what times during the day it is relevant to transport goods. This survey is one of the main inputs for planning. Further, the capacity is analyzed and bottlenecks are identified, and measures to avoid conflicts are evaluated. The lines are usually analyzed using capacity analysis tools like for example LUKS or Treno.

Operators find that the used methods are functioning well for internal needs and demands, but the difficulties related to coordination between each other will be increasing when more operators and stakeholders are involved. The current systems are quite old, but a lot of resources have been used in order to make them usable for today.

The operators were also asked if the plans are followed and what they do when deviations occur. They find that the given plans are followed precisely, which is necessary to ensure an efficient and cost effective operation. A lot of processes are dependent on each other and a fault in one step could influence many other steps as well, such as coordination of personnel, rolling stock planning, and plans for utilization of tracks at the terminals. Deviations from the planned activities do seldom occur. However, it happens sometimes and is more common during wintertime than summertime, which comes from faults in rolling stock, snow related problems, and closed line sections.

Planners emphasizes that there is a tendency that the same projects are evaluated several times, whereas the conclusion is usually the same every time. This is time consuming, and there exists a potential for limiting the number of times that the same aspects and projects are evaluated. A standardized approach for planning and follow-up of plans is mentioned as an important tool for help.

Infrastructure managers reveal that in all planning processes and methods the most important is to include all relevant stakeholders as early as possible, and to not leave any relevant stakeholders out of the process.

### 4.1.4 Other findings

Planners, infrastructure managers, and operators find that there is very positive momentum for railways right now, which should be addressed more than it already does. The volumes are increasing, but there is a need for a sufficiently good and robust infrastructure to handle this. Railway represents a very environmentally friendly mode of transport which we could and should utilize more, and which there already exists a large amount of knowledge and competence about. It could be considered as a "low hanging fruit" to transfer more freight to railways. On the other hand, there are possibilities for other modes of transport to be improved in the future. Road transport is up and coming, and with the process of developing zero emission technology this will become a lot more environmentally friendly than today, but might also be subjected to new and unknown challenges. Here, the challenges for railways are already very well known. Problems and disadvantages which might arise could be related to range and possible load for road vehicles, and would require a lot of research to be usable. In the case where electric trucks need to stop a lot of times to reload during the trip, use of the railway might be just as convenient and already well known.

## 4.2 Scenarios from the national freight model

One of the main challenges was identified as low prioritization of freight trains in timetabling compared to passenger trains. As there are ambitions to increase the amount of passenger transport in the coming years, this will also mean that the operation of freight transport could become more difficult than it is today. With more frequent passenger transport the available space for freight trains will be limited, and the travel time could therefore be longer than it is today. A longer travel time will be the result of more waiting time at passing sections or stations, as well as not being able to use as many time slots as today. A detailed study of this was done in NGM.

**Variation in performance time**

The scenarios analyzed in the modeled were described in Section 3.2.5. There are a number of output files produced by the model, and the most relevant were chosen and are summarized here. A more comprehensive summary of results is given in Appendix E.

The desired output from the analysis could be found in the output files *transportarbeid_tog.txt*, which represents the transport performances for given railway lines in Norway. A map of the railway network is shown in Figure 28, where most of the places used in this study are shown.


Figure 28: Map of the railway network in Norway, from Svingheim (2011).

The overall impression from the analysis is that change in average travel speed will have an influence on the demand for railway freight transport, especially for lines where other alternatives are present. For some lines, there seems to be no change in demand when the speed level changed, which can indicate that there are few other possibilities or that the current organization is very favorable. Some markets also appear to have a decrease in demand when the performance time is improved. For market segments where the results were zero for all scenarios, it was assumed that this type of market did not exist in the area and hence were not of interest to be studied here.

It is important to note that goods from the different market segments might be transported on the same train, and that it is not necessary to have an entire train solemnly for one market segment. The exemption from this is for timber and dry bulk, which usually have their own freight trains.

The transport performance is measured in tonnes-kilometres, and takes into account both directions of travel for both diesel and electric rail.

### 4.2.1 Bergen-Finse

Bergen-Finse is a part of Bergensbanen, which is mainly a single track line connecting the western and eastern regions in Norway. From the results, shown in Figure 29, Figure 30 and Figure 31, it is clear that the largest transport performances for this stretch are within the markets of general cargo and industrial goods. The market for general cargo has a large potential to increase if the average travel speed increases, but also a large potential to decrease if the speed is reduced. This indicates that the market is not saturated yet, and there is still room for larger volumes. The market for industrial goods will also have a positive effect of increased average travel speed, but not as prominent as for general cargo.

The effects of general cargo seem to be more sensitive around 55-70 km/h for the current situation, and outside of this domain, the influences follow a more flat increment. As the average travel speed today was found to be 60-61 km/h for Bergensbanen, this indicates that even small changes will make a significant difference.

The market for dry bulk appears to be very stable, but with a steep loss of almost 92% when the average travel speed is reduced to 40 km/h in the 2018 year of study. This is not so visible in the graphs, but can be seen in more detail in Appendix E. The markets for fish and thermal goods appear to have the same trends, and large effects measured in percentage depending on the speed level. For this stretch, the markets for wet bulk and timber were found to be zero.

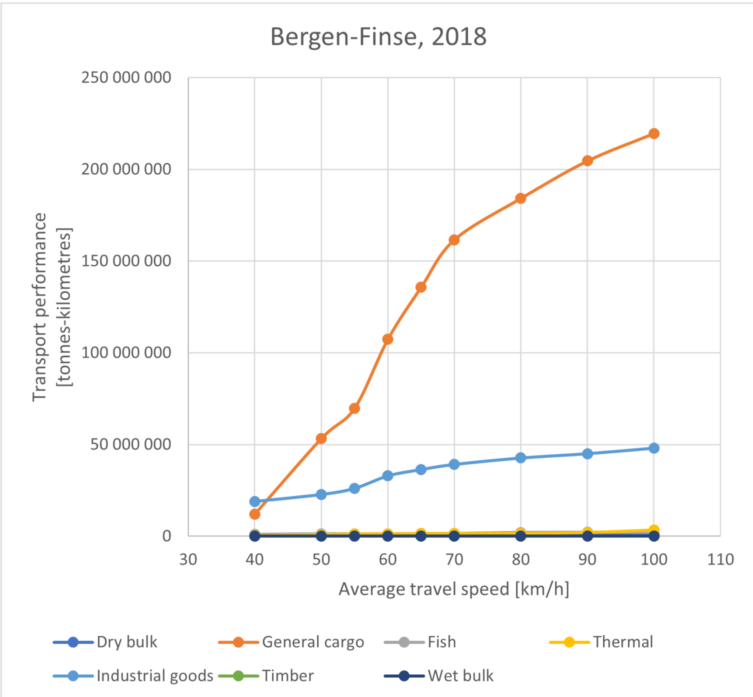


Figure 29: Transport performance as a function of travel speed, for Bergen-Finse in 2018.

The trends occur to have similar characteristics for all the studied years, which is logical given that this is a trend based model.

For all markets it appears to be an increase in transport performance from the current to the future situations. The market for general cargo appears to have a relatively small increase, whereas for dry bulk and fish the increases in transport performances are significant with more than doubling going from 2018 to 2030, and then further large increases from 2030 to 2050. For industrial goods, the trend is that market volumes will become smaller from 2018 to 2030.

Considering the sensitivity related to average travel speed, it can be seen from the graphs that the largest market for general cargo has a more flat curve for increasing travel speeds in the 2030 scenario indicating that the changes are more effective now than in the close future. However, for reduced travel speeds it occurs that the curve is steep for both 2018 and 2030, but with a steeper curve for 2018. From this one can read that a reduced travel speed will have a larger negative influence than an increased travel speed will have a positive influence.

For industrial goods the trends appear to have steeper curves for the 2030 situation for increased travel speeds and similar numbers for reduced travel speeds. A situation which was also observed for 2050. The market for dry bulk had very similar trends for all studied years, but with a varying loss when going from 50 to 40 km/h. The market for fish had similar trends for increasing average travel speed, and larger losses for reduced average travel speed in the future scenarios.

A change which was observed was that the market for thermal goods disappeared completely for both 2030 and 2050 in the basis scenarios, but then these occurred to be present again when the speed levels were above 80 km/h. There can be several reasons why this would occur, such as other routes without rail being more attractive, less time consuming, or less costly.

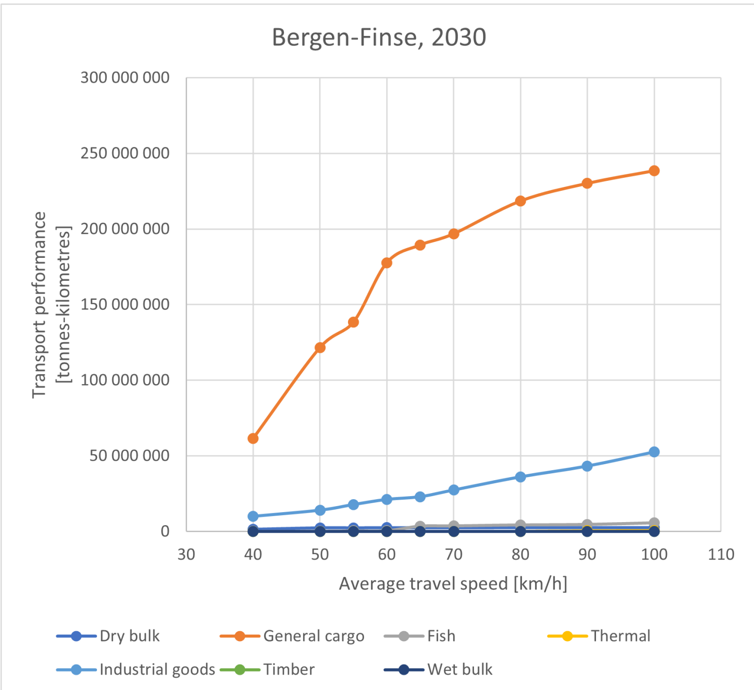


Figure 30: Transport performance as a function of travel speed, for Bergen-Finse in 2030.

For 2050, one interesting observation was that general cargo appears to be little affected by the average travel speed in the range from 55 km/h to 80 km/h, which differentiates quite a bit from the current and the 2030 situation. The reasons for this are unknown, but discussions of how realistic the values are for distant future scenarios are relevant. For the other markets, the trends appear very similar for 2030 and 2050.

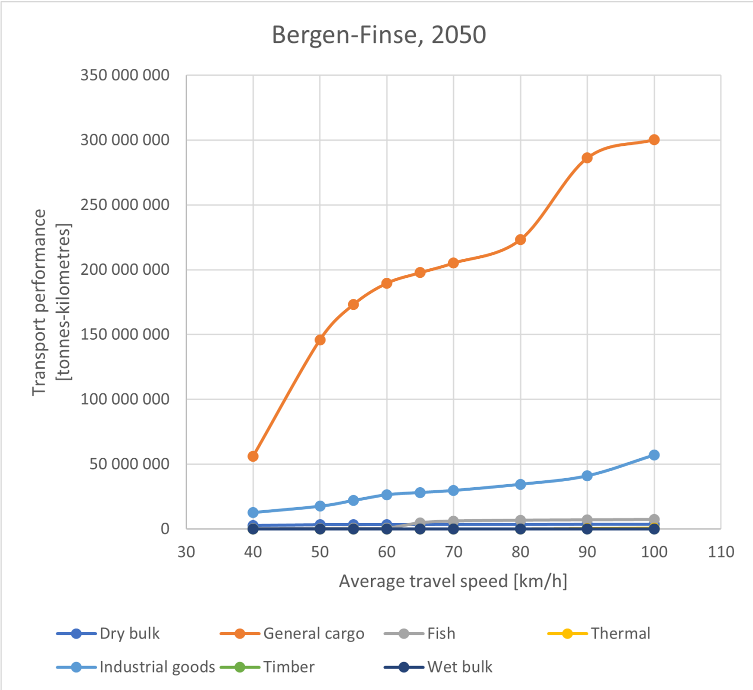


Figure 31: Transport performance as a function of travel speed, for Bergen-Finse in 2050.

### 4.2.2 Oslo-Finse

The stretch Oslo-Finse includes parts of Gjøvikbanen, Roa-Hønefossbanen, and Bergensbanen, and is characterized by single track line with passing sections. This stretch is closely connected to Bergen-Finse, described in Section 4.2.1, and it was therefore expected that these would have corresponding results. These two stretches have a lot of the same volumes which are being transported from Oslo to Bergen, but have been separated into two different sections in NGM. From the results, shown in Figure 32, Figure 33 and Figure 34, one can see that the market segments for this line will have different changes in demand depending on the speed level.

The market segment for general cargo currently has the largest transport performance followed by industrial goods, same as for Bergen-Finse. For 60-65 km/h average travel speed which is the current speed level, the impacts will be high for both negative and positive direction for general cargo. Similar to Bergen-Finse, the largest changes were found in the speed domain of 55-70 km/h for the current situation. The market for industrial goods appears to have a positive change for higher speed levels, but not as much as for Bergen-Finse.

Dry bulk has a very stable market here as well, with little changes when speed level is varied.

The market also has a loss of almost 92% when the average travel speed goes to 40 km/h. In comparison, the loss at 50 km/h is found to be 0.6%. The markets for fish and thermal goods are very similar to Bergen-Finse, with a large sensitivity depending on average travel speed. Thermal goods appear to have the largest variations measured in percentage, indicating that these types of goods have very high time values. The market for wet bulk was found to be zero for all the studied years.

For this stretch the market for timber was not zero, which differentiates from Bergen-Finse. From this one can assume that timber businesses are located at the eastern rather than the western part of Bergensbanen.

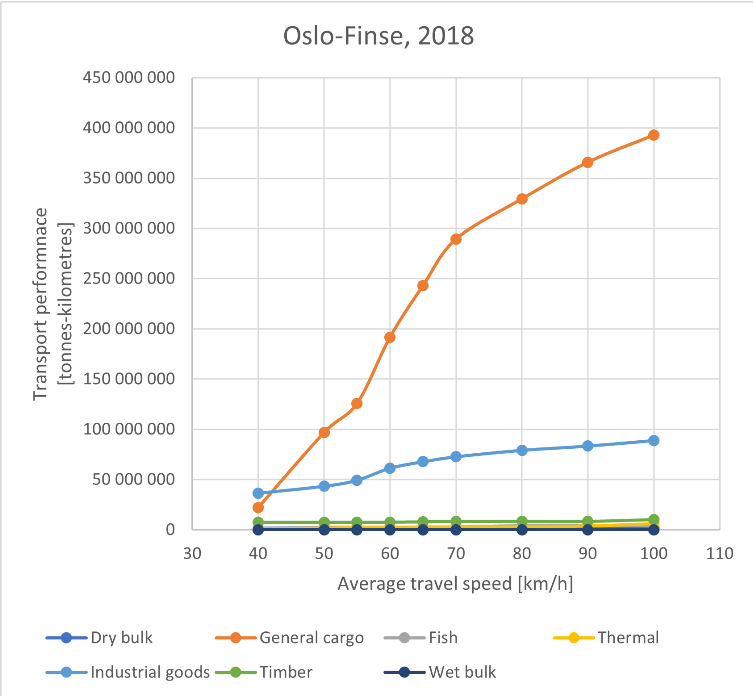


Figure 32: Transport performance as a function of travel speed, for Oslo-Finse in 2018.

The trends for the different years studied appear to be similar. General cargo has increasing and decreasing transport performances similar to Bergen-Finse, and industrial goods as well. The remaining markets also have similar trends, except for timber which was only present for the eastern part of Bergensbanen. The market for timber had large increasing trends for transport performance over time.

The market segment of general cargo has a large sensitivity towards average travel speed for the current and the 2030 situation, but seems to be less affected for the 2050 situation as long as the speed is between 55 km/h and 80 km/h. This was also observed for the stretch Bergen-Finse, and since these two stretches are closely connected it is found to be logical that the trends are corresponding.

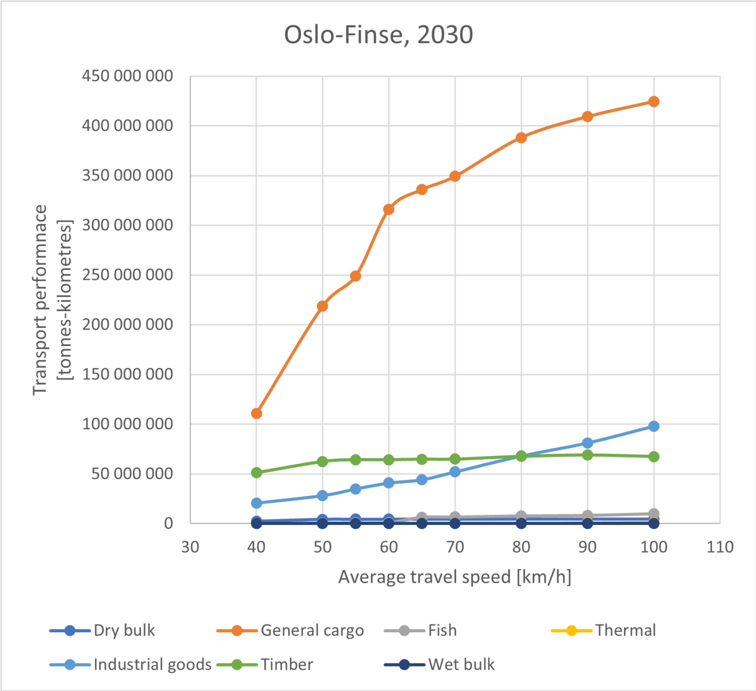


Figure 33: Transport performance as a function of travel speed, for Oslo-Finse in 2030.

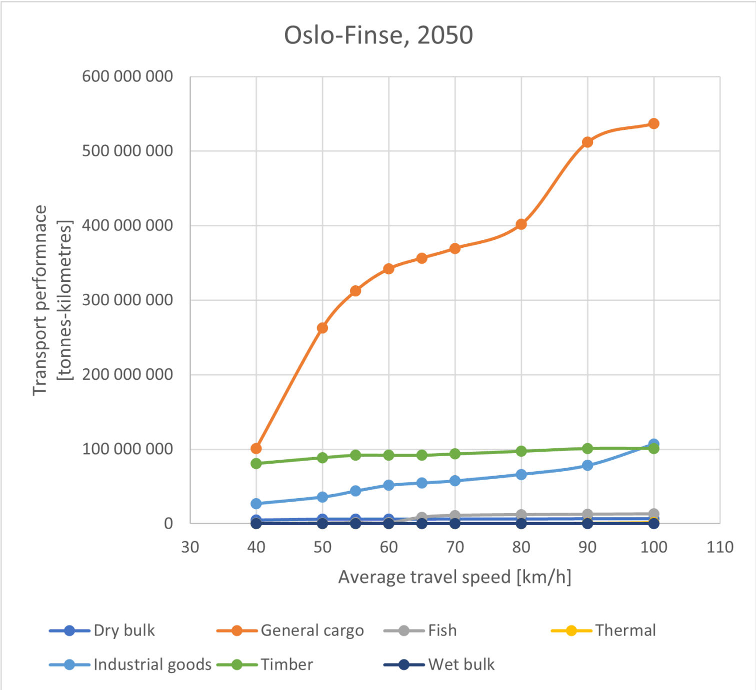


Figure 34: Transport performance as a function of travel speed, for Oslo-Finse in 2050.

### 4.2.3 Hokksund-Stavanger

The stretch Hokksund-Stavanger is part of Sørlandsbanen localized in the southern part of Norway, and can mainly be described as a single track line. The results in Figure 35, Figure 36 and Figure 37 show that the market segment for general cargo stands out considerably in volume compared to the other market segments. A change in average travel speed will have a considerable effect on this market, both positively and negatively.

The market for industrial goods at this stretch will also be majorly influenced by a change in average travel speed, having an increase of 38% when going from 65 to 70 km/h. Thermal goods were modeled to have small increases and decreases for variation of speed level here, which was a bit surprising to the author as this was found to be a very sensitive market at other stretches. The market for fish here had a somewhat different trend than others, as it had an extreme increase for higher speed levels and at the same time no decrease for lower speed levels.

An interesting observation for this stretch is that the market for dry bulk goes directly to zero when the average travel speed is below 65 km/h, indicating a loss of 100%. As the current travel speed today was found to be around 63 km/h for this stretch, these results indicate that the market is in huge danger of being lost. This does not appear very clear from the graphs, but can be studied more in detail from the tables given in Appendix E. For timber, the volumes appeared to be quite stable for the domain of 55 to 80 km/h, and to have larger variations outside of this. The market for wet bulk was found to be zero here.

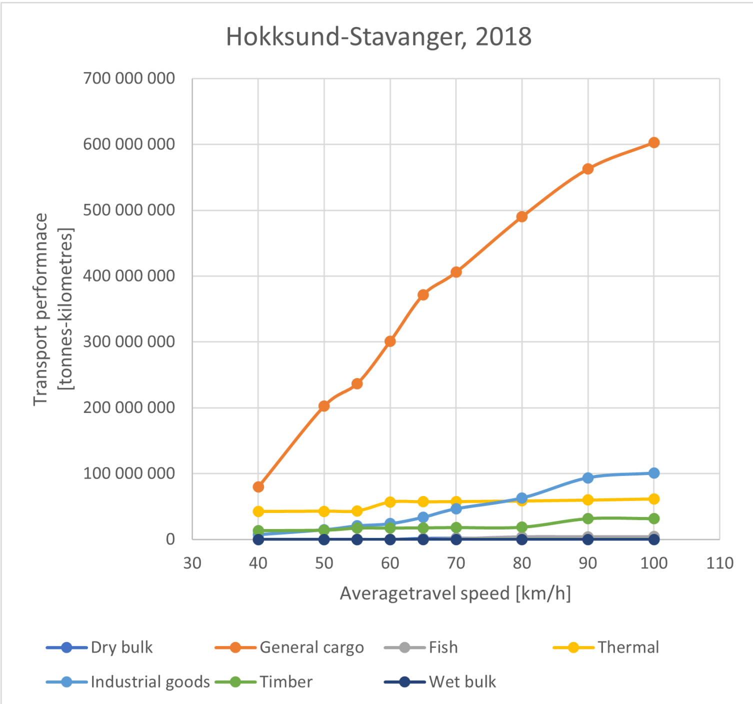


Figure 35: Transport performance as a function of travel speed, for Hokksund-Stavanger in 2018.

There are variations between the different study years. Most prominent were the differences modeled for the fish market, where the 2018 situation showed extreme increases and the future scenarios were a lot more moderate. The market for 2018 showed no decrease for reduced speed levels, whereas in 2030 and 2050 decreases can be observed. Similar to the Oslo-Finse stretch, it can be observed here that the market for thermal goods is disappearing in the base scenarios and reappearing for higher speed levels.

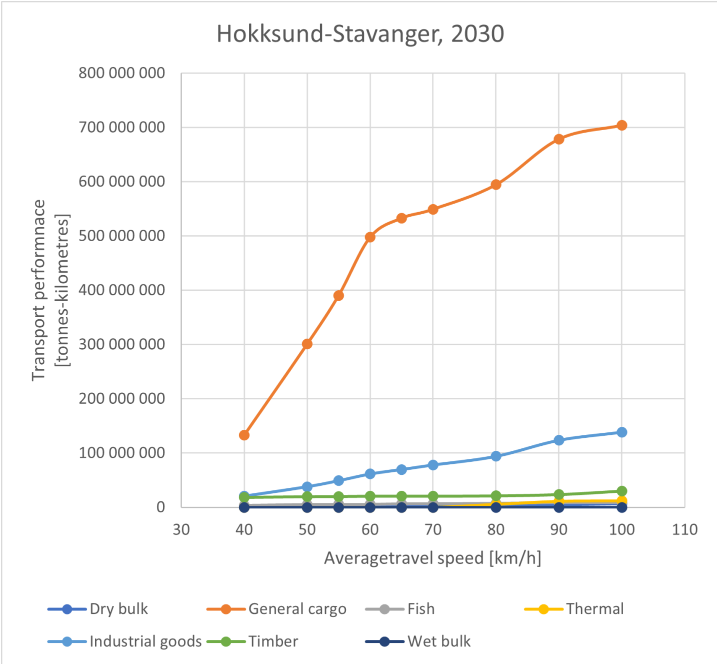


Figure 36: Transport performance as a function of travel speed, Hokksund-Stavanger in 2030.

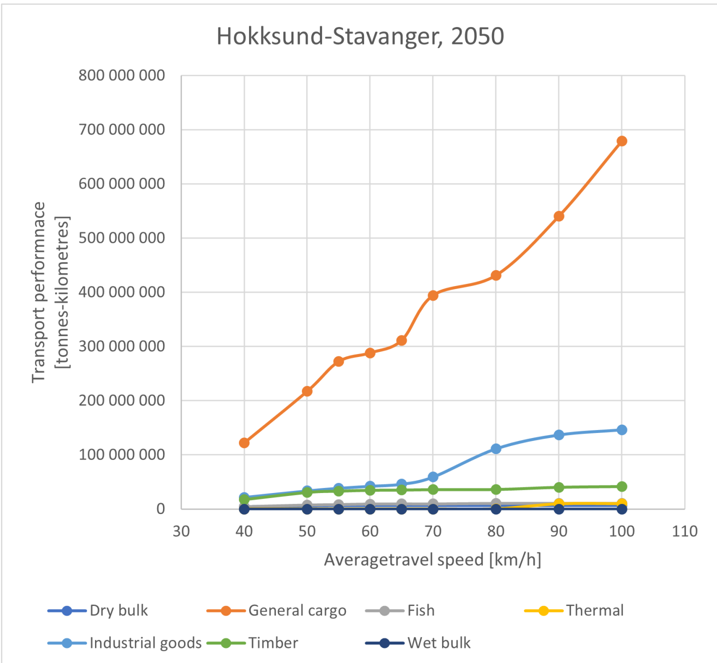


Figure 37: Transport performance as a function of travel speed, Hokksund-Stavanger in 2050.

### 4.2.4 Oslo-Støren

Oslo-Støren is a stretch localized in the central/eastern part of Norway, and includes Hovedbanen and part of Dovrebanen. From Figure 38, Figure 39 and Figure 40 one can see that general cargo is the largest market here measured in transport performance, and that this market has a significant change in demand when average travel speed changes, same as for the previous stretches.

Timber also occurs as a large market for this stretch, whereas the transport performance seems to be stabilizing from 55 km/h and upwards. This could be an indication that the market here is saturated, and that it is not possible to achieve a larger market share. A trend which can be observed for all the studied years.

Industrial goods seem to be a large market for this stretch, with a potential to both increase and decrease depending on speed level. The potential to increase appears to be greater than the potential to decrease for the future scenarios.

Fish have a potential for increased transport performance depending on speed, a trend which is most prominent for 2018 and more moderate for 2030 and 2050. Thermal goods was also observed to be influenced, but proved to be one of the more stable markets at this stretch.

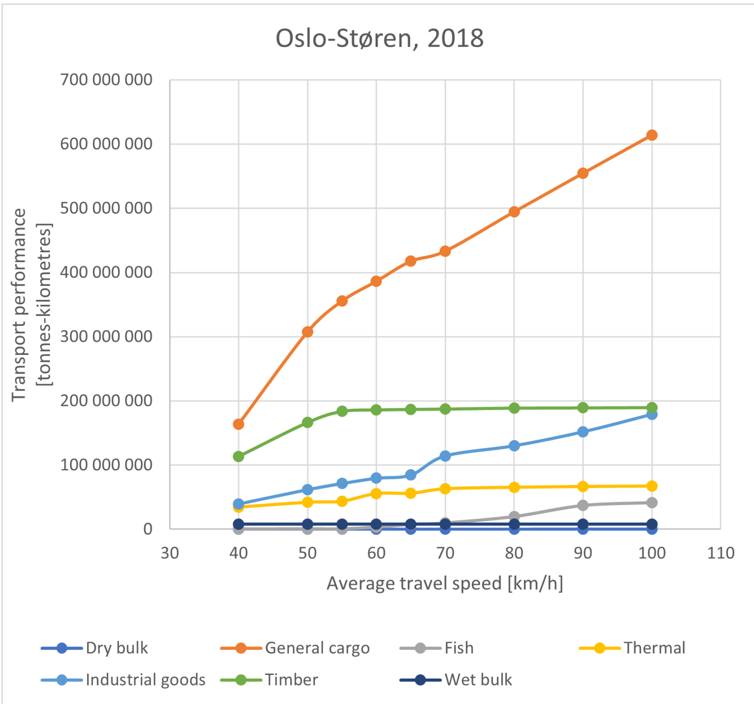


Figure 38: Transport performance as a function of travel speed, for Oslo-Støren in 2018.

Dry bulk showed to be less affected than the previously described markets for the speed domain of 40 to 80 km/h, but for higher speed there is an extreme increase. The market for wet bulk is constant for all speeds run in the model, and is not affected by any of the changes in the positive or the negative direction.

No markets were found to be zero in this case, but thermal goods lost their entire transport performance for 2030 and 2050 for average travel speeds lower than 55 km/h and 60 km/ respectively. A trend which has been observed previously in this study as well.

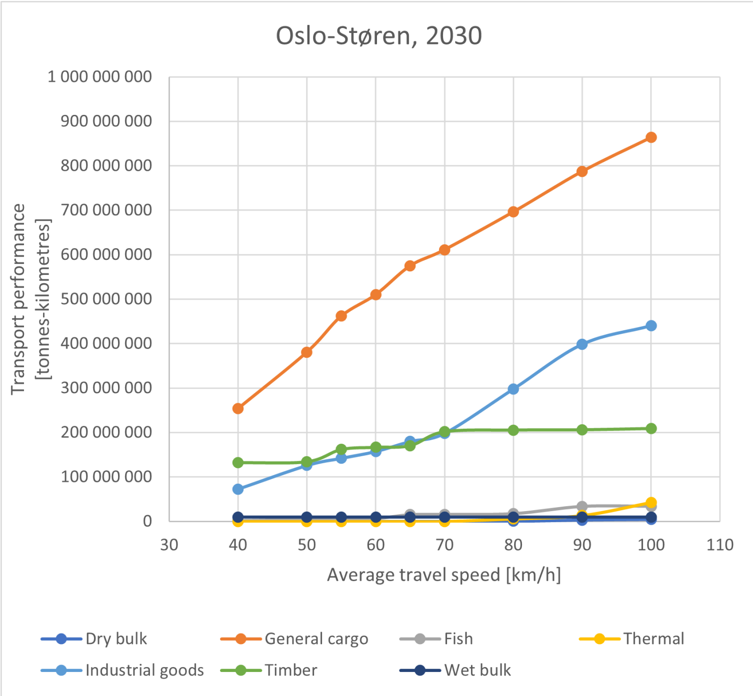


Figure 39: Transport performance as a function of travel speed, for Oslo-Støren in 2030.

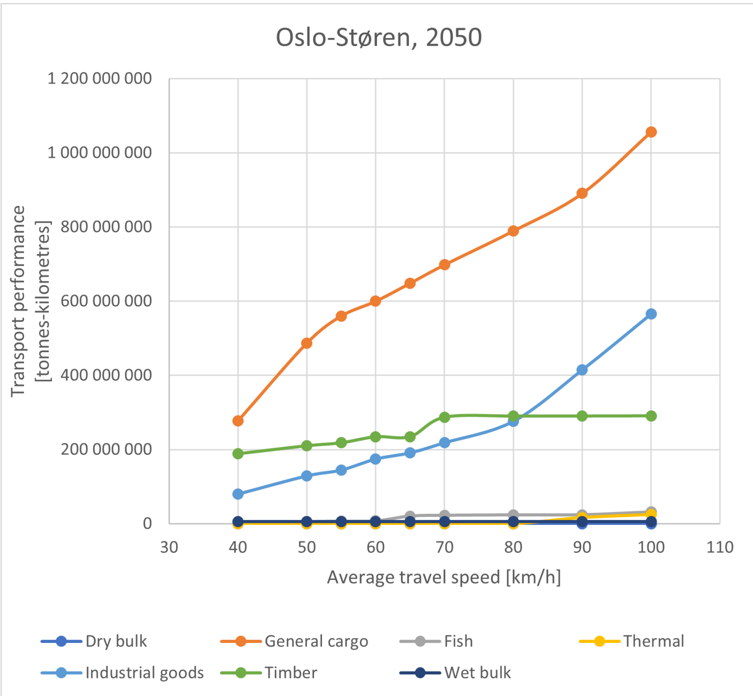


Figure 40: Transport performance as a function of travel speed, for Oslo-Støren in 2050.

### 4.2.5 Støren-Tronheim

Støren-Trondheim is the northernmost part of Dovrebanen, with close connections to the previously described stretch Oslo-Støren. Freight transport which goes from Alnabru to Trondheim/Heimdal will follow both of these stretches, and therefore similarities are to be expected. This northern part does also include freight coming from Rørosbanen, and some differences due to this will also be expected. In Figure 41, Figure 42 and Figure 43 it can be observed that general cargo has the largest transport performance at this stretch. The increase in transport performance for this market seems to be linear from 70 km/h for 2018 and 2030, and following a non-linear curve below this. For 2050 the demand is modeled to have a further extended growth when speed goes from 90 km/h to 100 km/h.

The market for industrial goods also appears to have large variations depending on speed level, but perhaps more prominent for higher speed levels than for lower speed levels. Dry bulk is the most stable market at this stretch, similar to the other stretches. However, for the 2030 scenario, there was an extreme increase here as well, which could also be observed for Oslo-Støren. It is very likely that these two incidents are connected.

Fish and thermal goods will also be influenced, and as observed earlier the market shares for thermal goods were completely lost for some speed levels. For 2030 this occurred at 55 km/h and for 2050 it occurred at 70 km/h. The markets for wet bulk and timber were found to be zero. As these were not zero for Oslo-Støren, it is indicated that these businesses are not located in the northern part. Especially timber has several small terminals along the line at the southern part of Dovrebanen.

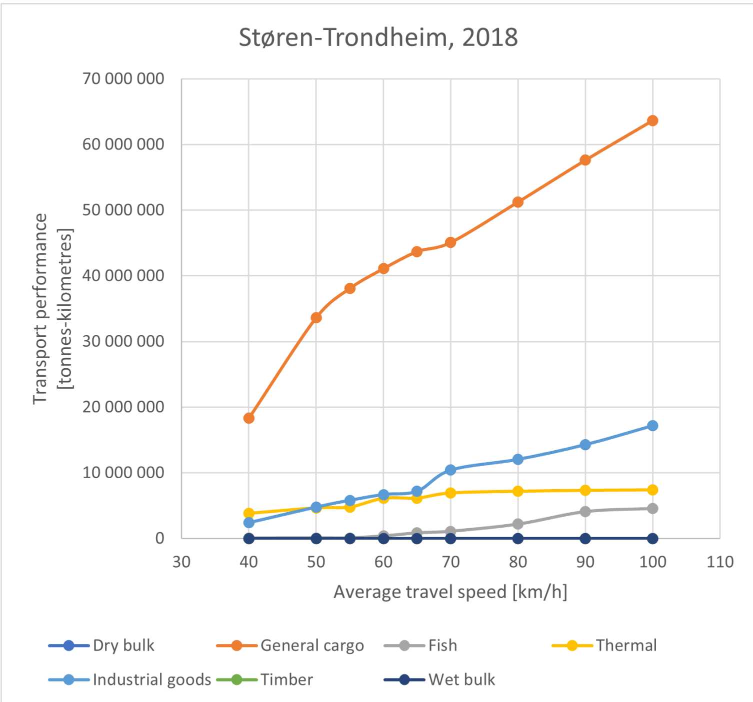


Figure 41: Transport performance as a function of travel speed, for Støren-Trondheim in 2018.

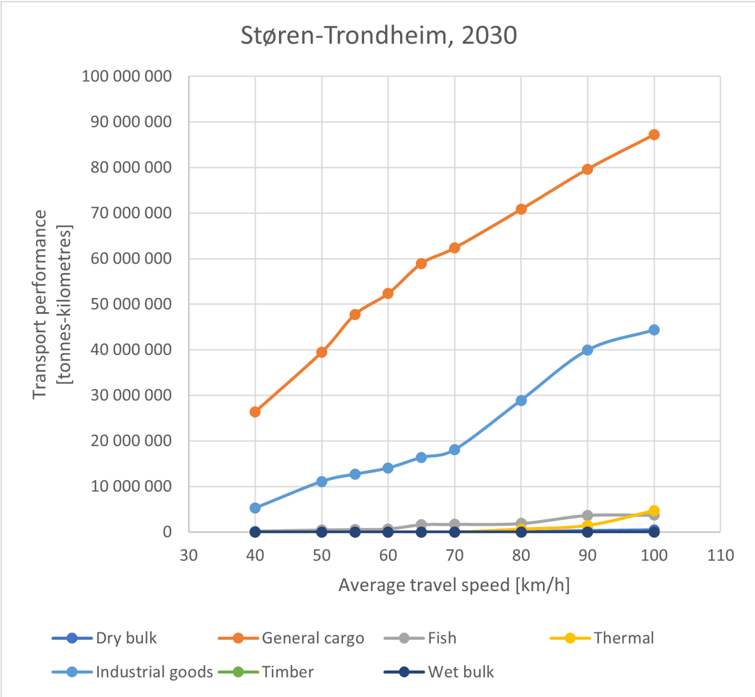


Figure 42: Transport performance as a function of travel speed, for Støren-Trondheim in 2030.

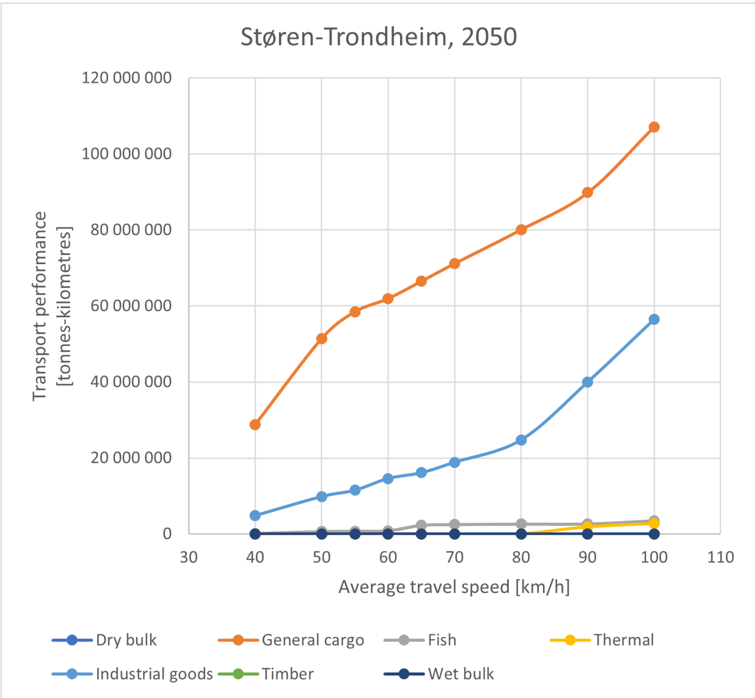


Figure 43: Transport performance as a function of travel speed, for Støren-Trondheim in 2050.

### 4.2.6 Bodø-Trondheim

Bodø-Trondheim is a stretch connecting the central and the northern regions in Norway, where Nordlandsbanen is placed. The stretch mostly consists of single track lines with passing sections. In Figure 44, Figure 45 and Figure 46 one can see that dry bulk and general cargo have the largest markets here. General cargo seems to be highly influenced by the change in average travel speed, although the influence is more present for increasing speed above 70 km/h and for reduced speed below 50 km/h. The domain in between has a more stable demand. As the average travel speed for Nordlandsbanen was found to be around 60-62 km/h, this indicates that small changes would not give significant effects. Dry bulk shows to be unaffected by the change in average travel speed, indicating that other variables are more important for the modal split or that there are limitations for other alternatives. One can assume that the current conditions and organization is very favorable and well established.

The markets for fish appeared to have the largest variances measured in percentage, where almost the entire market was lost for speeds of 55 km/h and below. On the positive side, a major increase could also be observed for increased speeds. Thermal goods at this stretch also experienced effects, whereas these were not in the same scale as for the fish market. This was somewhat unexpected by the author, as both these markets were believed to have similar high time values.

Industrial goods were also influenced and appeared to follow a somewhat linear curve depending on the speed level. The markets for wet bulk and timber were found to be zero here.

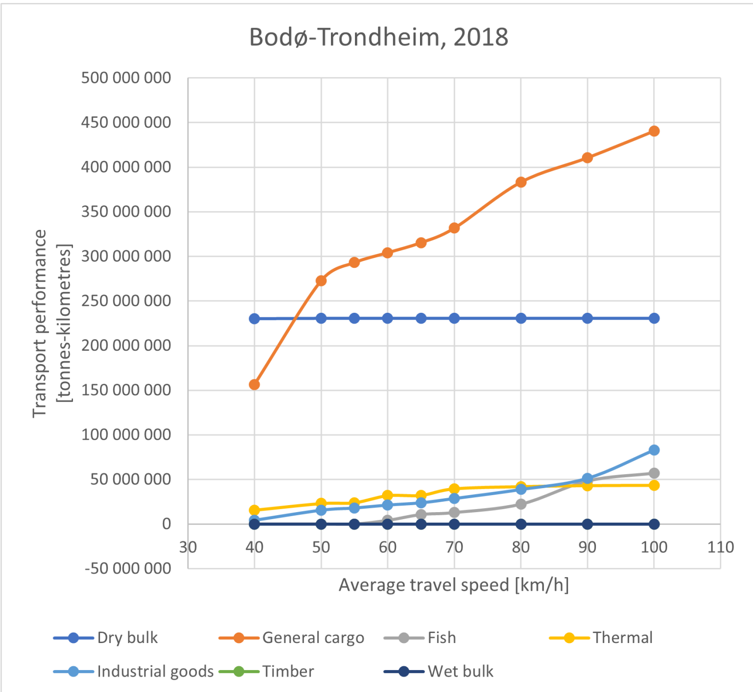


Figure 44: Transport performance as a function of travel speed, for Bodø-Trondheim in 2018.

The trends are similar for all the studied years, but for 2030 and 2050 some differences could be observed. Most prominent from the graphs is the significant increase for industrial goods for average travel speed above 70 km/h.

As also observed previously, the market for thermal goods disappeared for the basis scenarios and reappeared for higher speed levels. For both 2030 and 2050, this occurred at 80 km/h.

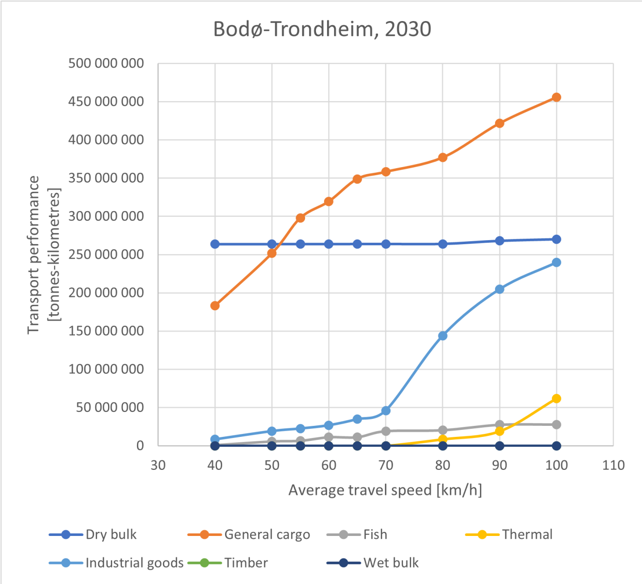


Figure 45: Transport performance as a function of travel speed, for Bodø-Trondheim in 2030.

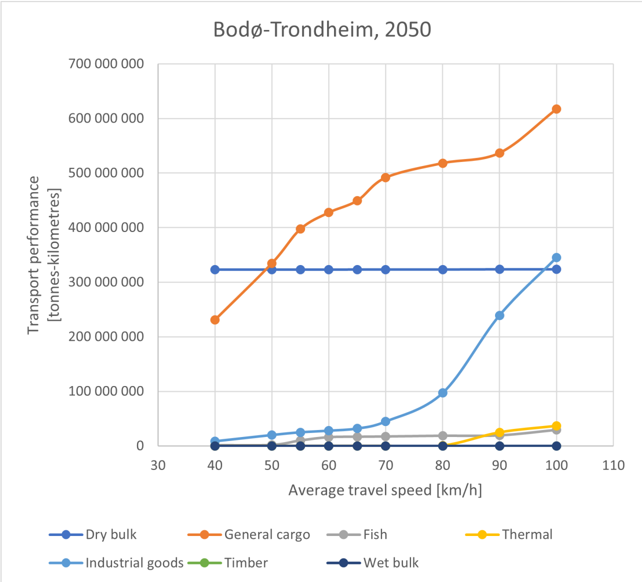


Figure 46: Transport performance as a function of travel speed, for Bodø-Trondheim in 2050.

Bodø-Trondheim is a longer stretch than the others studied here, and hence a change in average travel speed will mean a larger amount of travel time. It is not observed that this will give a majorly different results for this stretch compared to the others, which could have been expected.

### 4.2.7 Røros-Solør

Røros-Solør is a stretch in the eastern part of Norway, consisting of Solørbanen and parts of Rørosbanen. Solørbanen is a stretch that is solemnly used for freight transport, and hence there are very favorable conditions existing. Here the main markets are timber and industrial goods, which are also the only two markets present. Both markets seem to be very stable when a change in average travel speed occurs, but timber has a fall in transport demand going from 50 km/h to 40 km/h for 2018. This trend was not observed for the other study years. The results can be found in Figure 47, Figure 48 and Figure 49.

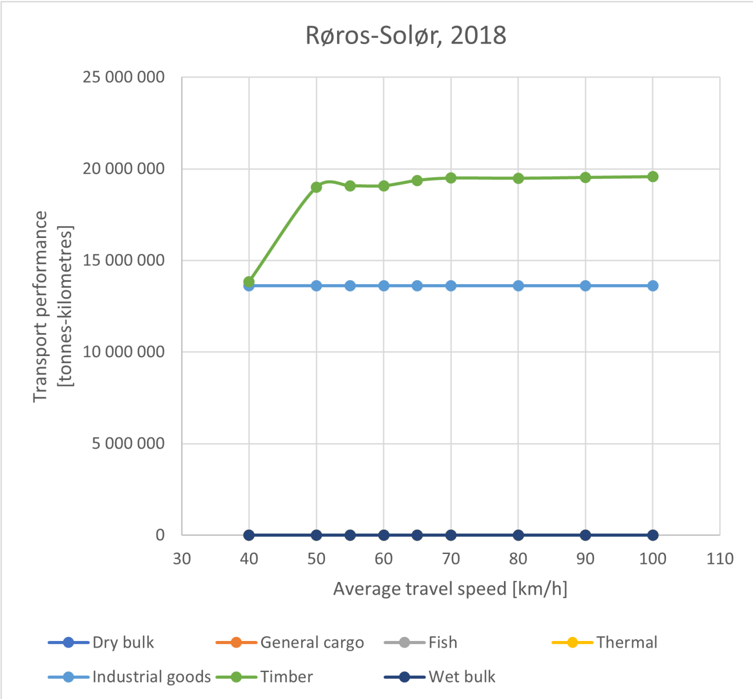


Figure 47: Transport performance as a function of travel speed, for Røros-Solør in 2018.

Over time the model predicts that the market for timber will have a small decrease from 2018 to 2030, but from 2018 towards 2050 there will be an increase from around 20 000 000 TKM to 25 000 000 TKM. For industrial goods the market is predicted to increase steadily, going from around 14 000 000 TKM in 2018 to 27 000 000 TKM in 2050.

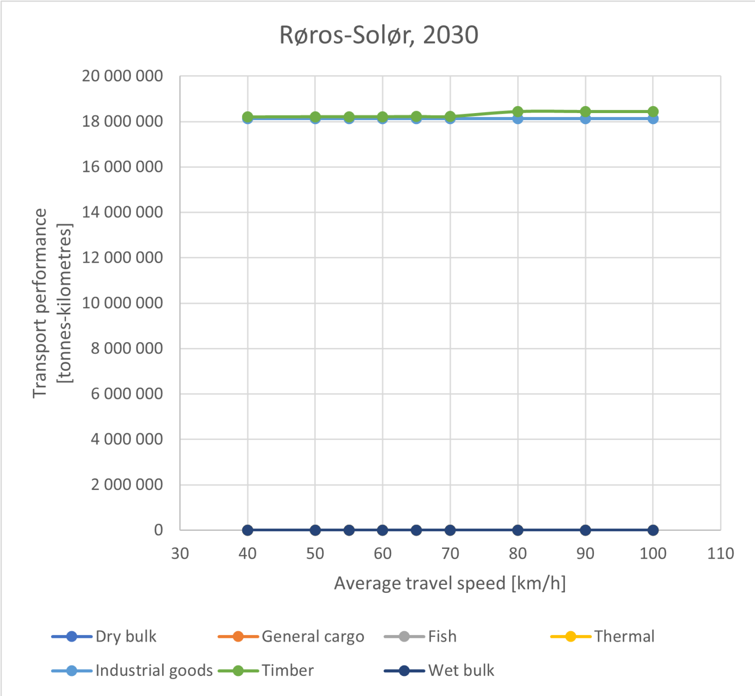


Figure 48: Transport performance as a function of travel speed, for Røros-Solør in 2030.

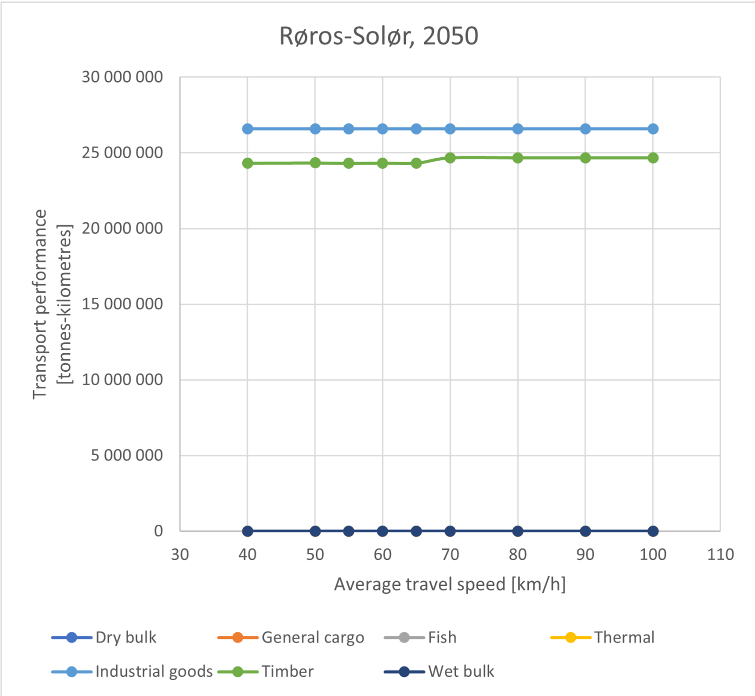


Figure 49: Transport performance as a function of travel speed, for Røros-Solør in 2050.

### 4.2.8 Ofotbanen

Ofotbanen is the northernmost line in Norway, which is majorly used for freight transport. It is not connected to the rest of the Norwegian network, but is connected to the Swedish network. Results are shown in Figure 50, Figure 51 and Figure 52. Here the main market is definetly dry bulk which seems unaffected by changes in average travel speed for all the studied years. This market has a much higher transport performance compared to all the other markets, and also compared to all other stretches in this study. The markets for wet bulk and timber were found to be zero for all years, and for 2030 and 2050 the market for thermal goods was also eliminated.

An interesting and unexpected result which was found for Ofotbanen was that markets for general cargo, fish, thermal and industrial goods had a reduced demand when the average travel speed increased. This phenomenon was observed for all the studied years, whereas for 2030 and 2050 the variance in demand seems to be fluctuating depending on the speed level. This is shown in more detail in Appendix E.

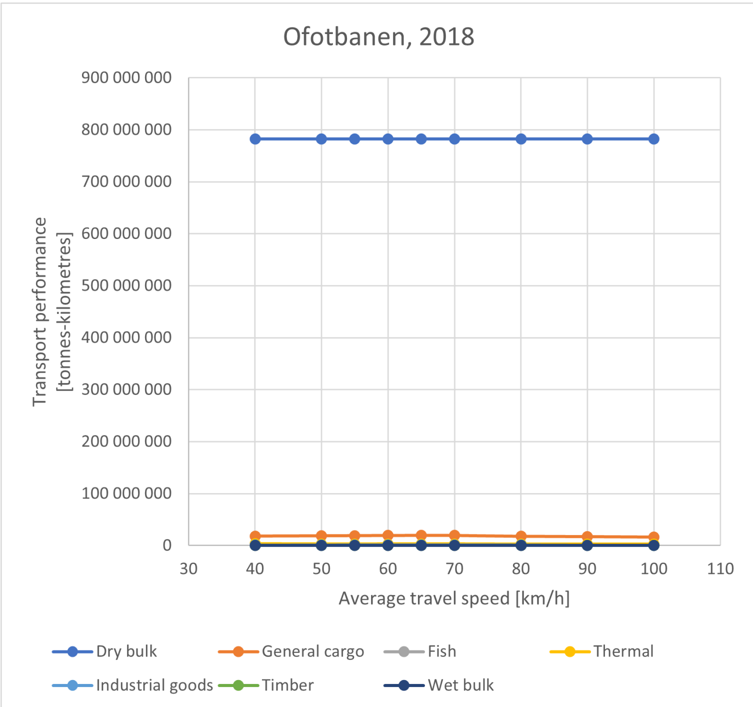


Figure 50: Transport performance as a function of travel speed, for Ofotbanen in 2018.

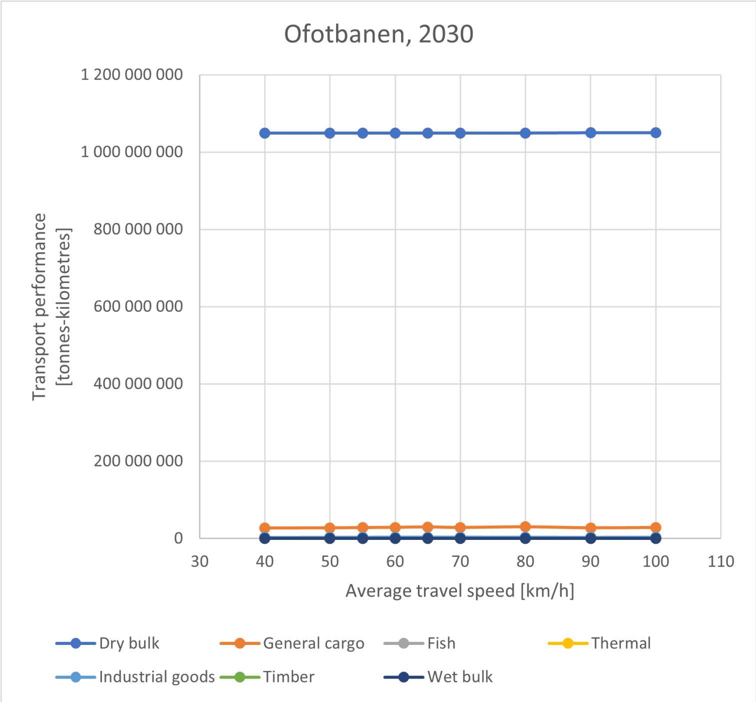


Figure 51: Transport performance as a function of travel speed, for Ofotbanen in 2030.

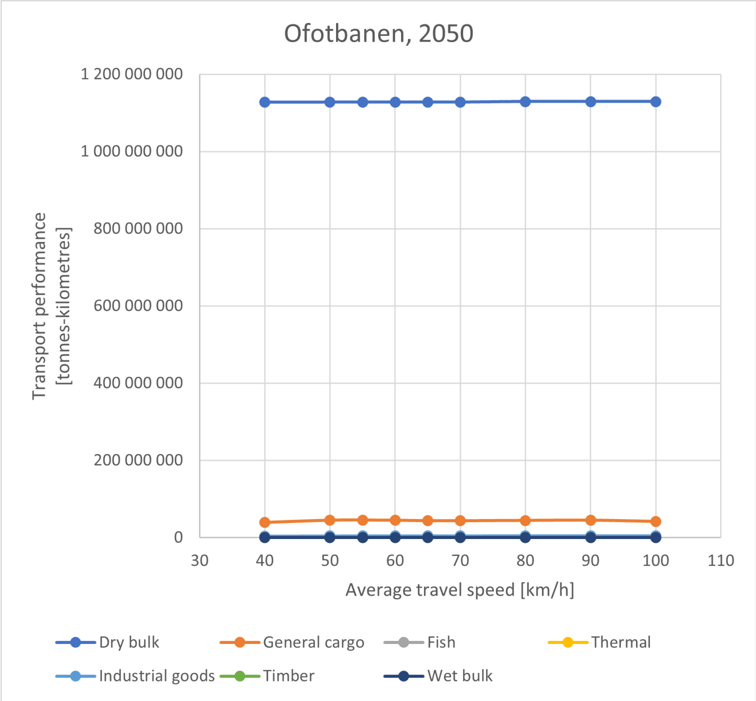


Figure 52: Transport performance as a function of travel speed, for Ofotbanen in 2050.

# 5 Discussion

In this section the results from the literature review, the interviews, and the analysis in NGM will be discussed and compared. A discussion of the methodology and weaknesses are also presented.

## 5.1 Results

The results from both interviews and simulations in NGM lead to increased knowledge about railway freight transport in Norway. A lot of challenges were mapped, and reasons and approaches to meet these were identified as best as possible. In total the impression is that railway freight transport finds itself in a challenging position with an aging infrastructure, large maintenance needs, high ambitions for increased passenger and freight transport, low prioritization in timetabling, and high competition towards road freight transport at certain stretches. The need for more digital and automatic solutions also introduced challenges related to the development, implementation, and introduction of new technologies.

The current infrastructure has a large variety in age and quality, and some locations are in serious need of maintenance and upgrade to keep functioning in the future. From multiple perspectives, it was found that the current ambitions and desires for increased railway transport of both passengers and freight need to be met with significant resources and means. With the present trends, the investments are not significant enough to handle the predicted future situations. Such findings are also supported by previous literature and studies, with one of the most recent being from RIF (2021) which found that much of the current infrastructure is outdated and not functioning for today's standards and requirements, even though the investments have been increasing in the latest period of time.

Improving the situation will require that sufficient means are given, and the power to decide this lies with the government and authorities. Lots of ways to approach this were suggested by respondents in the interviews, whereas the one which was found to have the largest possible impact was communication with decision makers. The current needs and possible projects have been mapped many times, and some of the reasons why there has still not been any further major progress are that making decisions is taking a lot of time and that the same projects are being reevaluated multiple times with the same conclusions. Of course, it is important to evaluate large projects thoroughly and correctly, but from the respondents in this study, it was found that the current processes might be too time consuming.

The knowledge and competence that exists within the branch today are significant, but it needs to be channeled and extended to decision makers with an understandable and pedagogic approach. A creative and interactive approach was believed by respondents to be most useful, where one could for example have a glass container filled with different types of goods to be exhibited.

Another large group of identified challenges was related to operation where the current timetabling process favors passenger trains over freight trains, for all periods through the day, the week, and the year. Simulations from NGM show that there exists a significant potential for higher demand on railway freight transport, especially for general cargo at the stretches between Oslo and the cities of Trondheim, Bergen, and Stavanger, as well as Trondheim-Bodø. Even though there are weaknesses and uncertainties related to these simulations, the overall indication of potential is corresponding to the hypothesis and idea that a better performance time will induce a larger demand.

From literature it was found that the stretches with the largest potential have had a significant increase and upgrade in road infrastructure creating a favorable situation for road freight. These stretches were also found to be sensitive to the change in performance time for multiple markets, represented by average travel speed. Especially general cargo would be affected by such changes, and this was also the largest market for most stretches. With the ongoing trend that performance time is increasing this indicates that these large markets will be reduced or lost from the railway. Other aspects which were observed from the simulation results were that the markets for fish and thermal goods were sensitive to average travel speed, a result which is believed to be because these markets have high time values and hence favors travel time as their impedance for the modal split.

A perhaps obvious way to meet these challenges is to change the current operational rules and regulations. The demand for passenger and freight trains have quite different peak periods through the day, where freight trains are run mostly at night time when demand for passenger transport is at its lowest. A periodic change in prioritization between daytime and nighttime has been analyzed and proposed in previous literature (Voldsund, 2020), and has been found to be very favorable in an overall perspective. The findings from this study indicate that such a change is highly doable and possible to realize using the existing infrastructure. It is interesting that this has been proposed for a long time without being extended to a pilot project or another tryout of the solution. Here is a golden opportunity to approach and perhaps reach the goals stated in national strategic plans, which have still not been tested fully in reality. Further research on this front is recommended.

Change of prioritization between passenger and freight trains could be achieved by the use of simultaneous entries, where both trains enter a passing section at the same time in opposite ends. This is relevant for single track lines, where some sections are built for passing. A rapid and smooth transition could be of high importance for capacity, punctuality, and travel time. However, there are also challenges with this approach as it requires a signal system with specific properties, longer safety zones, and resources. It will also require that both trains are at the current place at the same time, which is not always going to be the case. Another approach is the use of overlong crossings where the freight train uses the main track, and the passenger train uses the passing track. For both these approaches it is possible to run longer freight trains using the current infrastructure. A solution where the passenger train is to use the passing section and the freight train use the main track is doable and has been proven to have a favorable overall outcome. Further studies on how this can be implemented, as well as what the consequences will be for passenger trains needs to be mapped. Many of the stretches in Norway are characterized by single track lines with passing sections. For stretches with single track lines, the use of simultaneous entries or overlong crossings is particularly relevant.

The organization of the railway sector in Norway has been through a major change in recent years. The findings from this study have been that there is good communication between different stakeholders, and that internal communication is not highly related to the challenges within railway freight transport today. On the other hand, external communication towards decision makers and the public was found to be important and to have a potential for improvements.

Economy and financing are found to be decisive factors to whether or not projects will follow through. This was an overall concern for all of the respondents groups, both considering present and future situations. In total, a combination of multiple approaches are found to be necessary in order to increase the attractiveness of the railway for freight customers and forwarders.

### Scenarios from NGM

The scenarios from NGM gave many interesting results, and some unexpected findings as well. Some markets appeared to be influenced a lot by performance time, while others did not seem to be affected at all. Some markets even showed that an increased average travel speed gave a reduced demand, which was not expected by the author. The results were shown as graphs in Section 4.2 and a more comprehensive and detailed summary of results are given in Appendix E.

The overall impression is that change in average travel speed will have an influence on the demand for railway freight transport, especially for lines where other alternatives are present and relatively easy to use instead. For some lines there seemed to be no change in demand when the speed level changed, which can indicate that there are few other possibilities or that the current organization and operation is very favorable and well functioning. Such a case could be said to have a nonelastic elasticity, as explained in Section 2.7, and was found to be most prominent for transport of dry bulk at Bodø-Trondheim (Nordlandsbanen) and Ofotbanen, as well as for timber at Røros-Solør.

For the stretches and markets which were modeled to be totally or almost independent of the average travel speed, it is indicated that the conditions for rail are very favorable here. The large and homogeneous markets; timber, industrial goods, and dry bulk, can be expected to have good conditions to exploit the scale of economics, and hence that the long time relationships and steady patterns create stability and predictability which is desired. A transfer towards road transport for these markets would require huge adaptions and adjustments, and is likely not to be desired. Such a situation was observed for dry bulk and timber at most of the studied stretches, indicating that this market does not emphasize performance time a lot when deciding on transport mode.

The markets with low variations in demand depending on speed levels can be said to have inelastic demand, with the use of shortest distance for the impedance. Such a case would indicate that these types of goods have low time values, and that the goods will not be significantly worsened if the transport takes a longer time.

Some of the results showed a 100 % loss in transport performance when the average travel speed was reduced. This occurred for the market of dry bulk for Hokksund-Stavanger for all speed levels lower than 65 km/h in 2018, and for the thermal market at Oslo-Støren in 2030 and 2050 for all speed levels lower than 55 and 65 km/h respectively. A loss of 100 % means that the entire market is transferred to other transport modes, and can indicate that the competition for these markets at the certain stretches are exceptionally high and sensitive.

The largest variances in the demand appear to be present at stretches which have high competition towards road transport, and where other options can be used more easily. The market which appears to be most influenced by the average travel speed was general cargo. Large variances in demand were observed for Bergen-Finse and Oslo-Finse at Bergensbanen, for Hokksund-Stavanger at Sørlandsbanen, for Oslo-Støren, Støren-Trondheim at Dovrebanen, and for Bodø-Trondheim at Nordlandsbanen, which is a lot of the stretches in Norway. From this study it reads that changing the conditions for railway freight transport could potentially have considerable effects, as there are existing demands which could be exploited.

A sensitivity analysis will describe how certain or uncertain the parameters are. In this study such an analysis has not been performed, because the necessary data to execute this was not found available. Such an analysis would have given knowledge to how much one can trust the results of the study. However, it is possible to evaluate and comment the uncertainties of the values based on information and assumptions of the input parameters in the model. The transport performance in NGM is calculated based on supply and demand, and includes transportation costs, terminal costs, storage costs, time costs for the goods, and eventual degradation costs for goods during transport. Performance time is usually not the most dominant factor of these, but could have an influence towards the choices anyway. From the study one can assume that performance time will be a more decisive factor for some markets such as general cargo, fish, and thermal goods, whereas for other markets the other factors are more decisive such as for dry bulk, timber, and wet bulk.

## 5.2 Choice of methodology

The chosen methodology showed to be appropriate in order to answer the research questions.

### Literature review

The literature review aimed at getting insight and knowledge about the subject, which was achieved. All possible literature was not studied in detail, as this would have taken an unreasonable large amount of time. It is therefore a possibility that some important and relevant literature might have been overlooked.

The research had a very broad angle and hence a lot of literature could be found useful, relevant, and interesting. The creation of a more narrow and specific problem statement would have helped to limit the amount of relevant literature, but as the author knew very little of the subject beforehand this was difficult to establish at an early stage.

**Interviews**

The interviews proved to be useful in order to answer the research questions. As the aims and goals of the project changed a bit through the semester, the first stated research questions were formulated somewhat differently than the resulting ones. In the beginning, the focus was set to be towards railway terminals, but through the work it became clear that terminals and lines are so closely connected that they can not be evaluated independently of each other. Much of the information gained through interviews were as much relevant for lines as for terminals, and hence the results could be used to approach a more overall research. The author found that this approach was the best possible, and the one that would help gain the best knowledge.

Challenges related to getting in touch with relevant respondents and establishing contact occurred, resulting in some respondent groups being a lot more represented compared to others. The idea was to get a broad perspective, and hence varied respondents were desired. Getting in touch with planners and infrastructure managers proved to be quite achievable, whereas the people working with day-to-day operations were more difficult to get in touch with. The result was a more dominant perspective from the strategic and tactical planning, which could possibly have given a skewed impression of what the largest and most realistic challenges and possibilities are. On the other side, many of the respondents who work within strategic and tactical planning now had previous experience from the day-to-day operation, and will hence bring both perspectives into their answers even though they do not have the current inside knowledge of operators.

The number of respondents was found to give a significant broad overview, but of course a larger number would have given more weight and credibility to the answers and the study. However, given the time frame and the contact network of the author, it was found that the choice of using 10 interviews was successful.

The choice to not have audio recording might have been a mistake as the interview situation turned out to require more focus and multitasking than the author had anticipated. The idea was to create a comfortable atmosphere where the respondents could speak freely, whereas audio recording was thought to have worsened this. Looking back, the author finds that audio recording would not have harmed the results majorly, and would have helped to remember and recall more information from the interviews.

The use of questionnaires was considered and could have been an alternative to interviews. It would have been especially relevant to target the respondent group of forwarders, which was not included in this study. This would have given more depth and perspectives to the project, and could potentially have broadened the knowledge even more. However, as explained in Chapter 3 questionnaires would lock the answers to predefined questions and not give the respondents the possibility to elaborate on the different topics. Another disadvantage with questionnaires is that they require a large number of respondents to be representative, which will require access and contact with a lot of respondents. As the subject for this thesis has been planning and operation of freight transport and freight terminals, it would also require a very specific type of respondents which might be difficult to get in touch with.

#### Scenarios in NGM

The scenarios from NGM were used to get a numeric and qualitative measure of how performance time affects freight transport demand, and proved to be usable for this purpose. There are also many other parameters that could be studied in detail, but performance time was chosen as it is very relevant today and that it was emphasized by almost all respondents as a major challenge. It was also possible to be analyzed using the available tools, making it an appropriate choice.

NGM has a steep learning curve and requires a lot of time and effort to be understood. A lot of problems and challenges related to the model occurred during the project, such as getting the relevant output, avoiding errors and scenario runs giving zero output, as well as understanding what the output showed. As there have been made changes to the model over time it was necessary to access a model which gave possibilities to edit speed for different links. The latest version did not include the application "2 Network editing" which has such possibilities, and therefore an older version was accessed. One can question if all the time spent on accessing and learning how to use the model was well spent and if other methods could have been used instead.

A model will always be a simplification of reality, but gives an indication of where we are headed if current and historic trends are to be continued. There are many uncertainties and weaknesses related to the use of models. First of all is NGM a trend based model, where growth is predicted in markets and areas which have historically had growth. The model does not take into account new establishments appearing in regions where there have not been such establishments before, and is in that way not optimal to predict future situations. Historically we know that new establishments and businesses can occur at new locations, and that the system will change and adapt according to this.

The model will also be more uncertain for periods which are far ahead, and it will therefore be most reliable for the current situation (modeled as 2018), more uncertain for the 2030 situation, and most uncertain for the 2050 situation. Most of the trends were found to be similar for all the three periods studied, which is expected as it is based on predictions from historical trends.

The results from the model can therefore be said to be a good indicator for where we are headed, but that changes and deviations are highly expected to occur.

# 6 Conclusion and further research

This chapter will give a short and concise answer to the research questions which were studied, and proposals for further research are given.

## 6.1 Conclusion

### Current challenges for planning and operation of railway freight terminals

Freight transport on railways is in a challenging position, with high competition from road transport, an increase in passenger transport on railways, and a slow moving process for renewals, as well as a large maintenance gap and need for upgrades which influences the attractiveness. Combined all of these effects make it difficult to operate, and to meet current and future demands.

Through interviews it was clearly established that evaluating terminals on its own is not significant enough, and that lines and terminals have to be considered together. The main challenges were therefore mapped for the system on a more holistic level, and can be categorized into infrastructure, operation, organization, knowledge, and economy.

### Measures to improve the attractiveness of railway terminals and railway as the desired mode for freight transport

From this study it was found that a combination of multiple approaches is necessary in order to improve the situation for railway freight transport. The effect of performance time for demand was studied in detail, and it was found that a change in prioritization could give a significant change in demand for a lot of large markets.

Other measures to implement would be to increase the capacity through improved infrastructure and equipment, the introduction of digital and automatic technology, and further building of knowledge and communication towards decision makers and the public. These aspects were not studied in detail here, but would be of interest to study further.

### Effects of performance time on demand for railway freight transport

Interviews and scenarios in NGM indicate that performance time and prioritization in timetabling are important for the choice of transport mode. Different market segments were simulated to have very different effects of reduced or increased performance time. The largest effects were observed for general cargo for most lines, whereas large and homogeneous volumes such as dry bulk and timber showed to have the least effect. The effect appeared to be most distinguish at lines with high competition towards road transport.

**Influence of performance time on different markets and stretches**

The different markets and stretches were influenced differently, where general cargo was found to be the largest market at most stretches between the large cities. This market was significantly affected by a change in performance time, and was considered to have a large potential to increase or decrease. This study does however not include constraints in the infrastructure, which will have to be considered and mapped for further progress. The large and homogeneous markets of dry bulk, wet bulk, and timber were found to be very little influenced by the change of performance time, indicating that these markets have an inelastic demand depending on travel time. Thermal goods and fish were assumed to be markets with high time values and hence to be significantly influenced, and this was also observed from the results.

## 6.2 Further research

There is still a lot of research that could be done within this field. One subject which could be interesting to look more into is simultaneous entries or overlong crossings on single track lines. As Norway is a country with a lot of single track lines the use of passing sections is highly necessary. With the desire to use longer freight trains than today, this means that these passing sections need to be extended for the freight trains to use them. However, a solution where the passenger train uses the passing section and the freight train uses the main track could solve this challenge without having to invest a lot in new infrastructure. Such a solution would require looking into signaling systems and how these can be moderated. Challenges related to laws and regulations, economic aspects, and environmental aspects could also be studied.

Another aspect that could be studied is how small or large the willingness for an introduction of higher prioritization for freight trains is. Passenger train operators might not find this solution well as it will give worsened conditions for them, but freight operators might find this very appealing. It would also be interesting to do a survey among different railway undertakings in Norway to map the willingness of introducing different prioritization rules through the day, and to question how possible it is to implement. It could be interesting to look at aspects to how this will benefit society in total, what the consequences will be for passengers, and what the consequences will be for freight.

Evaluating the rules and guidelines for prioritization of different train categories in different countries is another possible subject to study. For the current regulations in Norway, freight trains will always be deprioritized compared to passenger trains, and it would be interesting to study if this is the case for most countries or if other ways of operating are used elsewhere.

Evaluation of how private and individual customers can contribute to the choice of transport mode can be studied. As an increase in e-commerce has shown to be a trend, it would be interesting to map if there exists a willingness from customers to take some of the costs related to transport. This could for instance be done through a survey, where participants are asked if they are willing to have a longer delivery time if it ensures the greenest or most sustainable transport possible is used, and also if they are willing to pay an extra fee for this.

Other interesting aspects to study further are testing of the solutions proposed during interviews, such as possibilities for establishing an independent terminal company which can handle the operations and equipment at the terminals, introduction of more automatic solutions, and more understandable ways of communicating towards decision makers, as well as how to collect and share more data in order to create better models. A terminal solution with an independent operator where the different railway undertakings could buy services from this terminal company, is one possibility. Such a solution might open up for better utilization of space and equipment inside the terminal area, and could possibly help increase efficiency and attractiveness. It will however have negative aspects related to customer relations between the train company and the freight customers.

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# Appendix

## A Scientific abstract

The demand for freight transport is expected to be increased in the coming years. In intermodal transport freight is transshipped between road and railway, and in order to make this system efficient and attractive both the terminals and the lines between them need to be optimized. Terminals are key elements in making the transport as smooth as possible, and have been pointed out as an important factor for increasing the utilization of railway lines for transport of freight. Between the terminals the performance time is one of the main factors that affect freight transport, and current trends indicate that this will be increasing in the coming years.

The findings from this master's thesis broadened the knowledge about intermodal freight transport, focusing on terminals and transport performance. The work included an overall mapping of existing challenges through in-depth interviews, where performance time was highlighted as one of the current main challenges. A detailed analysis of performance time at a selected set of rail stretches in Norway were conducted using the Norwegian national freight model (NGM).

The results from the study showed that the current situation for railway freight transport is pressuring, and that there are challenges related to infrastructure, operation, organization, knowledge and economy. The detailed modelling indicated that some markets, especially general cargo, will be highly influenced by the change in performance time, and that a change in current prioritization rules could have a large effect.

**Keywords:** Railway freight transport, Intermodal transport, Intermodal terminals, Performance time, Prioritization in timetabling

## B Interview guide

This interview guide was used as a tool during interviews, in order to keep track of what subjects have been discussed. The plan was to have the interviews in Norwegian, and the following guide is therefore in Norwegian.

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**ORIENTERING**

Dette prosjektet gjennomføres som en del av min masteroppgave som er den avsluttende oppgaven for studieprogrammet "Bygg og miljøteknikk" ved Norges Tekniske- og Naturvitenskapelige
Universitet (NTNU) i Trondheim. Gjennom masteroppgaven ønsker jeg å undersøke hvilke faktorer som påvirker kapasiteten til godsterminaler for jernbane, og hensikten med intervjuet er å tilegne meg kunnskap om hvordan terminal driftes og for å kunne besvare forskningsspørsmåletne:

1. *Hva er de nåværende utfordringene for planlegging og drift av godsterminaler på jernbane?*
2. *Hvilke parametere påvirker kapasiteten til en godsterminal på jernbane?*
3. *Hvordan kan man legge til rette for bedre utnyttelse av kapasiteten på terminaler?*

Det planlegges å gjennomføre intervjuer med operatører, infrastrukturforvaltere og planleggere for å belyse problemstillingen fra flere perspektiver.

**INTRODUKSJON**

1. Hvilken stilling/posisjon har du i jobben din?
2. Hvor lenge har du jobbet med godstransport?
3. Hva er de viktigste oppgavene du har i jobben din?

**HOVEDDEL**

Hovedutfordringer

4. Hva er din erfaring med planlegging og drift av godsterminaler i Norge?
5. Hva ser du som de største utfordringene for planlegging og drift av godsterminaler på jernbane?
6. Hvordan tenker du at man best kan møte disse utfordringene?

Begrensende faktorer

7. Hvilke faktorer ser du som begrensende for kapasiteten på godsterminaler?
8. Hvordan tenker du man best kan møte disse utfordringene?

Samarbeid mellom ulike aktører

9. Hvordan fungerer samarbeidet mellom ulike aktører som opererer innen godstransport og på godsterminaler?
10. Er det noe du tenker man burde gjøre annerledes, og i så fall hva?

Metoder for planlegging

11. Hvilke typer verktøy eller metoder brukes for å planlegge driften av en terminal?
12. Hvilken erfaring har du med denne typen verktøy og metoder?
13. Hvordan opplever du at planene funger i praksis? Blir oppgaver gjennomført slik de er tenkt? Hvordan følges dette opp?
14. Hvordan håndteres eventuelle avvik fra planene?
15. Er det noe du tenker man bør gjøre annerledes enn i dag, og i så fall hva?

## AVSLUTNING

12. Har du noe mer du ønsker å legge til angående disse temaene?
13. Kan jeg kontakte deg på et senere tidspunkt dersom jeg skulle ha behov for ytterligere informasjon?

## C Statement of consent

The sheet below was sent to NSD (Norsk senter for forksningsdata) as a part of getting the research project approved, and to give information about how privacy would be handled through the project. The plan was to have the interviews in Norwegian, and the following information sheet is therefor in Norwegian.

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# Vil du delta i forskningsprosjektet

# "Terminalkapasitet for intermodal godstransport"?

Dette er et spørsmål til deg om å delta i et forskningsprosjekt hvor formålet er å oppnå kunnskap om dagens godsterminaler og utfordringer for godstransport. I dette skrivet gir vi deg informasjon om målene for prosjektet og hva deltakelse vil innebære for deg.

**Formål**

Formålet med prosjektet er å undersøke hvordan godsterminaler i Norge fungerer i dag og hvilke utfordringer man har med planlegging og drift, samt hvilke faktorer/parametere som påvirker kapasiteten til en terminal. Arbeidet vil pågå over et semester våren 2021, og planlegges å være ferdig i juni.

Forskningsspørsmålene som skal undersøkes er:

1. Hva er de nåværende utfordringene for planlegging og drift av godsterminaler for jernbane?
2. Hvilke parametere påvirker kapasiteten til en godsterminal på jernbane?
3. Hvordan kan man legge til rette for bedre utnyttelse av kapasiteten på terminaler, og mer bruk av jernbane for godstransport?

En viktig del av data- og erfaringsinnsamlingen for prosjektet er intervju med erfarne personer innen godstransport. Prosjektet er en masteroppgave, og gjennomføres som den avsluttende delen av studiet Bygg- og Miljøteknikk ved Norges tekniske og naturvitenskapelige universitet (NTNU) i Trondheim.

**Hvem er ansvarlig for forskningsprosjektet?**

Institutt for bygg- og miljøteknikk er ansvarlig for prosjektet.

Følgende personer er ansvarlige for prosjektet:

1. Marie Malvik, student ved NTNU
2. Albert Lau, veileder og førsteamanuensis ved institutt for bygg- og miljøteknikk
3. Christine Handstanger, biveileder, Infraplan AS

**Hvorfor får du spørsmål om å delta?**
Du får spørsmål om å delta i prosjektet fordi du har erfaring med planlegging og drift av terminaler for godstransport.

**Hva innebærer det for deg å delta?**
Hvis du velger å delta i prosjektet innebærer det at du stiller til et intervju. Intervjuet vil ha en varighet på omtrent 45-60 minutter. Det vil bli gjort notater under intervjuet som senere skal skrives om til et referat. Intervjuet vil ha en semistrukturert form, som vil si at det ligner på en åpen samtale om temaet. Spørsmål som ønskes besvart vil være på formen:

- Hva er din erfaring med planlegging og drift av godsterminaler i Norge?
- Hvilke type verktøy og metoder brukes for planlegging og drift av godsterminaler?
- Hva ser du som de største utfordringene ved terminaler i dag?
- Hvordan tenker du at man best kan møte disse utfordringene?

Etter at intervjuet er gjennomført vil notatene transkriberes, og deretter sendes til deg som deltager slik at du kan forsikre deg om at det ikke har oppstått misforståelser. Du vil da også ha mulighet til å fjerne eller endre deler av din besvarelse, dersom dette er nødvendig. Notatene vil lagres på studentens personlige pc og kun være tilgjengelig for intervjuer, student Marie Malvik.

**Det er frivillig å delta**
Det er frivillig å delta i prosjektet. Hvis du velger å delta, kan du når som helst trekke samtykket tilbake uten å oppgi noen grunn. Alle opplysninger om deg vil da bli slettet. Alle opplysninger om deg vil også bli anonymisert. Det vil ikke ha noen negative konsekvenser for deg hvis du ikke vil delta eller senere velger å trekke deg.

**Ditt personvern – hvordan vi oppbevarer og bruker dine opplysninger**
Vi vil bare bruke opplysningene om deg til formålene vi har fortalt om i dette skrivet. Vi behandler opplysningene konfidensielt og i samsvar med personvernregelverket. Det er kun følgende personer som vil ha tilgang til opplysningene som foretas ved intervju:

- Marie Malvik, student ved NTNU
- Albert Lau, veileder og professor ved institutt for bygg- og miljøteknikk, NTNU

Ditt navn vil erstattes med en kode som lagres på en egen navneliste adskilt fra notatene. Navnelisten vil slettes sammen med notatene etter at referatet har blitt godkjent eller samtykket er trukket tilbake av deg som deltager. Navnelistene og notatene vil lagres på studentens personlige pc og kan kun låses opp og være tilgjengelige for student Marie Malvik.

Du vil som deltager ikke kunne gjenkjennes i publikasjonen som følger av prosjektet, da navn og andre opplysninger rundt intervjuet ikke vil være gitt i publikasjonen. Referatet fra intervjuet vil være lagt til som vedlegg til publikasjonen, dersom dette godkjennes av deg som deltager. Referatet vil da heller ikke inneholde noen form for opplysninger utover de svarene du gir i intervjuet.

**Hva skjer med opplysningene dine når vi avslutter forskningsprosjektet?**
Prosjektet skal etter planen leveres 10. juni 2021. Informasjon fra deg som ikke videre brukes i oppgaven under ditt samtykke vil da slettes umiddelbart.

**Dine rettigheter** Så lenge du kan identifiseres i datamaterialet, har du rett til:

- innsyn i hvilke personopplysninger som er registrert om deg, og å få utlevert en kopi av opplysningene,
- å få rettet personopplysninger om deg,
- å få slettet personopplysninger om deg, og
- å sende klage til Datatilsynet om behandlingen av dine personopplysninger.

**Hva gir oss rett til å behandle personopplysninger om deg?**
Vi behandler opplysninger om deg basert på ditt samtykke.

På oppdrag fra instituttet for bygg- og miljøteknikk, NTNU, har NSD – Norsk senter for forskningsdata AS vurdert at behandlingen av personopplysninger i dette prosjektet er i samsvar med personvernregelverket.

**Hvor kan jeg finne ut mer?**
Hvis du har spørsmål til studien, eller ønsker å benytte deg av dine rettigheter, ta kontakt med:

- Instituttet for bygg- og miljøteknikk ved førsteamanuensis Albert Lau på e-post (albert.lau@ntnu.no) og telefon: 94258319, eller student Marie Malvik på e-post (mariehma@stud.ntnu.no) og telefon: 97765511.
- Vårt personvernombud: Omar Sabri på e-post (omar.sabri@ntnu.no) eller telefon: 73559539.

Hvis du har spørsmål knyttet til NSD sin vurdering av prosjektet, kan du ta kontakt med:

- NSD – Norsk senter for forskningsdata AS på epost (personverntjenester@nsd.no) eller på telefon: 55 58 21 17.

Med vennlig hilsen

| | |
|---|---|
| Prosjektansvarlig<br>(Forsker/veileder) | Student |
| Albert Lau | Marie Malvik |

. . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .

**Samtykkeerklæring**
Jeg har mottatt og forstått informasjon om prosjektet *Terminalkapasitet for intermodal godstransport*, og har fått anledning til å stille spørsmål. Jeg samtykker til:

☐ å delta i intervju

Jeg samtykker til at mine opplysninger behandles frem til prosjektet er avsluttet, ca. 10. juni

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(Signert av prosjektdeltaker, dato)

## D Terminal visit at Brattøra, Trondheim

A visit was done at Brattøra terminal in Trondheim, giving a better insight to terminals and their practical operations.


Figure 53: Terminal visit at Brattøra.


Figure 54: Depot area.

Figure 55: Reach stacker.


Figure 56: Emergency preparedness container.


Figure 57: Gate system.

Figure 58: Gate system.

## E Results from NGM

Here the results from scenarios in NGM are given in detail, for the years 2018, 2030 and 2050. The blue tables indicate the transport performance are measured in tonnes-kilometres, and the red tables show the percentage change from the basis scenario. For market segments where the initial transport performance was found to be zero, the percentage change was removed.

## Results for Bergen-Finse

| Bergen-Finse 2018 | Speed [km/h] | Dry bulk | General cargo | Fish | Thermal | Industrial goods | Timber | Wet bulk |
|---|---|---|---|---|---|---|---|---|
| Scenario8 | 100 | 1 038 482 | 219 622 570 | 2 270 844 | 3 503 862 | 48 061 719 | 0 | 0 |
| Scenario7 | 90 | 1 038 482 | 204 654 490 | 2 228 311 | 2 110 056 | 45 031 483 | 0 | 0 |
| Scenario6 | 80 | 1 038 482 | 184 277 927 | 2 138 203 | 1 639 101 | 42 697 529 | 0 | 0 |
| Scenario5 | 70 | 1 038 482 | 161 679 842 | 1 568 052 | 1 523 614 | 39 176 079 | 0 | 0 |
| Basis2018 | 65 | 1 038 482 | 135 762 438 | 1 486 106 | 1 443 940 | 36 396 404 | 0 | 0 |
| Scenario2 | 60 | 1 036 946 | 107 371 772 | 1 372 764 | 1 364 827 | 32 956 199 | 0 | 0 |
| Scenario4 | 55 | 1 036 946 | 69 794 867 | 1 372 652 | 1 283 488 | 26 184 649 | 0 | 0 |
| Scenario1 | 50 | 1 032 785 | 53 290 837 | 1 372 652 | 938 069 | 22 867 242 | 0 | 0 |
| Scenario3 | 40 | 84 523 | 12 086 102 | 1 013 791 | 329 337 | 19 015 881 | 0 | 0 |

| Bergen-Finse 2018 | Speed [km/h] | Dry bulk | General cargo | Fish | Thermal | Industrial goods | Timber | Wet bulk |
|---|---|---|---|---|---|---|---|---|
| Scenario8 | 100 | 0.0 % | 61.8 % | 52.8 % | 142.7 % | 32.1 % | | |
| Scenario7 | 90 | 0.0 % | 50.7 % | 49.9 % | 46.1 % | 23.7 % | | |
| Scenario6 | 80 | 0.0 % | 35.7 % | 43.9 % | 13.5 % | 17.3 % | | |
| Scenario5 | 70 | 0.0 % | 19.1 % | 5.5 % | 5.5 % | 7.6 % | | |
| Basis2018 | 65 | 0.0 % | 0.0 % | 0.0 % | 0.0 % | 0.0 % | | |
| Scenario2 | 60 | -0.1 % | -20.9 % | -7.6 % | -5.5 % | -9.5 % | | |
| Scenario4 | 55 | -0.1 % | -48.6 % | -7.6 % | -11.1 % | -28.1 % | | |
| Scenario1 | 50 | -0.5 % | -60.7 % | -7.6 % | -35.0 % | -37.2 % | | |
| Scenario3 | 40 | -91.9 % | -91.1 % | -31.8 % | -77.2 % | -47.8 % | | |

| Bergen-Finse 2030 | Speed [km/h] | Dry bulk | General cargo | Fish | Thermal | Industrial goods | Timber | Wet bulk |
|---|---|---|---|---|---|---|---|---|
| Scenario8 | 100 | 2 517 963 | 238 557 288 | 5 614 621 | 706 248 | 52 729 070 | 0 | 0 |
| Scenario7 | 90 | 2 511 738 | 230 214 372 | 4 593 406 | 535 475 | 43 351 673 | 0 | 0 |
| Scenario6 | 80 | 2 511 738 | 218 545 907 | 4 285 512 | 544 | 36 192 380 | 0 | 0 |
| Scenario5 | 70 | 2 470 005 | 196 873 371 | 3 661 562 | 0 | 27 459 256 | 0 | 0 |
| Basis2018 | 65 | 2 470 005 | 189 477 232 | 3 493 749 | 0 | 23 021 341 | 0 | 0 |
| Scenario2 | 60 | 2 470 005 | 177 729 443 | 621 598 | 0 | 21 229 518 | 0 | 0 |
| Scenario4 | 55 | 2 407 437 | 138 402 863 | 465 498 | 0 | 17 811 586 | 0 | 0 |
| Scenario1 | 50 | 2 400 796 | 121 603 759 | 297 861 | 0 | 14 093 793 | 0 | 0 |
| Scenario3 | 40 | 1 413 473 | 61 473 812 | 182 599 | 0 | 9 979 695 | 0 | 0 |

| Bergen-Finse 2030 | Speed [km/h] | Dry bulk | General cargo | Fish | Thermal | Industrial goods | Timber | Wet bulk |
|---|---|---|---|---|---|---|---|---|
| Scenario8 | 100 | 1.9 % | 25.9 % | 60.7 % | | 129.0 % | | |
| Scenario7 | 90 | 1.7 % | 21.5 % | 31.5 % | | 88.3 % | | |
| Scenario6 | 80 | 1.7 % | 15.3 % | 22.7 % | | 57.2 % | | |
| Scenario5 | 70 | 0.0 % | 3.9 % | 4.8 % | | 19.3 % | | |
| Basis2018 | 65 | 0.0 % | 0.0 % | 0.0 % | | 0.0 % | | |
| Scenario2 | 60 | 0.0 % | -6.2 % | -82.2 % | | -7.8 % | | |
| Scenario4 | 55 | -2.5 % | -27.0 % | -86.7 % | | -22.6 % | | |
| Scenario1 | 50 | -2.8 % | -35.8 % | -91.5 % | | -38.8 % | | |
| Scenario3 | 40 | -42.8 % | -67.6 % | -94.8 % | | -56.7 % | | |

| Bergen-Finse 2050 | Speed [km/h] | Dry bulk | General cargo | Fish | Thermal | Industrial goods | Timber | Wet bulk |
|---|---|---|---|---|---|---|---|---|
| Scenario8 | 100 | 3 758 518 | 300 407 451 | 7 245 034 | 766 752 | 56 972 641 | 0 | 0 |
| Scenario7 | 90 | 3 752 037 | 286 325 785 | 6 980 233 | 378 063 | 41 001 750 | 0 | 0 |
| Scenario6 | 80 | 3 527 881 | 223 311 607 | 6 698 725 | 784 | 34 478 182 | 0 | 0 |
| Scenario5 | 70 | 3 523 945 | 205 241 603 | 6 098 346 | 0 | 29 753 464 | 0 | 0 |
| Basis2018 | 65 | 3 503 558 | 197 793 316 | 4 785 094 | 0 | 28 186 147 | 0 | 0 |
| Scenario2 | 60 | 3 503 558 | 189 661 577 | 717 018 | 0 | 26 425 128 | 0 | 0 |
| Scenario4 | 55 | 3 500 598 | 173 166 478 | 673 572 | 0 | 21 959 608 | 0 | 0 |
| Scenario1 | 50 | 3 407 370 | 146 007 511 | 483 116 | 0 | 17 598 824 | 0 | 0 |
| Scenario3 | 40 | 2 675 134 | 56 167 242 | 315 767 | 0 | 12 725 046 | 0 | 0 |

| Bergen-Finse 2050 | Speed [km/h] | Dry bulk | General cargo | Fish | Thermal | Industrial goods | Timber | Wet bulk |
|---|---|---|---|---|---|---|---|---|
| Scenario8 | 100 | 7.3 % | 51.9 % | 51.4 % | | 102.1 % | | |
| Scenario7 | 90 | 7.1 % | 44.8 % | 45.9 % | | 45.5 % | | |
| Scenario6 | 80 | 0.7 % | 12.9 % | 40.0 % | | 22.3 % | | |
| Scenario5 | 70 | 0.6 % | 3.8 % | 27.4 % | | 5.6 % | | |
| Basis2018 | 65 | 0.0 % | 0.0 % | 0.0 % | | 0.0 % | | |
| Scenario2 | 60 | 0.0 % | -4.1 % | -85.0 % | | -6.2 % | | |
| Scenario4 | 55 | -0.1 % | -12.5 % | -85.9 % | | -22.1 % | | |
| Scenario1 | 50 | -2.7 % | -26.2 % | -89.9 % | | -37.6 % | | |
| Scenario3 | 40 | -23.6 % | -71.6 % | -93.4 % | | -54.9 % | | |

## Results for Oslo-Finse

| Oslo-Finse 2018 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Speed [km/h] | Dry bulk | General cargo | Fish | Thermal | Industrial goods | Timber | Wet bulk |
| Scenario8 | 100 | 1 906 391 | 392 693 891 | 4 158 250 | 6 298 843 | 88 994 734 | 10 230 888 | 0 |
| Scenario7 | 90 | 1 906 391 | 365 767 027 | 4 082 827 | 3 772 767 | 83 453 851 | 8 296 234 | 0 |
| Scenario6 | 80 | 1 906 391 | 329 309 467 | 3 917 728 | 2 962 704 | 79 180 115 | 8 288 021 | 0 |
| Scenario5 | 70 | 1 906 391 | 289 243 680 | 2 873 067 | 2 755 808 | 72 740 668 | 8 241 964 | 0 |
| Basis2018 | 65 | 1 906 391 | 243 049 818 | 2 722 921 | 2 609 825 | 67 735 927 | 7 795 154 | 0 |
| Scenario2 | 60 | 1 903 576 | 191 751 903 | 2 515 249 | 2 469 652 | 61 392 839 | 7 451 025 | 0 |
| Scenario4 | 55 | 1 903 576 | 125 707 275 | 2 515 044 | 2 320 992 | 49 282 261 | 7 436 472 | 0 |
| Scenario1 | 50 | 1 895 782 | 96 707 464 | 2 515 044 | 1 693 951 | 43 325 396 | 7 388 836 | 0 |
| Scenario3 | 40 | 158 326 | 22 062 384 | 1 857 520 | 603 701 | 36 335 004 | 7 350 439 | 0 |

| Oslo-Finse 2018 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Speed [km/h] | Dry bulk | General cargo | Fish | Thermal | Industrial goods | Timber | Wet bulk |
| Scenario8 | 100 | 0.0 % | 61.6 % | 52.7 % | 141.4 % | 31.4 % | 31.2 % | |
| Scenario7 | 90 | 0.0 % | 50.5 % | 49.9 % | 44.6 % | 23.2 % | 6.4 % | |
| Scenario6 | 80 | 0.0 % | 35.5 % | 43.9 % | 13.5 % | 16.9 % | 6.3 % | |
| Scenario5 | 70 | 0.0 % | 19.0 % | 5.5 % | 5.6 % | 7.4 % | 5.7 % | |
| Basis2018 | 65 | 0.0 % | 0.0 % | 0.0 % | 0.0 % | 0.0 % | 0.0 % | |
| Scenario2 | 60 | -0.1 % | -21.1 % | -7.6 % | -5.4 % | -9.4 % | -4.4 % | |
| Scenario4 | 55 | -0.1 % | -48.3 % | -7.6 % | -11.1 % | -27.2 % | -4.6 % | |
| Scenario1 | 50 | -0.6 % | -60.2 % | -7.6 % | -35.1 % | -36.0 % | -5.2 % | |
| Scenario3 | 40 | -91.7 % | -90.9 % | -31.8 % | -76.9 % | -46.4 % | -5.7 % | |

| Oslo-Finse 2030 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Speed [km/h] | Dry bulk | General cargo | Fish | Thermal | Industrial goods | Timber | Wet bulk |
| Scenario8 | 100 | 4 618 891 | 424 354 535 | 10 059 433 | 1 294 025 | 97 994 636 | 67 439 583 | 0 |
| Scenario7 | 90 | 4 607 230 | 409 185 693 | 8 365 767 | 981 125 | 81 165 654 | 68 879 680 | 0 |
| Scenario6 | 80 | 4 607 230 | 388 227 100 | 7 801 627 | 997 | 68 048 025 | 67 587 493 | 0 |
| Scenario5 | 70 | 4 530 764 | 349 215 173 | 6 658 393 | 0 | 52 029 698 | 64 826 870 | 0 |
| Basis2018 | 65 | 4 530 764 | 335 896 181 | 6 375 541 | 0 | 44 151 626 | 64 813 517 | 0 |
| Scenario2 | 60 | 4 530 764 | 315 875 671 | 1 138 924 | 0 | 40 848 312 | 64 207 976 | 0 |
| Scenario4 | 55 | 4 416 009 | 249 025 059 | 852 910 | 0 | 34 945 528 | 64 207 976 | 0 |
| Scenario1 | 50 | 4 403 569 | 218 692 541 | 545 757 | 0 | 28 245 076 | 62 460 561 | 0 |
| Scenario3 | 40 | 2 594 544 | 110 675 960 | 334 567 | 0 | 20 690 593 | 51 430 421 | 0 |

| Oslo-Finse 2030 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Speed [km/h] | Dry bulk | General cargo | Fish | Thermal | Industrial goods | Timber | Wet bulk |
| Scenario8 | 100 | 1.9 % | 26.3 % | 57.8 % | | 122.0 % | 4.1 % | |
| Scenario7 | 90 | 1.7 % | 21.8 % | 31.2 % | | 83.8 % | 6.3 % | |
| Scenario6 | 80 | 1.7 % | 15.6 % | 22.4 % | | 54.1 % | 4.3 % | |
| Scenario5 | 70 | 0.0 % | 4.0 % | 4.4 % | | 17.8 % | 0.0 % | |
| Basis2018 | 65 | 0.0 % | 0.0 % | 0.0 % | | 0.0 % | 0.0 % | |
| Scenario2 | 60 | 0.0 % | -6.0 % | -82.1 % | | -7.5 % | -0.9 % | |
| Scenario4 | 55 | -2.5 % | -25.9 % | -86.6 % | | -20.9 % | -0.9 % | |
| Scenario1 | 50 | -2.8 % | -34.9 % | -91.4 % | | -36.0 % | -3.6 % | |
| Scenario3 | 40 | -42.7 % | -67.1 % | -94.8 % | | -53.1 % | -20.6 % | |

| Oslo-Finse 2050 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Speed [km/h] | Dry bulk | General cargo | Fish | Thermal | Industrial goods | Timber | Wet bulk |
| Scenario8 | 100 | 6 893 627 | 536 819 254 | 13 197 144 | 1 404 883 | 106 834 501 | 101 000 533 | 0 |
| Scenario7 | 90 | 6 881 753 | 511 883 801 | 12 711 962 | 692 707 | 78 196 423 | 100 976 115 | 0 |
| Scenario6 | 80 | 6 471 042 | 401 878 169 | 12 196 170 | 1 437 | 66 236 657 | 97 305 739 | 0 |
| Scenario5 | 70 | 6 463 669 | 369 471 247 | 11 173 708 | 0 | 57 556 715 | 93 731 997 | 0 |
| Basis2018 | 65 | 6 425 959 | 356 441 634 | 8 767 499 | 0 | 54 721 357 | 91 917 836 | 0 |
| Scenario2 | 60 | 6 425 959 | 341 983 271 | 1 313 757 | 0 | 51 549 586 | 91 879 316 | 0 |
| Scenario4 | 55 | 6 420 535 | 312 220 279 | 1 234 154 | 0 | 43 880 878 | 91 879 316 | 0 |
| Scenario1 | 50 | 6 249 391 | 262 791 423 | 885 191 | 0 | 35 903 508 | 88 679 505 | 0 |
| Scenario3 | 40 | 4 907 751 | 101 007 594 | 578 566 | 0 | 26 967 912 | 80 921 970 | 0 |

| Oslo-Finse 2050 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Speed [km/h] | Dry bulk | General cargo | Fish | Thermal | Industrial goods | Timber | Wet bulk |
| Scenario8 | 100 | 7.3 % | 50.6 % | 50.5 % | | 95.2 % | 9.9 % | |
| Scenario7 | 90 | 7.1 % | 43.6 % | 45.0 % | | 42.9 % | 9.9 % | |
| Scenario6 | 80 | 0.7 % | 12.7 % | 39.1 % | | 21.0 % | 5.9 % | |
| Scenario5 | 70 | 0.6 % | 3.7 % | 27.4 % | | 5.2 % | 2.0 % | |
| Basis2018 | 65 | 0.0 % | 0.0 % | 0.0 % | | 0.0 % | 0.0 % | |
| Scenario2 | 60 | 0.0 % | -4.1 % | -85.0 % | | -5.8 % | 0.0 % | |
| Scenario4 | 55 | -0.1 % | -12.4 % | -85.9 % | | -19.8 % | 0.0 % | |
| Scenario1 | 50 | -2.7 % | -26.3 % | -89.9 % | | -34.4 % | -3.5 % | |
| Scenario3 | 40 | -23.6 % | -71.7 % | -93.4 % | | -50.7 % | -12.0 % | |

## Results for Hokksund-Stavanger

| Hokksund-Stavanger 2018 | Speed [km/h] | Dry bulk | General cargo | Fish | Thermal | Industrial goods | Timber | Wet bulk |
|---|---|---|---|---|---|---|---|---|
| Scenario8 | 100 | 1 627 078 | 603 031 967 | 4 287 262 | 61 790 211 | 100 616 855 | 31 580 650 | 0 |
| Scenario7 | 90 | 1 627 078 | 562 942 914 | 4 154 069 | 59 989 981 | 93 578 288 | 31 547 795 | 0 |
| Scenario6 | 80 | 1 627 078 | 490 420 190 | 4 154 069 | 58 578 575 | 63 041 732 | 18 561 135 | 0 |
| Scenario5 | 70 | 1 586 224 | 406 197 169 | 1 258 939 | 57 652 723 | 46 700 803 | 17 990 210 | 0 |
| Basis2018 | 65 | 1 449 454 | 371 624 960 | 226 841 | 57 290 560 | 33 829 809 | 17 560 705 | 0 |
| Scenario2 | 60 | 0 | 301 245 351 | 226 841 | 57 034 557 | 24 056 601 | 17 223 451 | 0 |
| Scenario4 | 55 | 0 | 236 810 333 | 226 841 | 43 219 363 | 20 833 096 | 17 180 468 | 0 |
| Scenario1 | 50 | 0 | 202 723 123 | 226 841 | 42 771 700 | 14 944 786 | 14 057 853 | 0 |
| Scenario3 | 40 | 0 | 79 700 331 | 226 841 | 42 198 964 | 7 476 083 | 13 258 959 | 0 |

| Hokksund-Stavanger 2018 | Speed [km/h] | Dry bulk | General cargo | Fish | Thermal | Industrial goods | Timber | Wet bulk |
|---|---|---|---|---|---|---|---|---|
| Scenario8 | 100 | 12.3 % | 62.3 % | 1790.0 % | 7.9 % | 197.4 % | 79.8 % | |
| Scenario7 | 90 | 12.3 % | 51.5 % | 1731.3 % | 4.7 % | 176.6 % | 79.6 % | |
| Scenario6 | 80 | 12.3 % | 32.0 % | 1731.3 % | 2.2 % | 86.3 % | 5.7 % | |
| Scenario5 | 70 | 9.4 % | 9.3 % | 455.0 % | 0.6 % | 38.0 % | 2.4 % | |
| Basis2018 | 65 | 0.0 % | 0.0 % | 0.0 % | 0.0 % | 0.0 % | 0.0 % | |
| Scenario2 | 60 | -100.0 % | -18.9 % | 0.0 % | -0.4 % | -28.9 % | -1.9 % | |
| Scenario4 | 55 | -100.0 % | -36.3 % | 0.0 % | -24.6 % | -38.4 % | -2.2 % | |
| Scenario1 | 50 | -100.0 % | -45.4 % | 0.0 % | -25.3 % | -55.8 % | -19.9 % | |
| Scenario3 | 40 | -100.0 % | -78.6 % | 0.0 % | -26.3 % | -77.9 % | -24.5 % | |

| Hokksund-Stavanger 2030 | Speed [km/h] | Dry bulk | General cargo | Fish | Thermal | Industrial goods | Timber | Wet bulk |
|---|---|---|---|---|---|---|---|---|
| Scenario8 | 100 | 6 971 224 | 703 829 224 | 9 033 732 | 11 712 018 | 138 657 329 | 30 188 814 | 0 |
| Scenario7 | 90 | 4 904 771 | 678 375 521 | 8 971 820 | 10 991 711 | 123 776 113 | 23 498 818 | 0 |
| Scenario6 | 80 | 4 857 922 | 594 424 694 | 7 569 007 | 5 488 372 | 94 063 288 | 21 097 972 | 0 |
| Scenario5 | 70 | 4 556 072 | 549 197 217 | 6 883 195 | 0 | 78 049 483 | 20 432 548 | 0 |
| Basis2018 | 65 | 4 528 668 | 532 736 353 | 6 766 659 | 0 | 69 696 752 | 20 426 843 | 0 |
| Scenario2 | 60 | 4 528 668 | 497 618 359 | 5 609 817 | 0 | 61 388 937 | 20 425 063 | 0 |
| Scenario4 | 55 | 4 528 668 | 390 468 119 | 5 540 908 | 0 | 49 066 136 | 19 794 923 | 0 |
| Scenario1 | 50 | 3 541 358 | 300 878 603 | 5 368 403 | 0 | 37 981 935 | 19 462 589 | 0 |
| Scenario3 | 40 | 2 076 187 | 132 941 315 | 3 859 805 | 0 | 20 447 101 | 18 165 793 | 0 |

| Hokksund-Stavanger 2030 | Speed [km/h] | Dry bulk | General cargo | Fish | Thermal | Industrial goods | Timber | Wet bulk |
|---|---|---|---|---|---|---|---|---|
| Scenario8 | 100 | 53.9 % | 32.1 % | 33.5 % | | 98.9 % | 47.8 % | |
| Scenario7 | 90 | 8.3 % | 27.3 % | 32.6 % | | 77.6 % | 15.0 % | |
| Scenario6 | 80 | 7.3 % | 11.6 % | 11.9 % | | 35.0 % | 3.3 % | |
| Scenario5 | 70 | 0.6 % | 3.1 % | 1.7 % | | 12.0 % | 0.0 % | |
| Basis2018 | 65 | 0.0 % | 0.0 % | 0.0 % | | 0.0 % | 0.0 % | |
| Scenario2 | 60 | 0.0 % | -6.6 % | -17.1 % | | -11.9 % | 0.0 % | |
| Scenario4 | 55 | 0.0 % | -26.7 % | -18.1 % | | -29.6 % | -3.1 % | |
| Scenario1 | 50 | -21.8 % | -43.5 % | -20.7 % | | -45.5 % | -4.7 % | |
| Scenario3 | 40 | -54.2 % | -75.0 % | -43.0 % | | -70.7 % | -11.1 % | |

| Hokksund-Stavanger 2050 | Speed [km/h] | Dry bulk | General cargo | Fish | Thermal | Industrial goods | Timber | Wet bulk |
|---|---|---|---|---|---|---|---|---|
| Scenario8 | 100 | 6 343 118 | 679 052 401 | 10 640 880 | 9 732 503 | 145 939 248 | 41 381 428 | 0 |
| Scenario7 | 90 | 6 335 979 | 540 459 308 | 10 548 670 | 9 390 516 | 136 564 711 | 40 048 285 | 0 |
| Scenario6 | 80 | 6 335 979 | 431 250 782 | 10 520 359 | 202 974 | 111 144 437 | 36 055 902 | 0 |
| Scenario5 | 70 | 6 282 429 | 394 270 632 | 9 520 391 | 0 | 59 179 234 | 35 761 272 | 0 |
| Basis2018 | 65 | 6 282 429 | 311 169 623 | 9 518 857 | 0 | 46 023 799 | 34 995 749 | 0 |
| Scenario2 | 60 | 6 196 287 | 288 054 561 | 9 280 793 | 0 | 42 277 464 | 34 623 084 | 0 |
| Scenario4 | 55 | 6 096 997 | 272 126 093 | 8 240 638 | 0 | 38 626 857 | 33 052 585 | 0 |
| Scenario1 | 50 | 5 646 388 | 217 141 147 | 7 306 392 | 0 | 33 699 528 | 30 705 658 | 0 |
| Scenario3 | 40 | 4 140 967 | 121 918 184 | 4 188 965 | 0 | 21 771 592 | 17 870 180 | 0 |

| Hokksund-Stavanger 2050 | Speed [km/h] | Dry bulk | General cargo | Fish | Thermal | Industrial goods | Timber | Wet bulk |
|---|---|---|---|---|---|---|---|---|
| Scenario8 | 100 | 1.0 % | 118.2 % | 11.8 % | | 217.1 % | 18.2 % | |
| Scenario7 | 90 | 0.9 % | 73.7 % | 10.8 % | | 196.7 % | 14.4 % | |
| Scenario6 | 80 | 0.9 % | 38.6 % | 10.5 % | | 141.5 % | 3.0 % | |
| Scenario5 | 70 | 0.0 % | 26.7 % | 0.0 % | | 28.6 % | 2.2 % | |
| Basis2018 | 65 | 0.0 % | 0.0 % | 0.0 % | | 0.0 % | 0.0 % | |
| Scenario2 | 60 | -1.4 % | -7.4 % | -2.5 % | | -8.1 % | -1.1 % | |
| Scenario4 | 55 | -3.0 % | -12.5 % | -13.4 % | | -16.1 % | -5.6 % | |
| Scenario1 | 50 | -10.1 % | -30.2 % | -23.2 % | | -26.8 % | -12.3 % | |
| Scenario3 | 40 | -34.1 % | -60.8 % | -56.0 % | | -52.7 % | -48.9 % | |

# Results for Oslo-Støren

| Oslo-Støren 2018 | Speed [km/h] | Dry bulk | General cargo | Fish | Thermal | Industrial goods | Timber | Wet bulk |
|---|---|---|---|---|---|---|---|---|
| Scenario8 | 100 | 149 789 | 614 305 917 | 41 433 363 | 67 315 105 | 179 406 211 | 189 820 301 | 8 194 336 |
| Scenario7 | 90 | 145 539 | 554 999 370 | 37 062 907 | 66 679 231 | 152 138 747 | 189 346 899 | 8 194 336 |
| Scenario6 | 80 | 129 798 | 494 834 162 | 19 790 928 | 65 439 071 | 130 377 296 | 188 964 839 | 8 194 336 |
| Scenario5 | 70 | 129 798 | 433 584 685 | 9 873 886 | 63 086 714 | 114 463 038 | 187 538 250 | 8 194 336 |
| Basis2018 | 65 | 129 798 | 417 815 252 | 7 590 572 | 56 126 301 | 84 602 558 | 186 969 537 | 8 194 336 |
| Scenario2 | 60 | 115 179 | 386 618 816 | 3 393 677 | 55 751 632 | 79 586 806 | 186 063 500 | 8 194 336 |
| Scenario4 | 55 | 115 179 | 355 629 599 | 672 953 | 43 704 535 | 71 397 478 | 183 857 098 | 8 194 336 |
| Scenario1 | 50 | 109 715 | 307 541 961 | 672 953 | 42 136 048 | 61 718 873 | 166 437 394 | 8 194 336 |
| Scenario3 | 40 | 78 468 | 163 966 880 | 456 887 | 34 522 267 | 39 502 723 | 113 423 433 | 8 194 336 |

| Oslo-Støren 2018 | Speed [km/h] | Dry bulk | General cargo | Fish | Thermal | Industrial goods | Timber | Wet bulk |
|---|---|---|---|---|---|---|---|---|
| Scenario8 | 100 | 15.4 % | 47.0 % | 445.9 % | 19.9 % | 112.1 % | 1.5 % | 0.0 % |
| Scenario7 | 90 | 12.1 % | 32.8 % | 388.3 % | 18.8 % | 79.8 % | 1.3 % | 0.0 % |
| Scenario6 | 80 | 0.0 % | 18.4 % | 160.7 % | 16.6 % | 54.1 % | 1.1 % | 0.0 % |
| Scenario5 | 70 | 0.0 % | 3.8 % | 30.1 % | 12.4 % | 35.3 % | 0.3 % | 0.0 % |
| Basis2018 | 65 | 0.0 % | 0.0 % | 0.0 % | 0.0 % | 0.0 % | 0.0 % | 0.0 % |
| Scenario2 | 60 | -11.3 % | -7.5 % | -55.3 % | -0.7 % | -5.9 % | -0.5 % | 0.0 % |
| Scenario4 | 55 | -11.3 % | -14.9 % | -91.1 % | -22.1 % | -15.6 % | -1.7 % | 0.0 % |
| Scenario1 | 50 | -15.5 % | -26.4 % | -91.1 % | -24.9 % | -27.0 % | -11.0 % | 0.0 % |
| Scenario3 | 40 | -39.5 % | -60.8 % | -94.0 % | -38.5 % | -53.3 % | -39.3 % | 0.0 % |

| Oslo-Støren 2030 | Speed [km/h] | Dry bulk | General cargo | Fish | Thermal | Industrial goods | Timber | Wet bulk |
|---|---|---|---|---|---|---|---|---|
| Scenario8 | 100 | 4 197 968 | 863 808 266 | 34 019 072 | 42 608 183 | 440 462 294 | 208 826 609 | 9 422 013 |
| Scenario7 | 90 | 2 901 992 | 787 546 810 | 33 695 861 | 13 278 773 | 398 774 436 | 205 943 581 | 9 422 013 |
| Scenario6 | 80 | 245 677 | 696 534 507 | 17 505 241 | 5 852 002 | 298 243 394 | 205 398 705 | 9 422 013 |
| Scenario5 | 70 | 212 330 | 611 241 185 | 15 812 162 | 11 630 | 198 271 201 | 201 673 775 | 9 422 013 |
| Basis2018 | 65 | 196 496 | 575 003 359 | 15 113 661 | 11 630 | 180 078 660 | 170 571 233 | 9 422 013 |
| Scenario2 | 60 | 190 144 | 510 172 491 | 6 673 910 | 11 630 | 157 414 763 | 166 765 774 | 9 422 013 |
| Scenario4 | 55 | 190 144 | 461 946 199 | 5 522 775 | 0 | 142 189 689 | 161 964 567 | 9 422 013 |
| Scenario1 | 50 | 184 305 | 380 802 858 | 4 376 849 | 0 | 125 969 322 | 134 637 871 | 9 422 013 |
| Scenario3 | 40 | 175 431 | 253 668 637 | 1 801 999 | 0 | 72 806 104 | 132 497 437 | 9 422 013 |

| Oslo-Støren 2030 | Speed [km/h] | Dry bulk | General cargo | Fish | Thermal | Industrial goods | Timber | Wet bulk |
|---|---|---|---|---|---|---|---|---|
| Scenario8 | 100 | 2036.4 % | 50.2 % | 125.1 % | 366264.4 % | 144.6 % | 22.4 % | 0.0 % |
| Scenario7 | 90 | 1376.9 % | 37.0 % | 122.9 % | 114076.9 % | 121.4 % | 20.7 % | 0.0 % |
| Scenario6 | 80 | 25.0 % | 21.1 % | 15.8 % | 50218.2 % | 65.6 % | 20.4 % | 0.0 % |
| Scenario5 | 70 | 8.1 % | 6.3 % | 4.6 % | 0.0 % | 10.1 % | 18.2 % | 0.0 % |
| Basis2018 | 65 | 0.0 % | 0.0 % | 0.0 % | 0.0 % | 0.0 % | 0.0 % | 0.0 % |
| Scenario2 | 60 | -3.2 % | -11.3 % | -55.8 % | 0.0 % | -12.6 % | -2.2 % | 0.0 % |
| Scenario4 | 55 | -3.2 % | -19.7 % | -63.5 % | -100.0 % | -21.0 % | -5.0 % | 0.0 % |
| Scenario1 | 50 | -6.2 % | -33.8 % | -71.0 % | -100.0 % | -30.0 % | -21.1 % | 0.0 % |
| Scenario3 | 40 | -10.7 % | -55.9 % | -88.1 % | -100.0 % | -59.6 % | -22.3 % | 0.0 % |

| Oslo-Støren 2050 | Speed [km/h] | Dry bulk | General cargo | Fish | Thermal | Industrial goods | Timber | Wet bulk |
|---|---|---|---|---|---|---|---|---|
| Scenario8 | 100 | 284 632 | 1 056 826 595 | 31 647 294 | 24 968 585 | 565 581 813 | 290 779 460 | 6 167 785 |
| Scenario7 | 90 | 253 899 | 891 025 533 | 24 073 350 | 16 969 514 | 414 997 297 | 290 227 094 | 6 167 785 |
| Scenario6 | 80 | 253 899 | 789 628 840 | 23 670 644 | 330 649 | 276 327 364 | 290 204 395 | 6 167 785 |
| Scenario5 | 70 | 247 500 | 698 223 751 | 22 588 025 | 7 016 | 218 497 076 | 287 048 034 | 6 167 785 |
| Basis2018 | 65 | 247 500 | 648 512 917 | 20 557 628 | 7 016 | 191 303 928 | 234 856 412 | 6 167 785 |
| Scenario2 | 60 | 247 500 | 599 918 386 | 7 750 123 | 0 | 174 556 344 | 234 366 057 | 6 167 785 |
| Scenario4 | 55 | 247 500 | 560 094 209 | 6 671 100 | 0 | 144 770 108 | 218 149 012 | 6 167 785 |
| Scenario1 | 50 | 247 500 | 487 006 493 | 5 816 037 | 0 | 129 057 109 | 210 030 537 | 6 167 785 |
| Scenario3 | 40 | 220 316 | 277 164 824 | 1 174 959 | 0 | 80 129 443 | 188 627 433 | 6 167 785 |

| Oslo-Støren 2050 | Speed [km/h] | Dry bulk | General cargo | Fish | Thermal | Industrial goods | Timber | Wet bulk |
|---|---|---|---|---|---|---|---|---|
| Scenario8 | 100 | 15.0 % | 63.0 % | 53.9 % | 355780.6 % | 195.6 % | 23.8 % | 0.0 % |
| Scenario7 | 90 | 2.6 % | 37.4 % | 17.1 % | 241768.8 % | 116.9 % | 23.6 % | 0.0 % |
| Scenario6 | 80 | 2.6 % | 21.8 % | 15.1 % | 4612.8 % | 44.4 % | 23.6 % | 0.0 % |
| Scenario5 | 70 | 0.0 % | 7.7 % | 9.9 % | 0.0 % | 14.2 % | 22.2 % | 0.0 % |
| Basis2018 | 65 | 0.0 % | 0.0 % | 0.0 % | 0.0 % | 0.0 % | 0.0 % | 0.0 % |
| Scenario2 | 60 | 0.0 % | -7.5 % | -62.3 % | -100.0 % | -8.8 % | -0.2 % | 0.0 % |
| Scenario4 | 55 | 0.0 % | -13.6 % | -67.5 % | -100.0 % | -24.3 % | -7.1 % | 0.0 % |
| Scenario1 | 50 | 0.0 % | -24.9 % | -71.7 % | -100.0 % | -32.5 % | -10.6 % | 0.0 % |
| Scenario3 | 40 | -11.0 % | -57.3 % | -94.3 % | -100.0 % | -58.1 % | -19.7 % | 0.0 % |

## Results for Støren-Trondheim

| Støren-Trondheim 2018 | Speed [km/h] | Dry bulk | General cargo | Fish | Thermal | Industrial goods | Timber | Wet bulk |
|---|---|---|---|---|---|---|---|---|
| Scenario8 | 100 | 16 571 | 63 653 460 | 4 583 609 | 7 392 520 | 17 185 928 | 0 | 0 |
| Scenario7 | 90 | 16 100 | 57 620 329 | 4 100 123 | 7 322 305 | 14 294 056 | 0 | 0 |
| Scenario6 | 80 | 14 359 | 51 252 052 | 2 189 392 | 7 185 111 | 12 055 185 | 0 | 0 |
| Scenario5 | 70 | 14 359 | 45 092 663 | 1 092 309 | 6 928 022 | 10 413 029 | 0 | 0 |
| Basis2018 | 65 | 14 359 | 43 695 712 | 839 715 | 6 156 491 | 7 186 160 | 0 | 0 |
| Scenario2 | 60 | 12 742 | 41 102 726 | 375 429 | 6 115 920 | 6 683 504 | 0 | 0 |
| Scenario4 | 55 | 12 742 | 38 084 241 | 74 446 | 4 791 380 | 5 804 722 | 0 | 0 |
| Scenario1 | 50 | 12 137 | 33 632 479 | 74 446 | 4 660 706 | 4 770 696 | 0 | 0 |
| Scenario3 | 40 | 8 681 | 18 326 001 | 50 544 | 3 818 775 | 2 390 631 | 0 | 0 |

| Støren-Trondheim 2018 | Speed [km/h] | Dry bulk | General cargo | Fish | Thermal | Industrial goods | Timber | Wet bulk |
|---|---|---|---|---|---|---|---|---|
| Scenario8 | 100 | 15.4 % | 45.7 % | 445.9 % | 20.1 % | 139.2 % | | |
| Scenario7 | 90 | 12.1 % | 31.9 % | 388.3 % | 18.9 % | 98.9 % | | |
| Scenario6 | 80 | 0.0 % | 17.3 % | 160.7 % | 16.7 % | 67.8 % | | |
| Scenario5 | 70 | 0.0 % | 3.2 % | 30.1 % | 12.5 % | 44.9 % | | |
| Basis2018 | 65 | 0.0 % | 0.0 % | 0.0 % | 0.0 % | 0.0 % | | |
| Scenario2 | 60 | -11.3 % | -5.9 % | -55.3 % | -0.7 % | -7.0 % | | |
| Scenario4 | 55 | -11.3 % | -12.8 % | -91.1 % | -22.2 % | -19.2 % | | |
| Scenario1 | 50 | -15.5 % | -23.0 % | -91.1 % | -24.3 % | -33.6 % | | |
| Scenario3 | 40 | -39.5 % | -58.1 % | -94.0 % | -38.0 % | -66.7 % | | |

| Støren-Trondheim 2030 | Speed [km/h] | Dry bulk | General cargo | Fish | Thermal | Industrial goods | Timber | Wet bulk |
|---|---|---|---|---|---|---|---|---|
| Scenario8 | 100 | 462 757 | 87 196 235 | 3 717 228 | 4 713 115 | 44 338 137 | 0 | 0 |
| Scenario7 | 90 | 319 388 | 79 650 296 | 3 681 472 | 1 468 518 | 39 914 552 | 0 | 0 |
| Scenario6 | 80 | 25 530 | 70 824 420 | 1 890 368 | 646 924 | 28 930 183 | 0 | 0 |
| Scenario5 | 70 | 23 489 | 62 360 207 | 1 703 069 | 1 287 | 18 066 948 | 0 | 0 |
| Basis2018 | 65 | 21 738 | 58 937 306 | 1 625 797 | 1 287 | 16 358 567 | 0 | 0 |
| Scenario2 | 60 | 21 035 | 52 339 234 | 694 791 | 1 287 | 14 037 178 | 0 | 0 |
| Scenario4 | 55 | 21 035 | 47 735 195 | 558 806 | 0 | 12 673 034 | 0 | 0 |
| Scenario1 | 50 | 20 389 | 39 478 635 | 475 555 | 0 | 11 073 455 | 0 | 0 |
| Scenario3 | 40 | 19 407 | 26 389 161 | 199 348 | 0 | 5 248 509 | 0 | 0 |

| Støren-Trondheim 2030 | Speed [km/h] | Dry bulk | General cargo | Fish | Thermal | Industrial goods | Timber | Wet bulk |
|---|---|---|---|---|---|---|---|---|
| Scenario8 | 100 | 2028.8 % | 47.9 % | 128.6 % | 366109.4 % | 171.0 % | | |
| Scenario7 | 90 | 1369.3 % | 35.1 % | 126.4 % | 114004.0 % | 144.0 % | | |
| Scenario6 | 80 | 17.4 % | 20.2 % | 16.3 % | 50166.0 % | 76.9 % | | |
| Scenario5 | 70 | 8.1 % | 5.8 % | 4.8 % | 0.0 % | 10.4 % | | |
| Basis2018 | 65 | 0.0 % | 0.0 % | 0.0 % | 0.0 % | 0.0 % | | |
| Scenario2 | 60 | -3.2 % | -11.2 % | -57.3 % | 0.0 % | -14.2 % | | |
| Scenario4 | 55 | -3.2 % | -19.0 % | -65.6 % | -100.0 % | -22.5 % | | |
| Scenario1 | 50 | -6.2 % | -33.0 % | -70.7 % | -100.0 % | -32.3 % | | |
| Scenario3 | 40 | -10.7 % | -55.2 % | -87.7 % | -100.0 % | -67.9 % | | |

| Støren-Trondheim 2050 | Speed [km/h] | Dry bulk | General cargo | Fish | Thermal | Industrial goods | Timber | Wet bulk |
|---|---|---|---|---|---|---|---|---|
| Scenario8 | 100 | 31 488 | 107 164 242 | 3 497 139 | 2 761 400 | 56 503 786 | 0 | 0 |
| Scenario7 | 90 | 28 088 | 89 848 850 | 2 659 264 | 1 876 494 | 40 001 314 | 0 | 0 |
| Scenario6 | 80 | 28 088 | 80 115 782 | 2 614 714 | 35 802 | 24 764 971 | 0 | 0 |
| Scenario5 | 70 | 27 380 | 71 195 292 | 2 494 948 | 0 | 18 884 625 | 0 | 0 |
| Basis2018 | 65 | 27 380 | 66 545 349 | 2 270 333 | 0 | 16 131 932 | 0 | 0 |
| Scenario2 | 60 | 27 380 | 61 978 743 | 857 365 | 0 | 14 595 453 | 0 | 0 |
| Scenario4 | 55 | 27 380 | 58 508 152 | 737 997 | 0 | 11 513 306 | 0 | 0 |
| Scenario1 | 50 | 27 380 | 51 446 450 | 643 405 | 0 | 9 841 197 | 0 | 0 |
| Scenario3 | 40 | 24 373 | 28 786 427 | 129 981 | 0 | 4 834 080 | 0 | 0 |

| Støren-Trondheim 2050 | Speed [km/h] | Dry bulk | General cargo | Fish | Thermal | Industrial goods | Timber | Wet bulk |
|---|---|---|---|---|---|---|---|---|
| Scenario8 | 100 | 15.0 % | 61.0 % | 54.0 % | | 250.3 % | | |
| Scenario7 | 90 | 2.6 % | 35.0 % | 17.1 % | | 148.0 % | | |
| Scenario6 | 80 | 2.6 % | 20.4 % | 15.2 % | | 53.5 % | | |
| Scenario5 | 70 | 0.0 % | 7.0 % | 9.9 % | | 17.1 % | | |
| Basis2018 | 65 | 0.0 % | 0.0 % | 0.0 % | | 0.0 % | | |
| Scenario2 | 60 | 0.0 % | -6.9 % | -62.2 % | | -9.5 % | | |
| Scenario4 | 55 | 0.0 % | -12.1 % | -67.5 % | | -28.6 % | | |
| Scenario1 | 50 | 0.0 % | -22.7 % | -71.7 % | | -39.0 % | | |
| Scenario3 | 40 | -11.0 % | -56.7 % | -94.3 % | | -70.0 % | | |

# Results for Bodø-Trondheim

| Bodø-Trondheim 2018 | Speed [km/h] | Dry bulk | General cargo | Fish | Thermal | Industrial goods | Timber | Wet bulk |
|---|---|---|---|---|---|---|---|---|
| Scenario8 | 100 | 230 489 940 | 440 578 157 | 56 959 167 | 43 474 580 | 82 972 051 | 0 | 0 |
| Scenario7 | 90 | 230 489 940 | 410 732 889 | 48 244 666 | 43 168 000 | 51 400 709 | 0 | 0 |
| Scenario6 | 80 | 230 489 940 | 383 360 050 | 22 297 985 | 42 044 135 | 38 846 518 | 0 | 0 |
| Scenario5 | 70 | 230 489 940 | 331 799 397 | 12 947 916 | 39 581 288 | 28 777 136 | 0 | 0 |
| Basis2018 | 65 | 230 489 940 | 315 520 607 | 10 731 252 | 32 294 544 | 24 001 983 | 0 | 0 |
| Scenario2 | 60 | 230 489 940 | 304 298 803 | 4 204 661 | 31 975 120 | 21 487 850 | 0 | 0 |
| Scenario4 | 55 | 230 489 940 | 293 145 051 | 135 107 | 24 049 719 | 18 156 662 | 0 | 0 |
| Scenario1 | 50 | 230 489 940 | 272 786 460 | 135 107 | 23 160 070 | 15 699 379 | 0 | 0 |
| Scenario3 | 40 | 230 455 592 | 156 504 503 | 135 107 | 15 787 277 | 4 472 639 | 0 | 0 |

| Bodø-Trondheim 2018 | Speed [km/h] | Dry bulk | General cargo | Fish | Thermal | Industrial goods | Timber | Wet bulk |
|---|---|---|---|---|---|---|---|---|
| Scenario8 | 100 | 0.0 % | 39.6 % | 430.8 % | 34.6 % | 245.7 % | | |
| Scenario7 | 90 | 0.0 % | 30.2 % | 349.6 % | 33.7 % | 114.2 % | | |
| Scenario6 | 80 | 0.0 % | 21.5 % | 107.8 % | 30.2 % | 61.8 % | | |
| Scenario5 | 70 | 0.0 % | 5.2 % | 20.7 % | 22.6 % | 19.9 % | | |
| Basis2018 | 65 | 0.0 % | 0.0 % | 0.0 % | 0.0 % | 0.0 % | | |
| Scenario2 | 60 | 0.0 % | -3.6 % | -60.8 % | -1.0 % | -10.5 % | | |
| Scenario4 | 55 | 0.0 % | -7.1 % | -98.7 % | -25.5 % | -24.4 % | | |
| Scenario1 | 50 | 0.0 % | -13.5 % | -98.7 % | -28.3 % | -34.6 % | | |
| Scenario3 | 40 | 0.0 % | -50.4 % | -98.7 % | -51.1 % | -81.4 % | | |

| Bodø-Trondheim 2030 | Speed [km/h] | Dry bulk | General cargo | Fish | Thermal | Industrial goods | Timber | Wet bulk |
|---|---|---|---|---|---|---|---|---|
| Scenario8 | 100 | 270 024 468 | 455 677 544 | 27 856 418 | 61 802 271 | 240 053 062 | 0 | 0 |
| Scenario7 | 90 | 268 006 744 | 421 674 157 | 27 500 914 | 19 051 285 | 205 048 216 | 0 | 0 |
| Scenario6 | 80 | 264 087 867 | 376 966 976 | 20 469 059 | 8 536 122 | 144 061 364 | 0 | 0 |
| Scenario5 | 70 | 264 000 605 | 358 240 995 | 19 176 626 | 0 | 46 185 672 | 0 | 0 |
| Basis2018 | 65 | 263 928 450 | 349 020 228 | 11 347 881 | 0 | 34 848 876 | 0 | 0 |
| Scenario2 | 60 | 263 814 354 | 319 579 184 | 11 347 881 | 0 | 26 860 828 | 0 | 0 |
| Scenario4 | 55 | 263 814 354 | 298 065 854 | 6 722 682 | 0 | 22 532 169 | 0 | 0 |
| Scenario1 | 50 | 263 771 171 | 251 818 047 | 5 811 051 | 0 | 19 105 537 | 0 | 0 |
| Scenario3 | 40 | 263 769 107 | 183 218 419 | 1 040 360 | 0 | 8 349 456 | 0 | 0 |

| Bodø-Trondheim 2030 | Speed [km/h] | Dry bulk | General cargo | Fish | Thermal | Industrial goods | Timber | Wet bulk |
|---|---|---|---|---|---|---|---|---|
| Scenario8 | 100 | 2.3 % | 30.6 % | 145.5 % | | 588.8 % | | |
| Scenario7 | 90 | 1.5 % | 20.8 % | 142.3 % | | 488.4 % | | |
| Scenario6 | 80 | 0.1 % | 8.0 % | 80.4 % | | 313.4 % | | |
| Scenario5 | 70 | 0.0 % | 2.6 % | 69.0 % | | 32.5 % | | |
| Basis2018 | 65 | 0.0 % | 0.0 % | 0.0 % | | 0.0 % | | |
| Scenario2 | 60 | 0.0 % | -8.4 % | 0.0 % | | -22.9 % | | |
| Scenario4 | 55 | 0.0 % | -14.6 % | -40.8 % | | -35.3 % | | |
| Scenario1 | 50 | -0.1 % | -27.9 % | -48.8 % | | -45.2 % | | |
| Scenario3 | 40 | -0.1 % | -47.5 % | -90.8 % | | -76.0 % | | |

| Bodø-Trondheim 2050 | Speed [km/h] | Dry bulk | General cargo | Fish | Thermal | Industrial goods | Timber | Wet bulk |
|---|---|---|---|---|---|---|---|---|
| Scenario8 | 100 | 323 820 778 | 617 260 299 | 29 311 819 | 36 848 126 | 344 880 227 | 0 | 0 |
| Scenario7 | 90 | 323 820 778 | 536 950 473 | 19 294 736 | 24 982 059 | 239 363 716 | 0 | 0 |
| Scenario6 | 80 | 323 258 023 | 518 219 433 | 18 510 981 | 477 976 | 96 961 150 | 0 | 0 |
| Scenario5 | 70 | 323 210 563 | 491 738 380 | 17 210 098 | 0 | 44 777 118 | 0 | 0 |
| Basis2018 | 65 | 323 210 563 | 449 504 757 | 16 679 823 | 0 | 31 905 864 | 0 | 0 |
| Scenario2 | 60 | 323 056 802 | 427 656 103 | 15 938 358 | 0 | 27 938 379 | 0 | 0 |
| Scenario4 | 55 | 322 932 290 | 397 350 015 | 9 910 469 | 0 | 24 990 938 | 0 | 0 |
| Scenario1 | 50 | 322 932 290 | 334 794 144 | 1 691 368 | 0 | 20 009 974 | 0 | 0 |
| Scenario3 | 40 | 322 890 815 | 231 039 257 | 1 199 744 | 0 | 8 574 067 | 0 | 0 |

| Bodø-Trondheim 2050 | Speed [km/h] | Dry bulk | General cargo | Fish | Thermal | Industrial goods | Timber | Wet bulk |
|---|---|---|---|---|---|---|---|---|
| Scenario8 | 100 | 0.2 % | 37.3 % | 75.7 % | | 980.9 % | | |
| Scenario7 | 90 | 0.2 % | 19.5 % | 15.7 % | | 650.2 % | | |
| Scenario6 | 80 | 0.0 % | 15.3 % | 11.0 % | | 203.9 % | | |
| Scenario5 | 70 | 0.0 % | 9.4 % | 3.2 % | | 40.3 % | | |
| Basis2018 | 65 | 0.0 % | 0.0 % | 0.0 % | | 0.0 % | | |
| Scenario2 | 60 | 0.0 % | -4.9 % | -4.4 % | | -12.4 % | | |
| Scenario4 | 55 | -0.1 % | -11.6 % | -40.6 % | | -21.7 % | | |
| Scenario1 | 50 | -0.1 % | -25.5 % | -89.9 % | | -37.3 % | | |
| Scenario3 | 40 | -0.1 % | -48.6 % | -92.8 % | | -73.1 % | | |

## Results for Røros-Solør

| Røros-Solør 2018 | Speed [km/h] | Dry bulk | General cargo | Fish | Thermal | Industrial goods | Timber | Wet bulk |
|---|---|---|---|---|---|---|---|---|
| Scenario8 | 100 | 0 | 0 | 0 | 0 | 13 630 414 | 19 572 203 | 0 |
| Scenario7 | 90 | 0 | 0 | 0 | 0 | 13 630 414 | 19 529 773 | 0 |
| Scenario6 | 80 | 0 | 0 | 0 | 0 | 13 630 414 | 19 487 225 | 0 |
| Scenario5 | 70 | 0 | 0 | 0 | 0 | 13 630 414 | 19 496 191 | 0 |
| Basis2018 | 65 | 0 | 0 | 0 | 0 | 13 630 414 | 19 369 417 | 0 |
| Scenario2 | 60 | 0 | 0 | 0 | 0 | 13 630 414 | 19 074 805 | 0 |
| Scenario4 | 55 | 0 | 0 | 0 | 0 | 13 630 414 | 19 074 805 | 0 |
| Scenario1 | 50 | 0 | 0 | 0 | 0 | 13 630 414 | 18 991 758 | 0 |
| Scenario3 | 40 | 0 | 0 | 0 | 0 | 13 630 414 | 13 831 955 | 0 |

| Røros-Solør 2018 | Speed [km/h] | Dry bulk | General cargo | Fish | Thermal | Industrial goods | Timber | Wet bulk |
|---|---|---|---|---|---|---|---|---|
| Scenario8 | 100 | | | | | 0.0 % | 1.0 % | |
| Scenario7 | 90 | | | | | 0.0 % | 0.8 % | |
| Scenario6 | 80 | | | | | 0.0 % | 0.6 % | |
| Scenario5 | 70 | | | | | 0.0 % | 0.7 % | |
| Basis2018 | 65 | | | | | 0.0 % | 0.0 % | |
| Scenario2 | 60 | | | | | 0.0 % | -1.5 % | |
| Scenario4 | 55 | | | | | 0.0 % | -1.5 % | |
| Scenario1 | 50 | | | | | 0.0 % | -1.9 % | |
| Scenario3 | 40 | | | | | 0.0 % | -28.6 % | |

| Røros-Solør 2030 | Speed [km/h] | Dry bulk | General cargo | Fish | Thermal | Industrial goods | Timber | Wet bulk |
|---|---|---|---|---|---|---|---|---|
| Scenario8 | 100 | 0 | 0 | 0 | 0 | 18 134 409 | 18 436 209 | 0 |
| Scenario7 | 90 | 0 | 0 | 0 | 0 | 18 134 409 | 18 436 209 | 0 |
| Scenario6 | 80 | 0 | 0 | 0 | 0 | 18 134 409 | 18 436 209 | 0 |
| Scenario5 | 70 | 0 | 0 | 0 | 0 | 18 134 409 | 18 220 921 | 0 |
| Basis2018 | 65 | 0 | 0 | 0 | 0 | 18 134 409 | 18 220 921 | 0 |
| Scenario2 | 60 | 0 | 0 | 0 | 0 | 18 134 409 | 18 211 131 | 0 |
| Scenario4 | 55 | 0 | 0 | 0 | 0 | 18 134 409 | 18 211 131 | 0 |
| Scenario1 | 50 | 0 | 0 | 0 | 0 | 18 134 409 | 18 211 131 | 0 |
| Scenario3 | 40 | 0 | 0 | 0 | 0 | 18 134 409 | 18 202 762 | 0 |

| Røros-Solør 2030 | Speed [km/h] | Dry bulk | General cargo | Fish | Thermal | Industrial goods | Timber | Wet bulk |
|---|---|---|---|---|---|---|---|---|
| Scenario8 | 100 | | | | | 0.0 % | 1.2 % | |
| Scenario7 | 90 | | | | | 0.0 % | 1.2 % | |
| Scenario6 | 80 | | | | | 0.0 % | 1.2 % | |
| Scenario5 | 70 | | | | | 0.0 % | 0.0 % | |
| Basis2018 | 65 | | | | | 0.0 % | 0.0 % | |
| Scenario2 | 60 | | | | | 0.0 % | -0.1 % | |
| Scenario4 | 55 | | | | | 0.0 % | -0.1 % | |
| Scenario1 | 50 | | | | | 0.0 % | -0.1 % | |
| Scenario3 | 40 | | | | | 0.0 % | -0.1 % | |

| Røros-Solør 2050 | Speed [km/h] | Dry bulk | General cargo | Fish | Thermal | Industrial goods | Timber | Wet bulk |
|---|---|---|---|---|---|---|---|---|
| Scenario8 | 100 | 0 | 0 | 0 | 0 | 26 588 736 | 24 673 878 | 0 |
| Scenario7 | 90 | 0 | 0 | 0 | 0 | 26 588 736 | 24 673 878 | 0 |
| Scenario6 | 80 | 0 | 0 | 0 | 0 | 26 588 736 | 24 673 878 | 0 |
| Scenario5 | 70 | 0 | 0 | 0 | 0 | 26 588 736 | 24 665 737 | 0 |
| Basis2018 | 65 | 0 | 0 | 0 | 0 | 26 588 736 | 24 327 533 | 0 |
| Scenario2 | 60 | 0 | 0 | 0 | 0 | 26 588 736 | 24 327 533 | 0 |
| Scenario4 | 55 | 0 | 0 | 0 | 0 | 26 588 736 | 24 308 102 | 0 |
| Scenario1 | 50 | 0 | 0 | 0 | 0 | 26 588 736 | 24 336 596 | 0 |
| Scenario3 | 40 | 0 | 0 | 0 | 0 | 26 588 736 | 24 324 818 | 0 |

| Røros-Solør 2050 | Speed [km/h] | Dry bulk | General cargo | Fish | Thermal | Industrial goods | Timber | Wet bulk |
|---|---|---|---|---|---|---|---|---|
| Scenario8 | 100 | | | | | 0.0 % | 1.4 % | |
| Scenario7 | 90 | | | | | 0.0 % | 1.4 % | |
| Scenario6 | 80 | | | | | 0.0 % | 1.4 % | |
| Scenario5 | 70 | | | | | 0.0 % | 1.4 % | |
| Basis2018 | 65 | | | | | 0.0 % | 0.0 % | |
| Scenario2 | 60 | | | | | 0.0 % | 0.0 % | |
| Scenario4 | 55 | | | | | 0.0 % | -0.1 % | |
| Scenario1 | 50 | | | | | 0.0 % | 0.0 % | |
| Scenario3 | 40 | | | | | 0.0 % | 0.0 % | |

# Results for Ofotbanen

| Ofotbanen 2018 | Speed [km/h] | Dry bulk | General cargo | Fish | Thermal | Industrial goods | Timber | Wet bulk |
|---|---|---|---|---|---|---|---|---|
| Scenario8 | 100 | 782 789 984 | 16 554 948 | 27 797 | 3 109 997 | 624 725 | 0 | 0 |
| Scenario7 | 90 | 782 789 984 | 17 356 651 | 27 771 | 3 117 087 | 628 610 | 0 | 0 |
| Scenario6 | 80 | 782 789 984 | 17 947 447 | 423 172 | 3 138 712 | 876 440 | 0 | 0 |
| Scenario5 | 70 | 782 789 984 | 19 364 781 | 653 293 | 3 237 826 | 951 786 | 0 | 0 |
| Basis2018 | 65 | 782 789 984 | 19 511 572 | 646 048 | 3 237 441 | 962 284 | 0 | 0 |
| Scenario2 | 60 | 782 789 984 | 19 394 428 | 659 950 | 3 237 400 | 972 570 | 0 | 0 |
| Scenario4 | 55 | 782 789 984 | 19 097 216 | 661 368 | 3 206 097 | 989 453 | 0 | 0 |
| Scenario1 | 50 | 782 789 984 | 18 861 338 | 660 160 | 3 210 466 | 867 771 | 0 | 0 |
| Scenario3 | 40 | 782 789 984 | 18 404 060 | 603 791 | 3 334 349 | 756 561 | 0 | 0 |

| Ofotbanen 2018 | Speed [km/h] | Dry bulk | General cargo | Fish | Thermal | Industrial goods | Timber | Wet bulk |
|---|---|---|---|---|---|---|---|---|
| Scenario8 | 100 | 0.0 % | -15.2 % | -95.7 % | -3.9 % | -35.1 % | | |
| Scenario7 | 90 | 0.0 % | -11.0 % | -95.7 % | -3.7 % | -34.7 % | | |
| Scenario6 | 80 | 0.0 % | -8.0 % | -34.5 % | -3.0 % | -8.9 % | | |
| Scenario5 | 70 | 0.0 % | -0.8 % | 1.1 % | 0.0 % | -1.1 % | | |
| Basis2018 | 65 | 0.0 % | 0.0 % | 0.0 % | 0.0 % | 0.0 % | | |
| Scenario2 | 60 | 0.0 % | -0.6 % | 2.2 % | 0.0 % | 1.1 % | | |
| Scenario4 | 55 | 0.0 % | -2.1 % | 2.4 % | -1.0 % | 2.8 % | | |
| Scenario1 | 50 | 0.0 % | -3.3 % | 2.2 % | -0.8 % | -9.8 % | | |
| Scenario3 | 40 | 0.0 % | -5.7 % | -6.5 % | 3.0 % | -21.4 % | | |

| Ofotbanen 2030 | Speed [km/h] | Dry bulk | General cargo | Fish | Thermal | Industrial goods | Timber | Wet bulk |
|---|---|---|---|---|---|---|---|---|
| Scenario8 | 100 | 1 050 183 778 | 28 347 349 | 1 517 208 | 0 | 3 526 570 | 0 | 0 |
| Scenario7 | 90 | 1 050 285 669 | 27 478 096 | 1 518 313 | 0 | 3 321 331 | 0 | 0 |
| Scenario6 | 80 | 1 049 280 341 | 30 075 080 | 1 772 801 | 0 | 3 377 164 | 0 | 0 |
| Scenario5 | 70 | 1 049 250 451 | 28 360 685 | 1 776 697 | 0 | 3 566 720 | 0 | 0 |
| Basis2018 | 65 | 1 049 250 451 | 29 822 478 | 1 807 002 | 0 | 3 659 912 | 0 | 0 |
| Scenario2 | 60 | 1 049 250 451 | 28 698 061 | 1 801 307 | 0 | 3 617 897 | 0 | 0 |
| Scenario4 | 55 | 1 049 236 740 | 28 056 140 | 1 800 811 | 0 | 3 496 699 | 0 | 0 |
| Scenario1 | 50 | 1 049 165 882 | 27 431 633 | 1 720 538 | 0 | 3 320 906 | 0 | 0 |
| Scenario3 | 40 | 1 048 940 506 | 26 859 592 | 1 646 745 | 0 | 2 991 795 | 0 | 0 |

| Ofotbanen 2030 | Speed [km/h] | Dry bulk | General cargo | Fish | Thermal | Industrial goods | Timber | Wet bulk |
|---|---|---|---|---|---|---|---|---|
| Scenario8 | 100 | 0.1 % | -4.9 % | -16.0 % | | -3.6 % | | |
| Scenario7 | 90 | 0.1 % | -7.9 % | -16.0 % | | -9.3 % | | |
| Scenario6 | 80 | 0.0 % | 0.8 % | -1.9 % | | -7.7 % | | |
| Scenario5 | 70 | 0.0 % | -4.9 % | -1.7 % | | -2.5 % | | |
| Basis2018 | 65 | 0.0 % | 0.0 % | 0.0 % | | 0.0 % | | |
| Scenario2 | 60 | 0.0 % | -3.8 % | -0.3 % | | -1.1 % | | |
| Scenario4 | 55 | 0.0 % | -5.9 % | -0.3 % | | -4.5 % | | |
| Scenario1 | 50 | 0.0 % | -8.0 % | -4.8 % | | -9.3 % | | |
| Scenario3 | 40 | 0.0 % | -9.9 % | -8.9 % | | -18.3 % | | |

| Ofotbanen 2050 | Speed [km/h] | Dry bulk | General cargo | Fish | Thermal | Industrial goods | Timber | Wet bulk |
|---|---|---|---|---|---|---|---|---|
| Scenario8 | 100 | 1 129 171 694 | 41 807 064 | 2 366 630 | 0 | 4 771 371 | 0 | 0 |
| Scenario7 | 90 | 1 129 170 207 | 44 880 234 | 2 882 726 | 0 | 4 805 131 | 0 | 0 |
| Scenario6 | 80 | 1 129 118 769 | 44 381 885 | 2 881 804 | 0 | 4 737 203 | 0 | 0 |
| Scenario5 | 70 | 1 127 809 086 | 43 553 860 | 2 839 293 | 0 | 4 377 101 | 0 | 0 |
| Basis2018 | 65 | 1 127 806 406 | 43 591 898 | 2 787 786 | 0 | 4 485 939 | 0 | 0 |
| Scenario2 | 60 | 1 127 802 408 | 44 773 159 | 2 710 597 | 0 | 4 384 247 | 0 | 0 |
| Scenario4 | 55 | 1 127 795 169 | 45 303 766 | 2 682 333 | 0 | 4 221 750 | 0 | 0 |
| Scenario1 | 50 | 1 127 742 763 | 44 876 100 | 2 684 048 | 0 | 4 075 590 | 0 | 0 |
| Scenario3 | 40 | 1 127 470 796 | 39 392 401 | 2 680 887 | 0 | 3 492 336 | 0 | 0 |

| Ofotbanen 2050 | Speed [km/h] | Dry bulk | General cargo | Fish | Thermal | Industrial goods | Timber | Wet bulk |
|---|---|---|---|---|---|---|---|---|
| Scenario8 | 100 | 0.1 % | -4.1 % | -15.1 % | | 6.4 % | | |
| Scenario7 | 90 | 0.1 % | 3.0 % | 3.4 % | | 7.1 % | | |
| Scenario6 | 80 | 0.1 % | 1.8 % | 3.4 % | | 5.6 % | | |
| Scenario5 | 70 | 0.0 % | -0.1 % | 1.8 % | | -2.4 % | | |
| Basis2018 | 65 | 0.0 % | 0.0 % | 0.0 % | | 0.0 % | | |
| Scenario2 | 60 | 0.0 % | 2.7 % | -2.8 % | | -2.3 % | | |
| Scenario4 | 55 | 0.0 % | 3.9 % | -3.8 % | | -5.9 % | | |
| Scenario1 | 50 | 0.0 % | 2.9 % | -3.7 % | | -9.1 % | | |
| Scenario3 | 40 | 0.0 % | -9.6 % | -3.8 % | | -22.1 % | | |

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