LUMA-GIS Thesis nr 5

A CASE STUDY OF ROUTE SOLVING FOR OVERSIZED TRANSPORT:

– The use of GIS functionalities in transport of transformers, as part of maintaining a reliable power infrastructure.

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Abstract

Power supply is a social necessity, and will so continue to be in the near future. Therefore, safe and steady deliverance of power supply is a fundamental duty of the societies and the preparedness of the vulnerability of the infrastructures is highly prioritized.

The power supply comprises every component needed for transmission of electrical power from generation to consumption, power transformers are key components of this network, transforming electrical power to customized levels.

The aim of this master thesis was to present methods on how to improve the establishment of power transformers. More specifically, the scope of the aim was to improve the timeframe for the exchange of transformers by simplifying and improving the aspect of route planning, and thereby to generate improved transformer preparedness. This was done using Geographical Information Systems, involving the building of a multimodal network dataset and performing route calculations. The location of the study was set to southern Norway and the distance between the connector stations Sylling and Stølen. The analysis was based on information about the sea ways, landfalls, electronic road network, height, road block, weight, speed and distance. A method for effective route planning was developed and the distance Sylling-Stølen was used in a case study, where modeled and actual transport routines were compared.

The results show a difference between the actual and the modeled routes, both on duration and path, mainly due to a low focus on bridges and to inaccurate data. The overall difference in time was minor, the modeled route diverging only one hour from the actual, the difference on specific stretches were however greater, either witnessing of potential of faster transport or data which has not been adapted close enough to the actual situation.

Key words:

Network analysis, oversized transport, electrical power, obstacle, route calculation.

Sammendrag

Strømforsyning er et nødvendig gode for dagens samfunn og vil være det i fremtiden. Å sikre en trygg og stabil leveranse av strøm er en grunnleggende oppgave for samfunnet, beredskapen av den kritiske infrastruktur må derfor være høyt prioritert.

Strømforsyningen omfatter alle komponenter som er nødvendige for overføring av elektrisitet fra produsent til forbruker. Transformatorer er sentrale komponenter i strømnettet og har som oppgave å transformere strømmen til et brukertilpasset nivå.

Målet for denne masteroppgaven har vært å utvikle metoder som forbedrer prosessen rundt transformator bytte. Nærmere bestemt så har oppgaven sett på om det er mulig å redusere tiden på et transformatorbytte, ved å forenkle og utvikle ruteplanlegging. Det er et håp å generere bedre beredskap av transformatorer på denne måten. I oppgaven har det vært bygget multimodale nettverks datasett og utført rute beregninger i Geografiske informasjonssystemer. Studieområdet har omfattet Sør-Norge, nærmere bestemt strekningen mellom Sylling og Stølen. Analysen har vært basert på data om farleder, landingsplasser, elektronisk vegnett, høyde-, vekt- og farts restriksjoner, veg sperringer og ikke minst avstander. Det ble i løpet av prosjektet utviklet en metode for effektiv ruteplanlegging hvor strekningen Sylling - Stølen ble brukt som utgangspunkt. Resultatene fra den modellerte og den faktiske ruten ble til slutt sammenliknet.

Resultatene viser en differanse mellom den faktiske og den modellerte ruten, både i forhold til tidsbruk og veivalg, først og fremst grunnet et for lavt fokus på bro-attributtene og unøyaktige data. Den overordnede forskjellen i tid var liten, faktisk bare en time, differansen mellom mer spesifikke strekninger derimot var større. Resultatet beskriver at det enten er mulig å redusere den virkelige tidsbruken, eller at dataene ikke har vært tilpasset virkeligheten godt nok.

Nøkkelord:

Nettverksanalyse, overdimensjonert transport, strøm, restriksjon, rute beregninger.

Preface

This master thesis has been established on the student's wish to write about a real world case, preferably related to preparedness. Statnett SF were interested in a project based on the implementation of Geographical Information Systems (GIS) in the preparedness of transformer transport. This project has therefore been written in collaboration with Statnett SF and their subsidiary company Statnett Transport AS. The project has been written and mastered by the student, while the necessary resources have been organised by Statnett SF.

My hope for this master thesis is to reach my practical goal of developing a functional GIS-tool for the transport of oversized goods. I also wish to reach my theoretical goal which is to confirm and improve my knowledge, way of thinking and handling of GIS. Additionally I hope to raise my general knowledge of the Norwegian power supply and its organisation.

Statnett SF is a public enterprise responsible for developing and operating the Norwegian-main grid, making the ends of supply and demand meet at all times. They are moreover responsible for a safe and efficient power flow and transmission balance.

Statnett SF is placed under the Ministry of Petroleum and Energy, the regulatory authority is the Norwegian Water Resources and Energy Directorate. It is further regulated by the National State Enterprise Act (Statnett SF, 2009).

Statnett Transport AS is a transportation company which handles heavy goods of all kind, thereof transformers. All of Statnett SFs transformer transport is carried out by Statnett Transport AS. The company has been an important source of information throughout this thesis as they have hands on experience.

Acknowledgement

I would like to give a special thanks to my supervisors; Helena Eriksson for the positive and constructive response and Pål Herman Sund for challenging questions and GIS expertise.

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At last I need to thank my husband Are Shaw Waage for consideration and backing me up during this project, Hans Petter Blankholm for believing in me and my GIS-skills during earlier studies and Karen O`Brien for introducing and inspiring me to the world of GIS.

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Glossary:

Car ferry:	Seagoing vessel transporting people and vehicles. Car ferries are part of the Norwegian road network, constituting considerable parts of western Norway and to a certain extent northern Norway.
Critical infrastructure:	Installations and systems which are essential in order to keep societies' critical functions running, meeting the societies' basic needs and the population's feeling of security (Norges offentlige utredninger, 2006).
Connector station:	Node for power transmission, executed through transformers (Store norske leksikon, 2009).
County road (Fylkesvei) - F	Road administrated by the County Executive Committee (Magerøy, 2009).
Dependency	A relationship where somewhat or someone is controlled by somewhat or someone.
Elveg	The Norwegian electronical road-network, an extraction of NVDB , including geometry and some attribute information (Statens kartverk & Statens vegvesen, 2009).
European road (Europavei) - E	Administrated by NPRA and the Ministry of Transport and Communication (Magerøy, 2009).
Geographical Information Systems (GIS):	GIS are computer-based systems for the capture, storage, manipulation, display, and analysis of geographic information (Thill, 2001).
Landfall	Points were land is reached from the sea, often a harbour. In this study the landfalls are transfer stations between land and sea transport for Statnett Transport AS.
Local distribution grid	Power grid which distributes locally to the end user, 10 – 33 kV (Statnett SF, 2008).
Main grid	Highest level of power grid in Norway, 132 – 420 kV. Managed by Statnett SF (Statnett SF, 2008).
Municipal road (Kommunal veg) - K	Road administrated by the Municipal Executive Board (Magerøy, 2009).
National road (Riksveg) - R	Road administrated by the NPRA and the Ministry of Transport and Communication (Magerøy, 2009).

Norway digital	The Norwegian government's initiative to build the national geographical infrastructure. Norway digital is a working co-operation and infrastructure with reference data and thematic data (Norge digitalt - A, 2009).
Oversized transport/goods	Transport exceeding the national limits for weight, height, width and length
Preparedness	The state of being ready for something to happen.
Private road	Roads on private land (Magerøy, 2009).
Regional grid	Power grid distributing regionally, 33 – 132 kV (Statnett SF, 2008).
Risk	A combination of possible consequences and connected probabilities, or possible consequences and intrinsic insecurity (Norges offentlige utredninger, 2006).
Road standard	A collective term for all elements that classify the road quality, including everything from safety fence, hard shoulder, road marking and road surfacing to adaptation to the landscape and all sort of pollution (Monsrud, 2008).
Sea way	A dataset containing sea paths along the coast and to harbour areas (Arealis, 2002).
SOSI	Norwegian standard format for digital geographical data
Statens kartverk	National mapping & cadastre Authority
Statnett SF	Governmental party in the Norwegian power transmission. A grid system operator (Statnett SF - A, 2009).
Statnett Transport AS	A subsidiary company of Statnett SF handling transport of large goods. (Statnett Transport AS, 2009).
Transformer	An electric device consisting essentially of two or more windings wound on the same core, which by electromagnetic induction transforms electricity (Ask - B, 2009).
Transformer station	Se connector station.
Volt	Unit of measurement of electrical potential (Ask - A, 2009).
Vulnerability:	An expression for the problems a system will have when exposed to undesirable events, together with the problems resulting after the event has taken place. Vulnerability is connected to the possible loss of value (Norges offentlige utredninger, 2000).
Watt:	Unit of measurement of electrical power

Acronyms

DSB	Direktoratet for sikkerhet og beredskap (The Directorate for Civil Protection and Emergency Planning)
E	European road
F	County road
FFI	Forsvarets forskningsinstitutt (The Norwegian Defence Research Establishment)
G	Pedestrian walk
GIS	Geographical Information Systems
Gwh	Giga Watt per hour
K	Municipality road
KBO	Kraftforsyningens beredskapsorganisasjon (The preparedness organisation of the power supply)
NCA	Kystverket (The Norwegian Coastal Administration)
NOU	Norges offentlige utredninger (Norwegian Official Reports)
NPRA	Statens vegvesen (Norwegian Public Roads Administration)
NSM	Nasjonal sikkerhetsmyndighet (Norwegian National Security Authority)
NVDB	Nasjonal vegdatabank (The national road database)
NVE	Norges vassdrags- og energidirektorat (Norwegian Water Resources and Energy Directorate)
OED	Olje og energidepartementet (Ministry of Petroleum and Energy)
P	Private road
R	National road
SSB	Statistisk sentralbyrå (Statistics Norway)

1 Introduction:

Our modern society is closely related to all sorts of power. In Norway most power originates from hydroelectric power plants. The hydroelectric power is renewable and the production easily adjustable, though dependent on precipitation. Norway is blessed with a good situation when it comes to accessible power. The largest share of power consumption is domestic, and some is benefited from export.

The power consumption in Norway is increasing which is a result of both environmental aspects, such as the countries northern location with long, cold and dark winters, and social aspects, such as people's prosperity bringing materialism in its wake.

Electric power is important in all aspects of our lives. The consumption is constant and all-embracing, from an electric toothbrush and electric cooker, to heating, light, TV and power consuming industry. This power dependency involves several challenges associated with the demand to provide continuous availability and a production reflecting the consumption nearly instantaneous. To fulfil this demand, a well functioning supporting infrastructure, good management of transmission coordination, maintenance and flexible production is required. It all has to be secured through preparedness measures.

In Norway there are several parties involved in the line of; production, transmission and consumption. The party coordinating the electrical power flow through the main grid is the governmental appointed enterprise Statnett SF. As well as developing, operating and maintaining the main grid, the enterprise has a superior role of offering access to the power transmission grid on equal terms to all market participants. A heavy social burden is put on Statnett SFs hands, preparedness in all bodies has to be handled right in order to secure the needs and safety of society.

Safety and preparedness have high priority in today's society both through the population's awareness and legislation on the subject. A well-functioning society is dependent on preparedness as unforeseen incidents always take place at one time or another. To avoid as much trouble as possible even during emergency, preparedness is the tool for prevention.

Planning and preparedness is very important in all parts of the power industry and this is also reflected in the organisation of Statnett SF through for example access control, computer safety implementation, preparedness training and maintenance. Some of the preparedness transformers equipment is in stock, but when it comes to transport of this large and heavy commodity, challenges line up. The preparedness of transformer transport is a subject with improvement potential.

The "Grid owner"– division of Statnett SF has a self-imposed goal stating that; a transformer of critical importance must be dismantled, transported and connected to the power grid within a time frame of four weeks. The timeframe is challenging due to the combination of limited road capacity and a large and heavy transport unit.

The increasing demand for electric power put extra strain on power transformers. The more a transformer has to transmit and transform, the larger and heavier the physical dimensions of the transformer becomes. This implies that also the vehicle; be it a truck, railway or vessel, transporting the transformer has to be able to bear increasing loads.

The roads' carrying capacity, especially on bridges, is an ever recurring problem. This is a combination of a challenging geography and the fact that roads are dimensioned for a certain presumed pressure of daily traffic. The special road-dimensions needed for the transport of oversized goods are thereby set aside, weakening their ability to navigate.

The aim of this thesis is to develop and present a GIS tool based on network analysis, with the emphasis on simplifying the transport of oversized goods i.e. power transformers and thereby contribute to enhanced transformer preparedness. The resulting product will be developed through a case study. The objectives of the study are to:

- Find the most suitable transportation route considering factors such as height, weight, distance and speed.
- Develop a method for route solving based on oversized transport criteria.
- Create maps to ease transport of transformers, visualizing aspects of oversized transport, such as transportation routes, distribution of transformers and landfalls to easy workers and authorities ability of insight.
- Improve the timeframe of transformer transport through data structuring and route solving.

2 Background

2.1 Electrical power

This section will give an introduction to electrical power in relation to society's dependency, use and preparedness.

Electric power is important in all aspects of our lives, from an electric toothbrush and electric cooker, to heating, light and power consuming industry. The versatile use of this resource results in an enormous dependency involving difficult engagements.

The electric power in Norway is generated by different kinds of power plants, mostly hydro electrical plants, spread around the country. Most of the power generated is consumed domestic, hence due to variation in production and consumption, power is both exported and imported. In the year of 2007, 137164 GWh of power were generated, 15320 GWh were exported and 5284 GWh imported, the gross consumption being 127128 GWh (Statistisk sentralbyrå, 2009).

The electric power industry is a critical infrastructure of society. Preparedness in production, transmission and consumption, is important. In order to avoid emergency problems with power delivery and secure people's safety, preparedness is on the agenda.

2.1.1 The power grid

The national transmission grid provides the infrastructure connecting producer and consumer in relation to power. It consists of three hierarchical levels; the main-, the regional- and the local distribution grid. Public authorities at different administrative levels are in control of about 85% of the transmission grid, private parties control the other 15%.

The local distribution grid is operated by about 130 grid owners, each responsible for a certain geographical area delegated through concession. The grid operates on a voltage level spanning from 33 kV and downwards and is connected to the end user, the consumer, on different voltage levels (Norges offentlige utredninger, 2006), see figure 1.

The regional grid is operated by about 80 different owners. It is connected to the main and local distribution grid and operates on a voltage level of 33 – 132 kV.

The main grid is operated solely by the governmental enterprise Statnett SF. Statnett SF owns approximately 90 percent of the main grid and leases the remaining power installations. The power lines are interconnected, constituting a grid which makes diverse transmission routes of power possible. The grid is strengthened to a dissimilar degree throughout the country. In populated areas in the eastern regions, the grid is denser than in the northernmost sparsely settled county of Finnmark. The main grids voltage level spans from 132 – 420 kV (Fridheim et al., 2001).

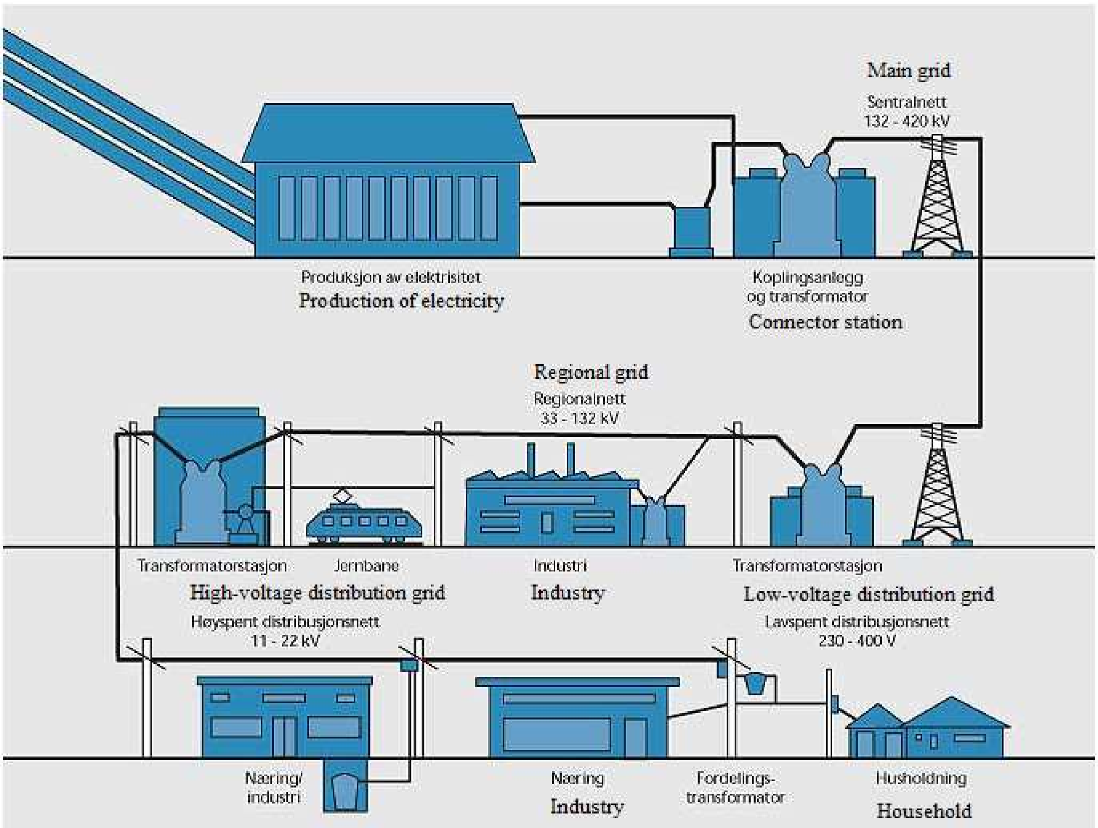


Figure 1: The line of electrical power from producer to consumer. Source: Skaansar, 2009.

In order for electricity to reach the consumer, be it a normal household or a large factory, the power in most cases has to transverse the whole hierarchy of power grids. To minimize physical power loss in the transmission grid, it is advantageous to operate with high voltage levels on longer distances. The distribution of power from generation via transmission, to consumption therefore requires both step-up and step-down transformation, the latter being the most common. The transformation process is conducted gradually in the grid hierarchy, from main-, regional- to local grid or the other way around. The process of transformation is performed by transformers in connector stations (Statnett SF - A, 2009).

2.1.2 Production and consumption

The balance between production and consumption of electricity varies from year to year. It all depends on natural variations in precipitation, snow melting and wind conditions, as well as the domestic consumption. Transmission capacity and the profitability in export and import play additionally a role.

When making use of an electrical device, for example a washing machine consuming 1kWh for each laundry, a commodity and a service has been utilized. The used commodity is electricity and the used commodity service is the transportation of electricity from the producer to the household. The awareness of this relation is at times forgotten as electricity is a natural part of our lives. The fact is however that an average household consumes 20 000 kWh every year, whereas an industry customer of medium size has an estimated yearly consumption of 160 GWh. The power generation and distribution industries combined, comprise some of the largest electricity consumption of the country (Skaansar, 2009).

The overall balance between production and consumption in Norway is good, although it fluctuates from year to year, see figure 4. On average, between 1997 – 2007, the production was 123604 GWh, the gross consumption 121655 GWh , the import 8064 GWh and the export 10013 GWh (Statistisk sentralbyrå, 2009).

As displayed in figure 2, the electricity in Norway is generated from four sources; hydroelectric power, wind power, gas and thermal power. The hydroelectric power dominates the production entirely with a share of 99%. Wind power produces at the present time 0,7 %, while gas and thermal power are in charge of the small remaining electric production (Fornybar, 2009).

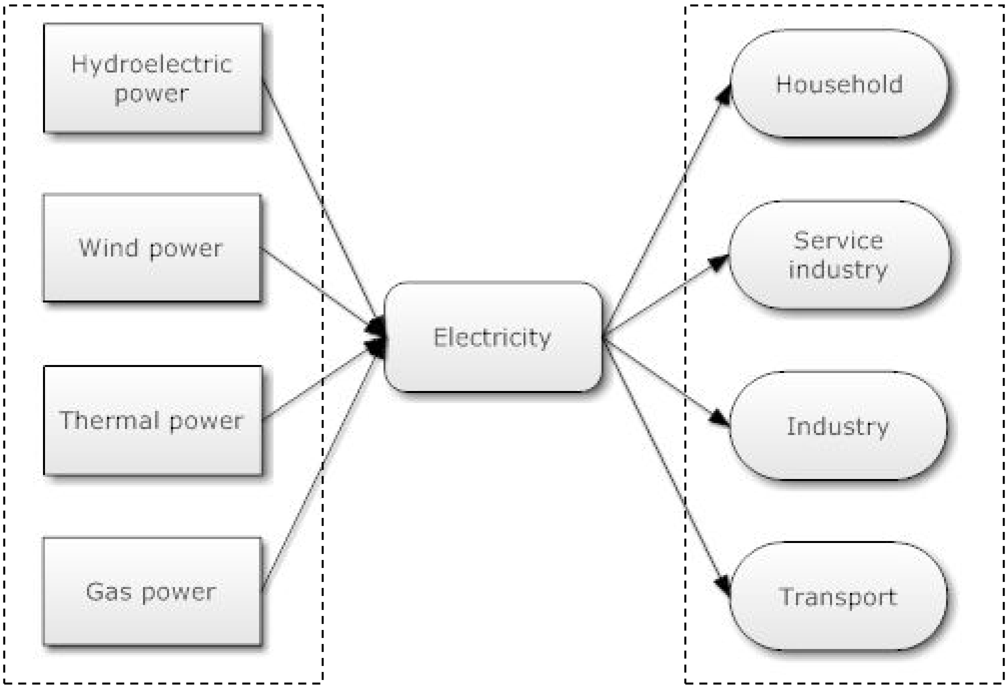


Figure 2: The electrical energy system. The figure is based on information from Skaansar, 2009.

Energy stored in water reservoirs or rivers is generated to electrical energy in hydroelectric power plants. The generation is heavily dependent on inflowing water from drainage basins, filling rivers and reservoirs. Precipitation varies from place to place and throughout the season. During winter, for example, large quantities of water are stored in snow covers, and are first released at the melt off in spring. Hydroelectric power production is fortunate due to the possibility of storing energy by containing water in reservoirs. At low consumption and high inflow the reservoirs are filled, and at times with low inflow and high consumption, they are drained down. The only loss of energy by storing water is evaporation. This factor has to be calculated in relation to the profit of storing (Fornybar, 2009).

Norway is fortunate to have plenty of water resources. The production of hydroelectricity is, as a rule, enough to serve the population. Nevertheless, this production is at the mercy of weather conditions. The production as well as reservoir filling therefore fluctuates somewhat from year to year. In the year of 2000 the production was extremely high in conformity with the availability of water, represented by the filling of water reservoirs. The year of 2003 on the other hand, seemed to experience the opposite, see figure 3 and 4.

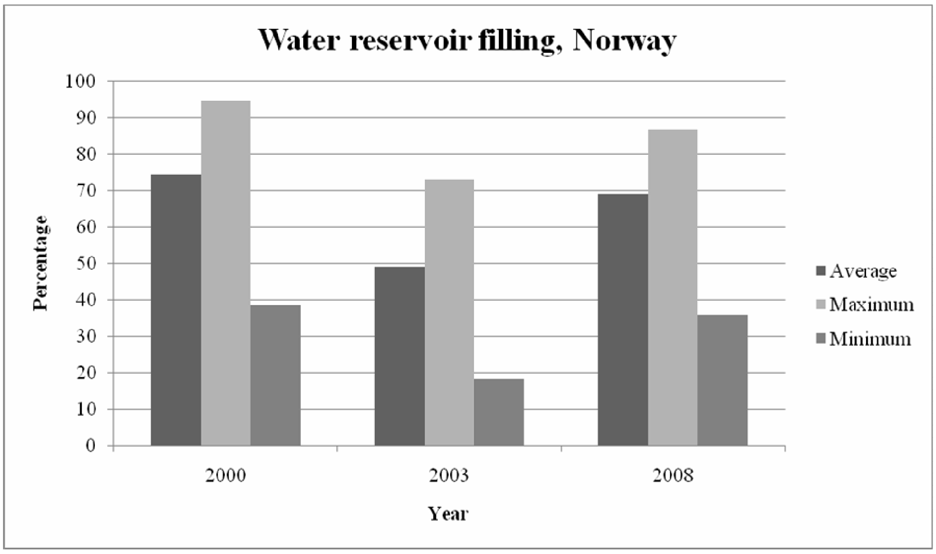


Figure 3: Water reservoir filling in Norway, percentage of the total amount of water stored in water reservoirs. Maximum = highest percent of filling, minimum = lowest percent of filling during the respective year. The figure is based on information from Norges vassdrags- og energidirektorat - A, 2009.

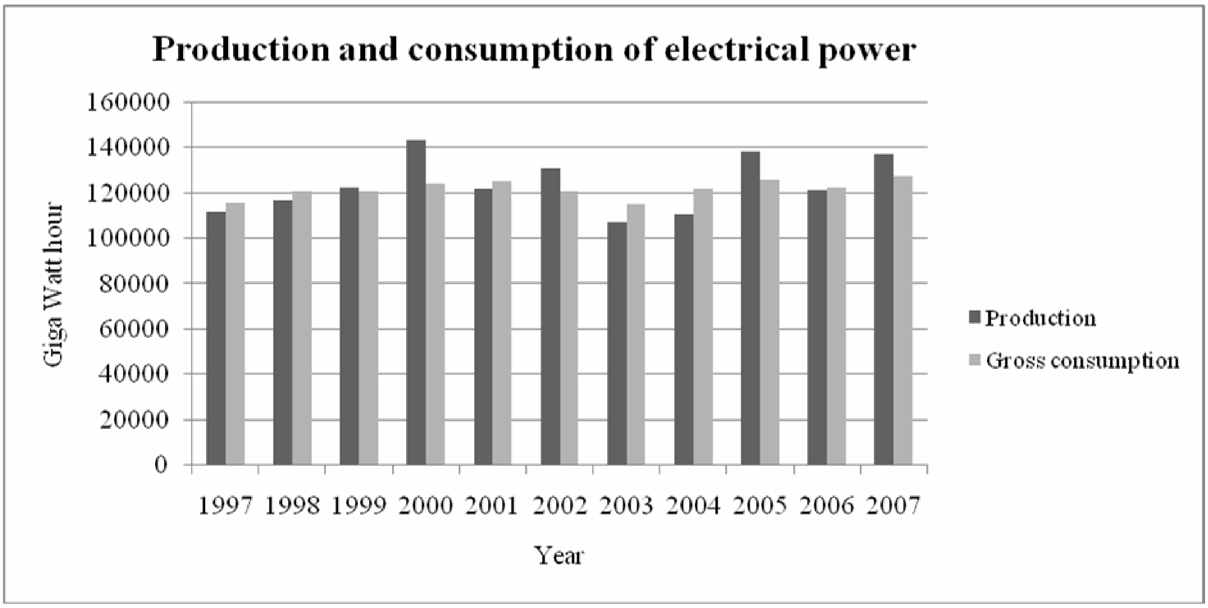
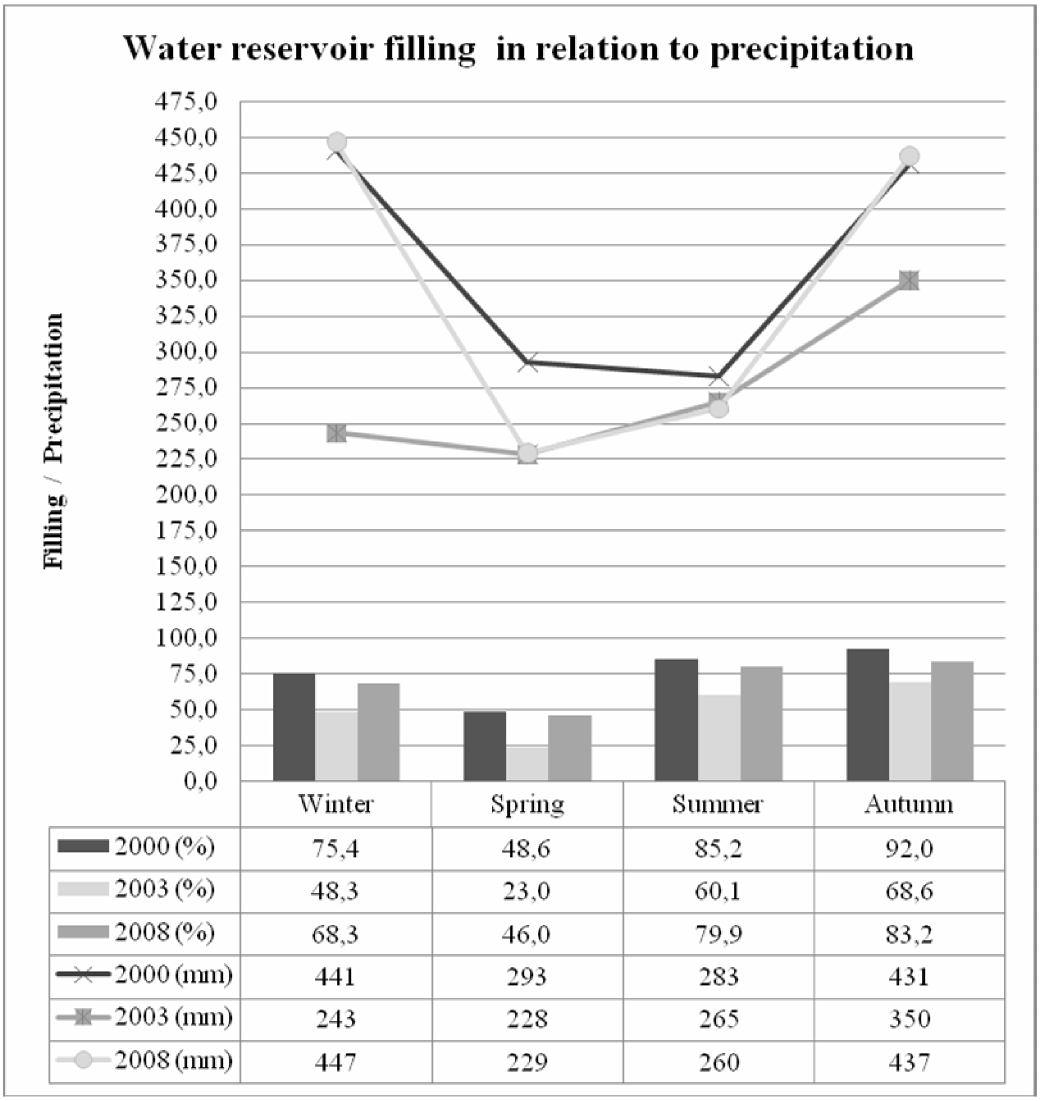


Figure 4: Production and consumption of electrical power. The figure is based on information from Statistisk sentralbyrå, 2009.

Precipitation function as the basis of water reservoir filling and it is therefore one of the most important factors regarding hydroelectric power production. The precipitation is generally higher during the winter and autumn, while less during the spring season, see figure 5. In the year of 2003, the precipitation was relatively low (243 mm.). This was reflected in the degree of filling, as well as the production.

A relation between precipitation and filling can be observed. The filling rises when precipitation rises. Another fact worth noting is that the filling during the spring is rather low compared to the winter. This can be explained by the delay of process. During summer the reservoirs are filled due to precipitation, but first and foremost because of the snow melting in higher areas. When autumn comes the reservoirs are already filled, hitting its peak with the additional autumn rain. In the winter season the reservoirs experience precipitation, but a large share of this is bound up as snow and ice, explaining the decrease in filling. Spring is both dry and relatively cold, no melting and no precipitation leads to further draining. The melting speeds up during summer, filling up the reservoirs again.



	Winter	Spring	Summer	Autumn
2000 (%)	75,4	48,6	85,2	92,0
2003 (%)	48,3	23,0	60,1	68,6
2008 (%)	68,3	46,0	79,9	83,2
2000 (mm)	441	293	283	431
2003 (mm)	243	228	265	350
2008 (mm)	447	229	260	437

Figure 5: Water reservoir filling in relation to precipitation. Winter = December to February, spring = March to May, summer = June to August and autumn = September to November. The figure is based on information from Statistisk sentralbyrå, 2009; Norges vassdrags- og energidirektorat - A , 2009.

Wind and hydroelectric power complement each other well. This is because water can be stored when it blows and wind power is produced. In that respect water power does complement all other kinds of power production (Norges vassdrags- og energidirektorat - b, 2009). Wind power is a very vulnerable form of energy production as the amount of wind is hard to influence. It is furthermore important that there is wind, but not too strong. Nevertheless with such a long coast as Norway, good spots for windmills are relatively easy to find and the production can therefore be quite stable.

Wind is transformed to electricity in wind power stations, mostly windmills. Wind based energy is a renewable and environmental friendly form of energy, it is therefore also becoming very popular kind of electrical production, minding the fact that nobody wants to be neighbour to a windmill. Many wind power projects are planned and several are developed. The take-off in wind power, however, is highly dependent on the government. Wind power is not yet commercially profitable, and therefore relies on governmental assistance.

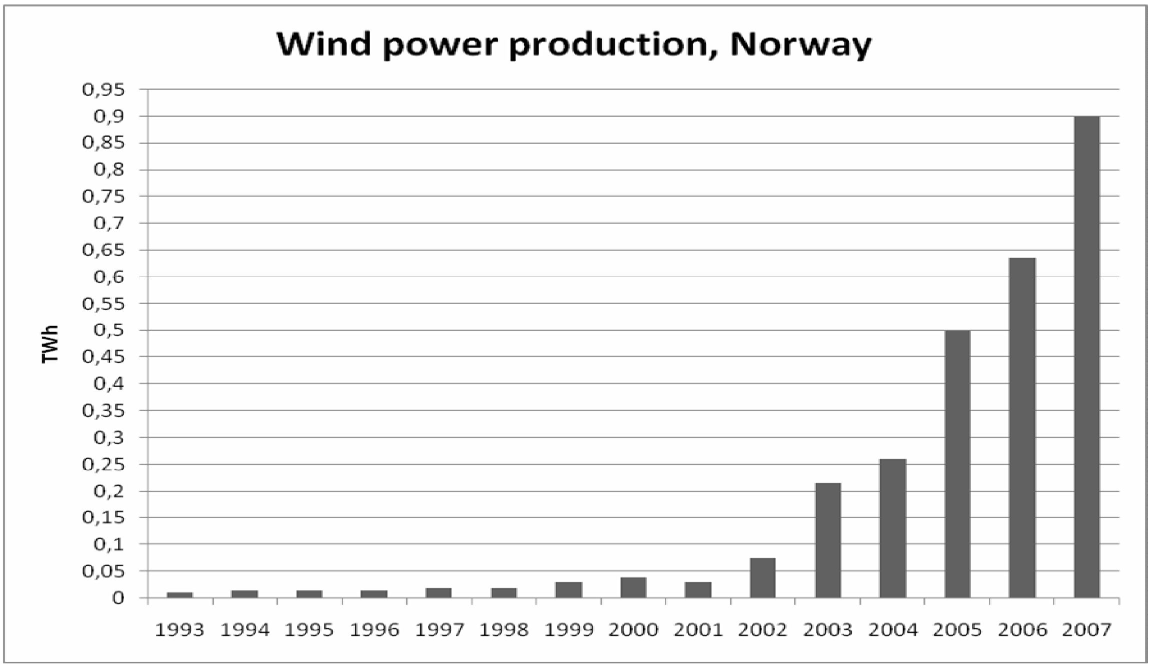


Figure 6: The increase of wind power production in Norway, 1993 to 2007. The figure is based on information from Skaansar, 2009, cited in SSB .

Production of electrical energy from gas accounts for a very small amount of the total production in Norway. Norway produces much gas, the share going to electricity production is surprisingly low. Natural gas is first of all utilized in industry, hence also as fuel in gasworks for production of energy, besides international export.

Thermal power production has so far constituted less than one percent of the total electric power production. The amount will however increase in the future as planned projects are commissioned. Most of these are located and owned by large industries which utilize the electricity produced for own consumption. The resources used in thermal power production are amongst others municipal waste, industrial waste, waste heat, oil, natural gas and coal. As distinct from the continental part of Norway all power on Spitsbergen is produced by thermal power. This is due to the amount of coal resources found and exploited there (Skaansar, 2009).

Power consumption in Norway and the neighbouring countries is increasing. In addition power export is a lucrative business. This makes the need for development of the power industry and the power grid an important challenge at present and for the future. Norway holds a valuable position compared to many other countries. While many countries production rely on difficult regulative nuclear- or coal power plants, Norway is able to store energy in water reservoirs. Norway has therefore the advantage of being able to export power at a high price during the day when business is running in Europe, and importing during the night when Europe is sleeping and prices are low. This trading of electricity gives considerable profit both economically and environmentally. With the rising consumption however, more power plants have to be evolved which is a challenge for Norway, as most of the available water resources are already developed (Fornybar, 2009).

2.1.3 The condition of the power grid

Power withdrawal is increasing and, despite some fluctuation, has been doing so the last ten years. The production and transmission capacity however has not been developed correspondingly, implicating more severe pressure on the existing industry. The challenge is therefore of renewing the industry, especially the power grid, at a fast enough pace. In fact the other Nordic countries experience the same trend, making the situation even more delicate (Olje- og energidepartementet, 2001).

It is claimed that the power grid's ability of withstanding heavy strain is weakened because of worn-out equipment which has been exploited past over its intended usage. The trend towards extreme efficiency and cost reduction, at the sacrifice of grid development, is put forward as the main reason. This is furthermore seen as a result of the deregulation of the power market, both in Norway, but especially internationally (Fridheim et al., 2001). The Directorate for Civil Protection and Emergency Planning (DSB) questions whether the power industry has come to an intersection between efficient use of the infrastructure and operational reliability (Norges offentlige utredninger, 2006). DSB has for many years focused on increased safety in the power industry, which unfortunately has resulted in a higher grid-lease. The work has however been in discrepancy with the Norwegian Water Resources and Energy Directorate's (NVE) focus on a more efficient power industry, intended to decrease the costs for the companies and protect the customers. Although DSB and NVE are communicating well, this disagreement does illustrate that not only is the market split in the question of safety versus profit, but likewise governmental institutions.

The condition of the grid in Norway is in a most diverging state, while the main grid operated by Statnett SF is in overall good condition, the local grid is worse off, according to the assistant director general Suhrke in DSB (Energibedriftenes landsforening, 2005 cited in aftenposten). This is because maintenance becomes postponed and the operating time of the components thereby strained, leading to older and more worn-down installations and reduced security (Fridheim et al., 2001).

A renewal rate of 2006 would give a renewal of the whole Norwegian power grid in 100-200 years. In contrast, the genuine operating time of a component is only 35 – 70 years. The situation of the power grid is not precarious at the moment, but it may soon develop to bee if the renewal rate continues to be lower than the components operating time (Bysveen, 2006). However, Suhrke (Energibedriftenes landsforening, 2005 cited in Aftenposten) also state that while maintenance has been poor, the power disruptions have been fewer. This may either indicate better technology and more efficient working routines, or a quantity of good luck which at any moment may result in a “Big Bang” and an intolerable grid situation. A good objective is regardless of the correct theory of the condition of the power grid, to keep the present standard of delivered energy, which in 2006 was 99,985 % of the total electric consumption (Bysveen, 2006).

2.1.4 Investments in the power grid

The power grid provides the whole country with electrical power. Nevertheless the investment in the power grid has been at an all time low during the nineteen nineties, especially the main- and regional grid. The local distribution grid displays a better result in figure 7, but this may also be due to large isolated projects and does not necessarily represent the overall investment. The overall investment has only increased over the last few years, from a total investment of 2729 million Norwegian kroner (NOK) in 2000 to 3762 million NOK in 2006. If the general investment is reflected in the investment of Statnett SF, the upgrading of the power grid will continue the next decade from an historical high investment the last couple of years (Lie, 2009). The power industry has presumably realized that investment is necessary with increased utilization and that preventive action will give a competitive advantage to other parties (Østby et al., 2000).

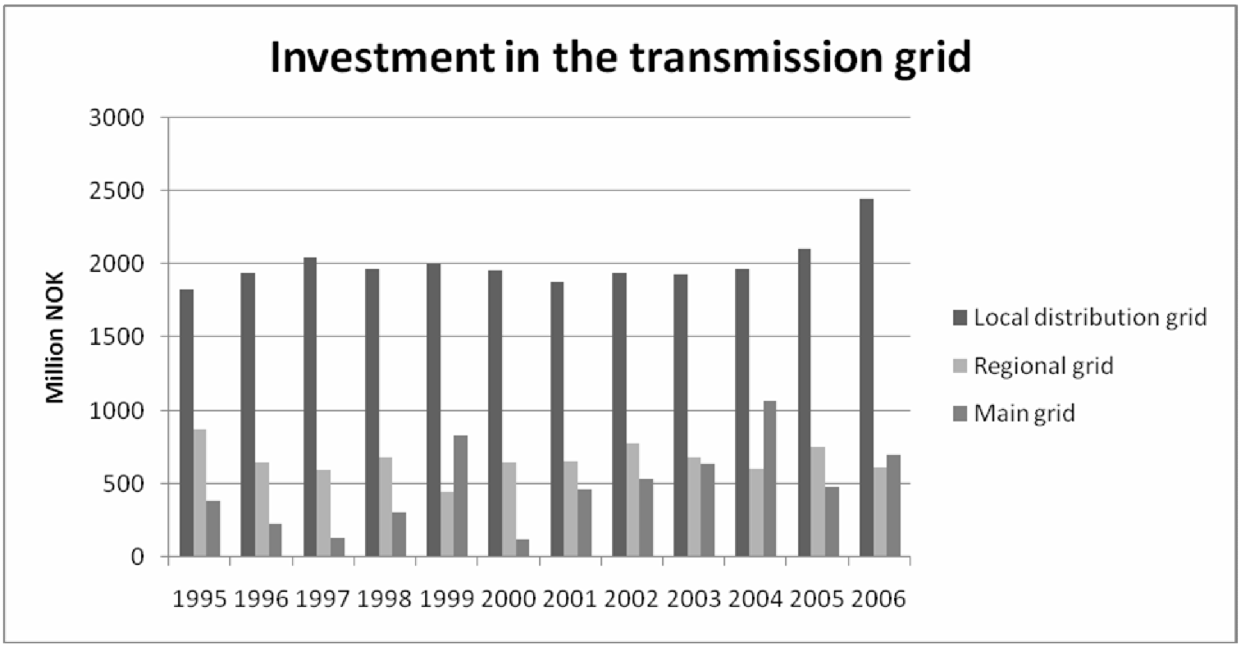


Figure 7: Investment in the power grid, 1995 to 2006, presented by grid level. Source: Norges vassdrags- og energidirektorat – A, 2009.

It would be expensive for society to operate parallel grids, therefore grid distribution and ownership is organised in companies which have a monopoly in their management domains delegated by concession. The grid owners are controlled by the authorities mainly through the energy law (Olje- og energidepartementet, 2009).

Through the regulation of income and the KILE-arrangement (Kvalitetsjusterte Inntektsrammer ved ikke-Levert Energi / Quality adjusted income limits of non-delivered energy), the grid owner’s income is reflected by the conditions of for example climate and topography in their management area, and their own actions in maintaining and developing the grid. The income limits are based on how rational and efficiently the grid is operated and how good the quality and safety of supply is maintained. NVE determines the limits such that revenues over time will cover the costs of deprecation and operation of the grid, as well as providing a reasonable return on the invested capital given efficiency, utilization and development of the grid (Skaansar, 2009). The regulation is meant to contribute to protecting the customers from being overcharged and also as an incentive meant to motivate companies to use their income on grid development (Fridheim et al., 2001).

Naturally the investment in the grid system also depends on the interest and social responsibility of the owner. In years with little investment the profit is transferred to the owner. How much resources that are transferred back when investment is needed is however an unanswered question (Energibedriftenes landsforening, 2005, cited in aftenposten).

Future obstacles that face the power grid are somewhat uncertain. That more investment is needed at present is known, however what climate changes will lead to is of a more uncertain matter. A common theory is that more energy will be available in the weather system; warmer, rougher and wetter weather is expected. How these consequences will influence the power industry is however not determined. On the one hand both wind and water resources may increase, on the other hand power installations may be exposed to heavier wind, flooding and snow weight than they are dimensioned for (Norges vassdrags- og energidirektorat - B, 2009). If the latter is the case even more measures have to be taken in order to secure a good power grid.

2.1.5 Preparedness measures

The operability of society is highly dependent on a range of physical and technical infrastructures. Electrical power is the basic energy for an amazingly number of these infrastructures and is a very critical infrastructure in itself. A serious power failure will lead to a society not capable of maintaining the supply of goods and services which people rely and are dependent on. The population’s basic needs are set to a test and the feeling of safety is more or less lost (Norges offentlige utredninger, 2006).

To avoid or moderate a failure of critical infrastructure, preparedness is crucial. Preparedness is put on the agenda in today's Norwegian society and different measures have been and are taken to secure stability and safety of critical infrastructure. According to the committee appointed for the consideration of Norway’s safety in 2006, the power industry has come a long way in relation to preparedness (Norges offentlige utredninger, 2006). There is always potential for improvement in relation to preparedness, hence the awareness and the focus in this industry is comprehensive.

In the following section preparedness measures are presented based on the organisation of Statnett SF.

Statnett SF is obligated through the Energy Law to deliver electricity with given quality requirements. In order to comply with the directives, security of supply has to be satisfying. It is intolerable for society and extremely expensive if an area was out of electricity with every power failure. The security of supply has therefore been organised in a back-up system called N-1. N-1 implies that the grid must be able to bear a failure at all times. The system is organised such that load limits are calculated for the grid every day, the grid is split into different power corridors where different lines are able to take over the load of a failing line, avoiding sequential errors. The main grid is a mesh-type network and redistribution is therefore always possible as long as the calculations and corridors are set up right (Statnett SF - B, 2009).

The grid is widely developed and extra strengthened around densely populated areas, for example in the eastern part of Norway. Redistribution will as follows be more easily implemented there.

The power supply system is a so called “just in time” system which adapts production to consumption. This implies that the transport of power through the grid is regulated continuously (Fridheim et al., 2001). The main control centre is responsible for distributing the power produced in the grid such that the load limits are complied with. If work has to be performed on a power line, disconnection is necessary and the safety measures may deviate from the N-1 rule (Bakke, 2009).

Statnett SF as the operator of the main grid has a superior goal that no end-user shall be struck by a continuous power failure for more than two hours by their grid. This is connected with the rule of N-1. Although the installation might be damaged and have to be repaired, which can easily take more than two hours, internal re-linking between the power corridors contains any further power surge to the customer. This implies that the time the operator has, in which to get hold of the situation, is two hours (Statnett SF- A, 2009).

In Norway, the main grid is operated by a public enterprise, Statnett SF. By assuring public ownership or sufficient public shares in the power grid Norwegian interests are taken care of. As there is a lack of adequate economical and juridical regulating mechanisms to keep the socio-economic investment to the grid, the public ownership is probably a good instrument to consolidate grid safety. This secures that the population’s interests are met; it assures that critical infrastructure is national in the case of an international conflict, and it assures that preparedness, safety and suitable dimensioning is given preference as opposed to profit (Norges offentlige utredninger, 2006).

The most obvious preparedness measure to take, to secure the main grid, is probably to keep enough preparedness material and good preparedness routines. Friedheim et al., (2001), recommend that the power supply should be secured through action which reduces vulnerability, in other words, by preventive measures. This includes protection of the IT-systems, concentrating on personnel and competence and bettering chances of re-establishment and repair. Important objects must be protected by surveillance, and critical system control centres located inside mountains.

In Statnett SF most of the recommendations listed above are pursued. The IT-systems are secured by strict rules, workers have to sign a declaration of confidentiality, relevant training and equipment is given to the staff amongst others through the Kraftforsyningens beredskapsorganisasjon (KBO), preparedness equipment and vessels are available and surveillance projects are introduced (Statnett SF, 2009).

Safety and preparedness would be further improved if more main grid installations were placed under ground or in mountains. The security of these centres is naturally high, but due to their location they are not protected against special threats.

2.1.6 Power dependency & social consequences of power failure

There is a close connection between the use of energy and a country's prosperity. The use of energy increases with the economical growth as a result of higher demands for goods and services, and thereby electricity (Olje- og energidepartementet, 2001). Welfare in Norway is high which implies added demands for comfort, such as more technical equipment and larger housing. A natural consequence of this together with a changing population composition, towards a rising proportion of one person homes, all results in a higher energy consumption and thereby dependency (Fridheim et al., 2001). Dependency is so high that availability is expected at all times. This availability however is no matter of course and it is neither technically nor economically possible to guarantee one hundred percent against power failure. (Olje- og energidepartementet, 2001; Energibedriftenes landsforening, 2005).

Different fields of society are mutually dependent. If one function fails, it may result in consequences for others. A good example is the mutual dependency between the telecommunication and the energy sector. Electronical payment, the most common means of payment now-a-day, grinds to a halt as transactions need telecommunication and telecommunication needs power (Fridheim et al., 2001). This complexity affects all parts of society in one way or another. Consequences of one failure, especially if it occurs in a critical infrastructure, typically develop further into other failures along the way.

There is always a consequence to a power failure, as short as it may be. Some consequences will occur on all failure occasions; whereas others first emerge after several days or weeks. In general is a *power failure defined as a state, characterised by failed delivery of electrical energy to one or several end-users, were the supplied voltage is less than one percent of the agreed voltage level. Furthermore are failures classified as short- and long lasting failures with duration of respectively three minutes and longer than three minutes* (Skaansar, 2009). Consequently a long lasting power failure is set to be more than three minutes. A long failure however usually lasts no longer than some hours at the most, on average 2,5 hours (Sveaas, 2009).

The power failures presented in this section represent extensive failures of days or weeks that do occur, if not very often. These long term failures are actually most interesting to observe as problems and challenges, both socially and economically, become so clear.

Some of the most important challenges connected to first and foremost long term power failure are listed below:

- Household:
    - All light and heating based on electrical power stop functioning
    - Electric cookers, automatic kettles and hot water tanks are not able to heat water or food. At the same time storing of food in freezers and refrigerators is difficult. This can lead to health problems due to unhygienic preparation of food and lack of cleanliness.
    - Communication through computers or phones will end when the battery gets low and re-charging power is unavailable.
- Company:
    - Security systems, electrical locks and control systems stop functioning. Additionally may machinery be broken because there is no time for shutting down procedures
    - Production time and working hours are lost due to computers or production machines dependency of power.
    - Livestock may have to be rescued, either due to hot or cold buildings, or because equipment, such as milking machines, do not work.
- Society:
    - Some people in society, such as security, health and service workers, are important during emergency. These groups will experience heavy pressure and overtime work.
    - Short supply of cash and unavailable banking services will halt business or even lead to bankruptcy of businesses.

- There will be a need for hotels and shelters where people in need can seek help. Fight over the available resources may occur and at the same time may the crime rate rise due to empty and unsecured houses and offices.

- Death occurs, however normally because of side-effects of the power loss, such as food poisoning, freezing to death or accidents in relation to machinery failure.

(Fridheim et al., 2001; Henriksen, 2001)

A short presentation of consequences of power loss, based on time periods, based on Henriksen, (2001):

One week: That the electricity is lost for up to one week may occur in connection with the storm period during autumn and winter. Human life is seldom lost, the economical consequences are relatively high and normal society procedures come to a stop. The problems occurring are normally of an acute nature and seldom long lasting.

One month: Long lasting consequences for society is present. The geographical extent however is here of importance. Adaptation to the situation will make all the difference and much of society can function close to normal even with limited power resources. Hence, to cope with this situation, resource demanding companies have to move out of the area for some time to establish elsewhere. This may lead to permanent consequences for the local economy.

One year: Except from the first time period, acute situations are not common. Solutions to problems are found and things are handled based on provisional solutions. The stricken area will however be thrown back in time because of abandonment of companies and all economical business, either caused by relocation or by bankruptcy.

2.1.7 Social handling of power loss

In connection with a power failure the preparedness, cooperation and organisation of society at all levels is put to the test. A short power failure is mostly not spoken of, maybe some data on the computer which had not been saved is lost, or a dinner is eaten cold, however people do manage to cope and bear the cost. Indeed most people manage without extensive assistance, even in cases of longer failures of a day or two (Fridheim et al., 2001).

If the power failure is not complete, or if it is possible to re-connect some of the power supply, one solution is to have fixed hours a day where a given zone gets power supply. All activity such as business, showering, cooking and so on, has to be within this timeframe, before the power is disconnected and re-directed to another zone. Other solutions are either to supply the most needy people and industry, or to supply everybody under the condition that power must be economized. Certain activities are thereby limited, for example showering, floor heating, or street lighting.

Society has many possibilities to stand together and find solutions, and luckily human lives are seldom lost due to power loss. (Henriksen, 2001).

2.1.8 Stress and strain of the power grid

What kind of standard the power grid ought to have is a trade-off between probable future scenarios and the will to invest in safety. As a minimum a grid needs to have a standard able to operate during average conditions, moreover the question is whether the grid additionally should be dimensioned to withstand extreme icing, storms, 50-years flooding or even terror attacks.

The security situation is today predominantly positive. Europe is a stable region, both politically and military. Russia is experiencing quite a positive development, and the country constitutes per today no immediate military threat to Norway. Although the situation may change quickly, the chance of an extensive attack on Norwegian territory in the foreseeable future is low. Limited attacks however are more likely to take place.

The power industry is a critical infrastructure and as such an attractive goal of terror. The Norwegian power industry is fortunate in that respect that the production of power is spread across the country. Attacks intended to do extensive damage are therefore complicated as several power stations or plants need to be hit in order to de-energize large areas. If only one station or plant be hit, the production and transmission is able to re-organise (Fridheim et al., 2001).

Weather is a natural strain which the power grid on all hierarchical levels must be dimensioned for. The grid is however not dimensioned to withstand the stress of future climatic scenarios. More extreme precipitation and wind, as well as faster changing temperature during winter, thus causing heavier ice loads, are predicted. A danger emerging out of this prediction is the rise in damaged electronic components, which furthermore leads to more frequent power failure. Additionally it is likely that the ability to navigate, and thereby the possibility of executing fast emergency repair work, becomes difficult as the communication sector is considered especially vulnerable to climate change (Justis- og politidepartementet, 2002; Norges offentlige utredninger, 2006).

The scenarios described in this section will inflict extremely much stress and strain on society if they should take place. To reduce the consequences of destructive incidents, society's security has to be safeguarded (Norges offentlige utredninger, 2006). That is managed through the Norwegian principle of "Totalforsvaret", which is based on division of responsibility. It involves public as well as private institutions, and other important social enterprises which are all instructed to maintain their peacetime activity as long as possible, irrespective of the cause of emergency, be it a military attack, a natural disaster or human mistakes (Østby et al., 2000). The bottom line is that co-operation and communication at all levels of society is important, especially during extraordinary situations.

The challenges presented in this section are to be taken seriously, nevertheless they are so extraordinary in their own ways that they are not further included in this study.

2.2 Power transformers

A power transformer is a fundamental element of the power grid transforming the electric voltage both up and down, adapting the energy for different usage.

The required time-frame of a transformer replacement is set to 40 days in the enterprise Statnett SF. This time-frame might seem quite liberal, but is in fact hard to keep. This is due to a comprehensive process were several thousand litres of oil have to be bled off, the transformer has to be dismantled and transported before it is set up again and connected. The transformers covered in this study are of large dimension, the weight is around 250 tons, the height between 4,5 – 5 meters and the length about eight meters (72 meters including trailer and truck), making all handling challenging (Nordskog, 2009).

The time frame of 40 days is set with the premise that a back-up transformer actually exists. To order, build and ship a new transformer is likely to take months or even years. Preparedness planning becomes even more important in that respect.

2.2.1 What a transformer is and how it works

A transformer is an electric device designed to transform and transfer electric current from one system to another, made possible through electromagnetic induction. In it’s most simple form a transformer consists of two (or more) separate windings on the same core, usually iron. The two circuits are named the primary and secondary winding and they are respectively connected to the inlet and outlet of power from the power grid.

When a circuit becomes connected to voltage a current starts flowing. The current forms a magnetic field which in turn induces voltage in the winding. Induction of voltage in a secondary winding caused by change in the magnetic field in the primary winding is the process named “the transformer principle”. The outgoing voltage is in proportion to the incoming voltage if the windings are of the same size. If the windings are of different sizes the voltage changes. In the case where the secondary winding has less turns than the primary, the outgoing voltage is lower than that coming in. The effect stays nevertheless the same, except for some loss of heat. This implies that when the voltage decreases the current intensity or amperage increases (Strømme & Alvestad, 1997; Ask - B, 2009).

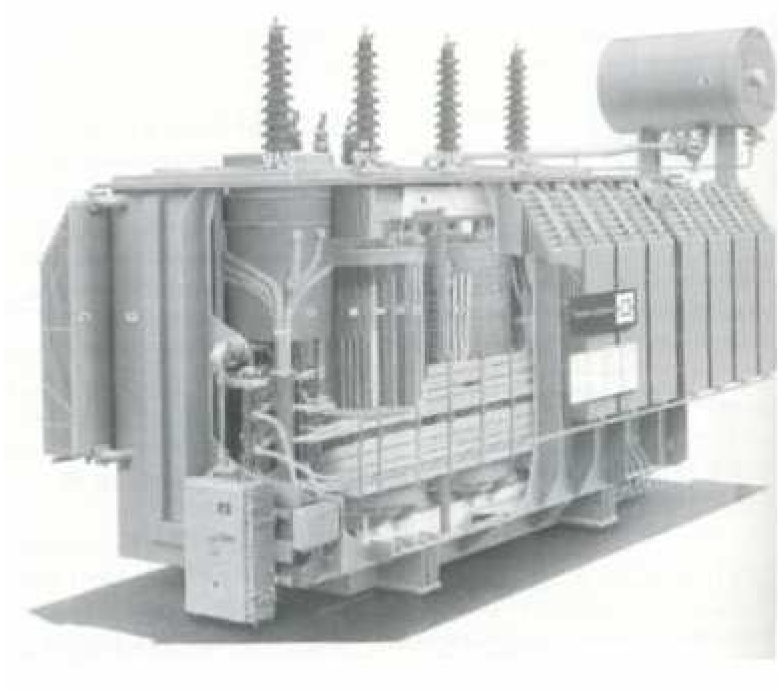


Figure 8: Example of an oil transformer. Source: Strømme & Alvestad, 1997.

2.2.2 Transformers natural challenges

As the power consumption in society rises higher pressure on the grid generates heat. This implies that the frequency of maintenance and attendance needs to be intensified in order to avoid breakdown. The breakdown of one transformer is usually backed up by a reorganization of the power flow in the system. Such an incidence nevertheless weakens the supply and makes the system more vulnerable. To be aware of the challenging elements of a transformer is preferable in order to incorporate relevant safety systems.

Transformers suffer from both iron loss and copper loss. In simple terms this means that heat is lost. The iron loss is relatively constant, whereas the copper loss varies in relation to the power charge. Heat may break the transformer directly and indirectly, directly by over-heating and short-circuiting and indirectly by heating of the oil inside the transformer.

The heat produced is conducted away by surface increase, the sink and pipe constructions are cooled down by natural air current or aeration. Furthermore the transformer is secured through expansion tanks, thus avoiding leakage and high pressure. The expansion tank absorbs redundant, warm and expanded oil and leads it back when it is cooled and contracted.

Gasification caused by leakage or other errors is another challenge. Most transformers hold a system called “sudden pressure relay” (Bucholtz relay) to secure against this problem. The pressure relay alerts the system about gasification and disconnects the transformer if errors are discovered. The problem leads to a power failure, but protects the transformer unit and the system against overvoltage or more severe problems like explosions (Strømme & Alvstad, 1997).

Transformer maintenance is undertaken to avoid break down. By physical inspections one will be able to inspect the elements, take oil samples and check for physical damage. Surveillance monitoring through control centres allows for additional surveying of the system and finding failures in the electrical system. Everything controlled in advance, contributes to avoidance of break down situations.

3 Materials and methods

3.1 Oversized transport in Norway

Oversized transport may potentially occur all over the country and variations in road standard, weather and seasonal conditions as well as topography, are obvious. The importance of these elements varies from region to region. In some regions oversized transport suffer from lack in route choice, while other areas struggle with bridge limitations. Nothing related to an oversized transport is normal, every element of the route has to be analysed and adapted.

Possible means of transport for oversized goods in Norway are railway, vehicle and vessel. All means of transport are presented in this study, nevertheless only vehicle and vessel transport is included in the case study. The reason for this is the low usage of railways in oversized transport due to several limitations on the railway network.

In this study an oversized transport includes all transport that exceeds the national limits for weight, height, width and length. In Norway the maximum weight limit is 60 tons, the length 25,25 meters and the width 2,55 meters. The height is not limited, hence the EU standard of 4 meter is a guide line. A physical height limit is set by tunnels and bridges which normally have a height of around 4, 5 meters (Statens vegvesen, 2007; Samferdselsdepartementet, 2009). The values given above are of course the maximum allowed dimensions, the limitations differ however between road classes and road sections. Information about physical road limits can be found in the national road list (Statens vegvesen - A, 2009).

The given limitations stand somewhat in contrast to oversized transformer transport. Transformer transports tend to be 70 - 80 meters long, weigh about 400 tons and be 4 to 5 meters high, the width is normally 4,8 meters. (Nordskog, 2009).

3.1.1 Geographical settings and surroundings

Norway is a small costal country in northern Europe. It is besides Iceland the least populated country in Europe. More than half of the land area is above the timber line, 25 % is covered by forest and less than 3% crop land. Most of the settlement and agriculture is situated along the coast or in fertile valleys (Caplex, 2009; Statistisk sentralbyrå – B, 2009).

The climate of continental Norway is marked by; it's length, stretching from (57 – 71)° N lat., the large difference in height, from 0 – 2469 meter, and the Gulf stream influencing the 25 148 km long costal line. The Gulf Stream together with the temperate North Atlantic Current, contributes to a relatively mild climate to a country located on the same degree of latitude as Alaska and Siberia. Based on the Köppen classification system Norway experience temperate mesothermal climate marked by significant precipitation and mild winters in the south, south-west, continental microthermal climates with both warm humid summers and cool subarctic summers, as well as cool winters in the eastern and more northern areas. Furthermore the northernmost area of continental Norway is influenced by polar tundra climate (Christopherson, 2006; Caplex, 2009).

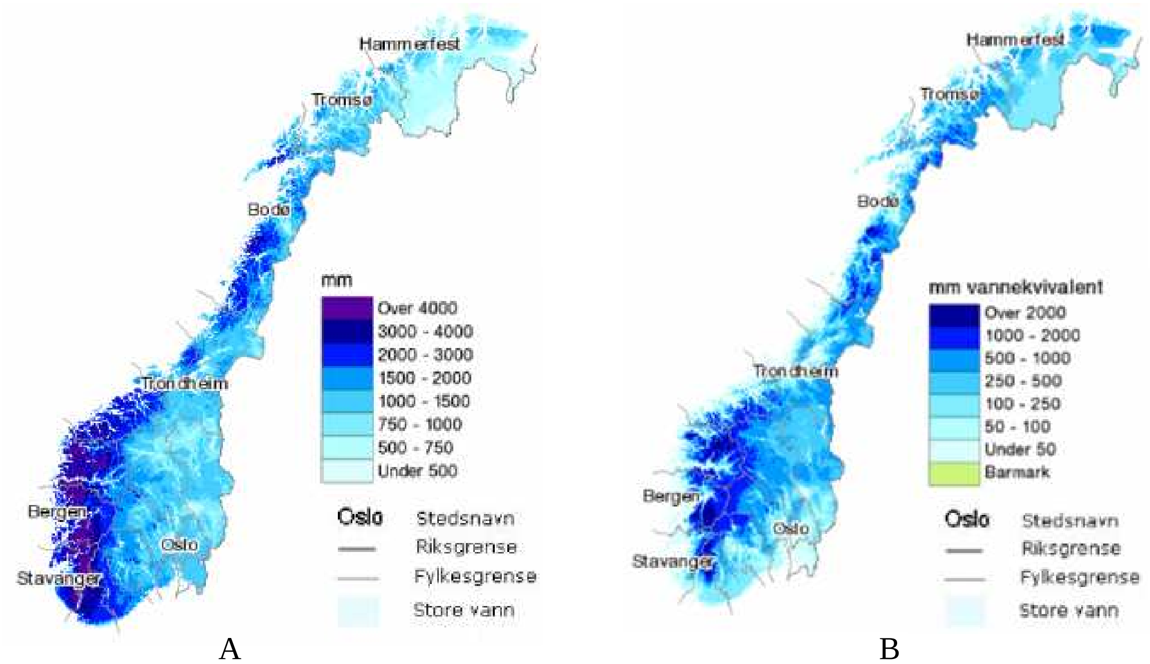


Figure 9: A: Sum of precipitation, 2008. Source: SeNorge, 2009 cited in metereologisk institutt. B: Maximum snow quantity, 2008. Source: SeNorge, 2009 cited in Norges vassdrags- og energidirektorat.

The amount of precipitation varies from less than 500 mm a year to over 4000 mm a year. The south-western area, particularly a belt 50 – 60 meters from the coast of Norway, experience most overall rain, as displayed in figure 9 A. Easily explained does the humid air blown in from the sea and onto mountain areas trigger precipitation due to the cooling down of ascending air; orographic precipitation (Grønås et al., 2005).

Large parts of Norway, primarily inland and northern areas, are covered by snow during winter. The snow quantity in 2008 varied from a maximum equalling less than 50 mm of water, to over 2000 mm of water. Snow pile up on the earth surface. In relation to oversized transport this phenomenon is a challenge causing closed roads, unstable ground conditions and narrower and slippery road surfaces (SeNorge, 2009).

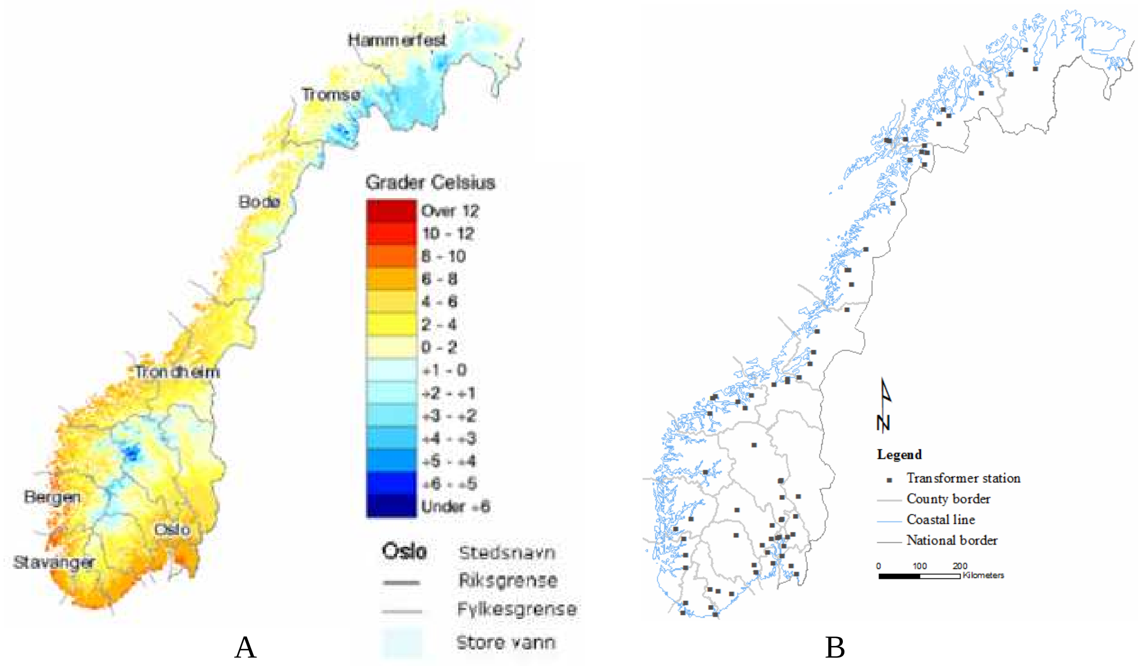


Figure 10: A: Average temperature, 2008. Source: SeNorge, 2009 cited in Meteorologisk institutt. B: Distribution of Statnett SF's transformer stations. The figure is based on data from Norges vassdrags- og energidirektorat.

The average temperature in 2008 varied from less than +6° Celsius to over +12° C, whereby the tundra area of inner northern Norway and the mountain areas in the south where coldest and the coastal areas in southern Norway warmest. This relates to stable sea temperatures and seasonally dependent sun radiation. The average temperature does tell something about where oversized transport is accessible most of the year, and where most likely the road is closed due to snow or ice.

Figure 10 B displays most of the transformer stations of Statnett SF. A comparison between figure 9 A and 10 B describe a relationship between areas of heavy precipitation and the density of transformer stations; quite many transformer stations are located along the coast and several are located in heavily precipitation areas, probably connected to hydroelectric power plants. In addition, the transformer stations are situated relatively close to populated areas; along the coast and in the south-eastern inland.

Norway is a windy country influenced by the west-wind belt and breezes related to the relation between land and sea. The coastal areas are particularly exposed to wind. At sea a large obstacle is strong wind and resulting waves. Most of the time sea traffic is accomplished, but with too strong wind conditions a sea transport may be weather-bound. Whether a transport at sea is safe or not, is up to the ship’s captain to decide (Nordskog, 2009).

Continental Norway’s winters are marked by snow, ice and relatively cold and hard weather, at sea and on land. Spring is a lighter and warmer season, but brings along spring thaw, weakening the ground of roads and railways. Summer and autumn are good transport months, although during autumn the risk of flooding and strong gales increase (Statistisk sentralbyrå - B, 2009).

The understanding of the seasonal limits indicates that oversized transport is preferably performed during summer. To be able to manoeuvre on the whole road or fjord, not limited by snow and ice, is of great advantage. Moreover the possibility to get driving permission is more likely during summer, as damage on road or railway is less probable.

Seasonal limits are potentially a problem in relation to preparedness. An arranged transport is naturally planned for the summer. An emergency situation however is not planned and may occur all year round. If the emergency situation is a transformer break down, then the degree of emergency depends on which transformer that is damaged and if reorganisation in the transmission grid is possible in order to avoid transformer replacement during difficult seasons. All in all the preparedness in challenging seasons come down to two things (Nordskog, 2009);

- Good preparedness plans with arrangements including standby of shuffle cars and salt vehicles for example, as bare asphalt is required.

- Knowledge of the captain or transport manager of the possibility of transport, including both the vessels and transportation-teams safety and possibility to cope with the conditions.

In connection with extreme weather, wind and snow, roads and especially mountain roads are often closed. The driving conditions and the driver's safety are top priority. Transportation is thereby limited, and delay must be envisaged. Diversion routes exist, but they may be long distances away because of the topography.

To get insight in the amount of road closures, table 1 displays the regularities of the closed mountain roads in southern Norway during winter 2007-2008. Only two distances; Gaularfjell and Sognefjellet, are closed during the whole winter, limiting the traffic enormously at that particular location. The most important stretches however, E16 Filefjell and E134 Haukelifjell are next to not affected. Filefjell has only some isolated closures, affecting the traffic that hour or day, but not the whole season.

Table 1: Winter road regularity, 07/08, southern-Norway. Based on information from Barstad, 2009.

	Temporarily closed	Night closed	Assisted driving	Winter closed
E16 Filefjell	122:33:00 (h:m:s)	00:00	96:05:00	x
E134 Haukelifjell	00:00:00	x	00:00:00	x
R7 Hardangervidda	582:45:00	x	323:04:00	x
R13 Vikafjell	1615:49:00	645:20:00	154:58:00	x
R13 Gaularfjell	14:55:00	10:40:00	x	171 (24 h)
R15 Strynefjellet	39:05:00	00:00	18:23	x
R50 Hol- Aurland	907:30:00	20:00	132:36:00	x
R52 Hemsedal	168:15:00	00:00	229:17:00	x
R53 Tyin - Årdal	927:00:00	54:05:00	00:00	x
R55 Sognefjellet	4005:00:00	00:00:00	x	150
F243 Aurland - Lærdal	119:30:00	00:00	x	x

Road closure is essential information for all transport at the time of closure. The information is however hard to predict and thereby fix as an attribute in route calculating tools. One solution is to connect route solving tools with real time traffic messages. This is however not done in this thesis case study, most of all because mountain roads are avoided in oversized transport due to steep slopes and periodically rough weather, and because such a connection is a study in itself.

Norway is a glaciated country with mostly high plateaus and rugged mountains broken by fertile valleys and small, scattered plains. The coastline is deeply indented by fjords (Climate-zone, 2004*)*. Steep roads are therefore common in Norway. In relation to oversized transport, steep inclines are a challenge. The steeper the gradient, the more machine power is needed to drag or decelerate the vehicle and commodity. Land transport often has no other choice but to drive the steep roads, the transport vehicle therefore has to have powerful motor power and good breaking solutions.

Roads built on slopes, either horizontally or vertically, involve often narrow roads. On such roads it is essential to keep to one’s side of the road in the traffic. The utilisation of the whole road width combined with scarce ground conditions can lead to distortion and cracks in the road surfacing. In the cases where road maintenance is not undergone, road damages are allowed to evolve. In a worst case scenario the road may yield due to a heavy vehicle load. When route planning an oversized transport, it can be well worth considering such scenarios, even though the national road authorities should have extensive knowledge of the road standards and decline driving permissions on hazardous roads.

In transformer transport steep roads are mostly no problems. The power of a transformer transport can be up to 1660 horsepower, all depending on the number of trucks dragging and pushing the transformer trailer. An incline greater than 10 percent however is a non traversable barrier. Fortunately there are few roads steeper than that (Nordskog, 2009).

Data for the degree of road incline was not included in this case study because it was not available.

3.1.2 Transport routines

Every oversized transport differs in destination, cause and dimension, and they encounter obstacles of varying kind, for example with the geography, authorities and the physical limitations. Only the basic procedures and methods are approximately constant from transport to transport. The routines are described and displayed, see figure 11, in the following section based on a transformer transport of Statnett Transport AS.

1. **A transformer break down occurs or an inquiry is sent:**

   For a transport to bee needed a planned replacement, a new station in need for a transformer or a break down has to take place. An inquiry or break down message is therefore the element that starts the whole process off.

2. **Rough planning & organisation:**

   A sketch of the route, the dimensions of the goods to be transported, the parties involved, whom to contact and a cost estimation is outlined for the process. If the sketch is accepted by the buyer of the service, an order is made and more exact planning is initiated.

   Simultaneously with the planning, the prospective transformer is tapped off, dismantled and made ready for transport. This has to be done even with emergency transformers as a transformer is best preserved connected to a voltage.

3. **Calculation of the best route, including outlining possible obstacles:**

   The exact transport route has to be found, including outlining obstacles and barriers. A GIS-tool built with the correct attributes may be useful.

   Axel load is often an obstacle causing problems, because of the weight limitations, especially on bridges. Necessary calculations should be performed synchronously with the route planning in order to find the best possible route as fast as possible.

4. Handing in of dispensation applications to public authorities:

When the route, and possible obstacles have been identified, several applications of dispensation have to be handed in, in order to get driving permission. Usually this is done parallel with other parts of the transport process.

5. Exploring the route:

The physical route is explored either by a GIS or by running a survey on the chosen route. There may be several obstacles that are not easily detected on a map, for example bad road standard, overhanging cables or ongoing construction work that have to be taken into consideration. The more precise information that is stored in a GIS or other assisting tools, the fewer are the surveys that have to be undergone, saving time and money.

Obstacle problems that are found have to be solved, for example by unlocking a road bar. If it is impossible to pass or remove an obstacle, the route has to be recalculated, taking one step backwards in the process. The same is the case if a dispensation application is declined.

6. The transport is carried out

Before the actual transport is carried out, the cooperation of all parties involved has to be organised. The parties are for example: The orderer of the transport, the executor and the official authorities.

During the transport the teamwork of the transport-team is the most important task. It includes constant adjustment of the vehicle, while passing obstacles such as bridges, tunnels, curves and roundabouts.

7. **The route information is stored and the transformer connected:**

The last, but not least, task of the transportation process is of course to evaluate and store transport information as well as connecting the transformer to the grid. If the data concerning the route, dispensations, obstacles etc. is stored it will benefit future transports.

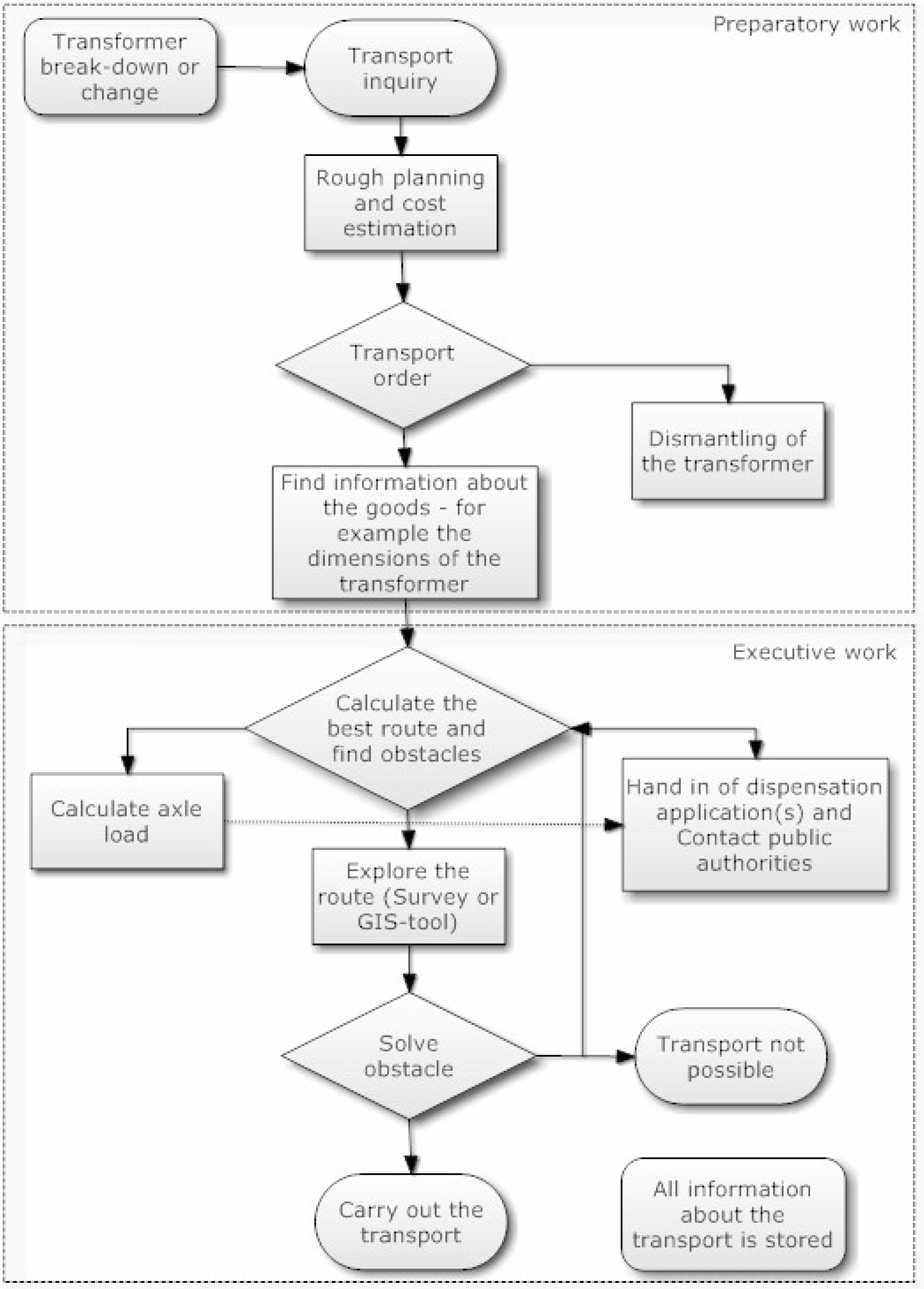


Figure 11: Flow diagram of transport routines. The figure is based on information from Nordskog, 2009.

3.1.3 Transport plan

A transport plan is a preparedness measure which is mandatory to have available before a transport or emergency takes place. An ideal transport plan holds all possible information related to the transport process. That includes technical specifications of the transformer, which tools that are available, pictures and transformer station description, as well as history, such as; standardized on-site reports from every transformer, routes driven, dispensations given and calculations performed.

All information should be stored in one database, the information should be easily accessible in case of an emergency and preferably connected to calculation and visualisation tools.

The organisation and structuring of workers knowledge, technical data and historical data is not always easy. In Statnett SF the transportation plans are stored in one folder on the same server disk. The transformers technical information is however stored in a another database (IFS). The data is of fluctuating quality and completeness.

The most complete plans holds information about nearly all elements described above as the ideal plan. The least complete plans however only present some pictures.

There is a need for greater effort if the parts of the puzzle are to fit together forming an ideal collection of transport plans. Statnett SF has started the process of improving the preparedness of transformer transport by improving the transport plans. This is being done through this thesis with the method development for a route-solving tool, and by collecting transformer data into one database. At the completion of these processes, only the establishment of improved routines for the collection of on-site reports and the organisation of historic data remain to be carried out.

3.1.4 Transportation means

The means of transport that is naturally chosen for an oversized transport depends on the goods to be transported, the point of departure and the destination. It is assumed that oversized transport follow the general trend in transportation, at least to a certain extent.

In oversized transport long distances are generally travelled by boat, whereas shorter and inland transport is carried out on road, with the exception of some occasional railway transports. This coincides with the 2006 figures of the Norwegian transport of goods, split on means, with 47 % on road, 46 % at sea and only 7% on railway (Monsrud, 2009).

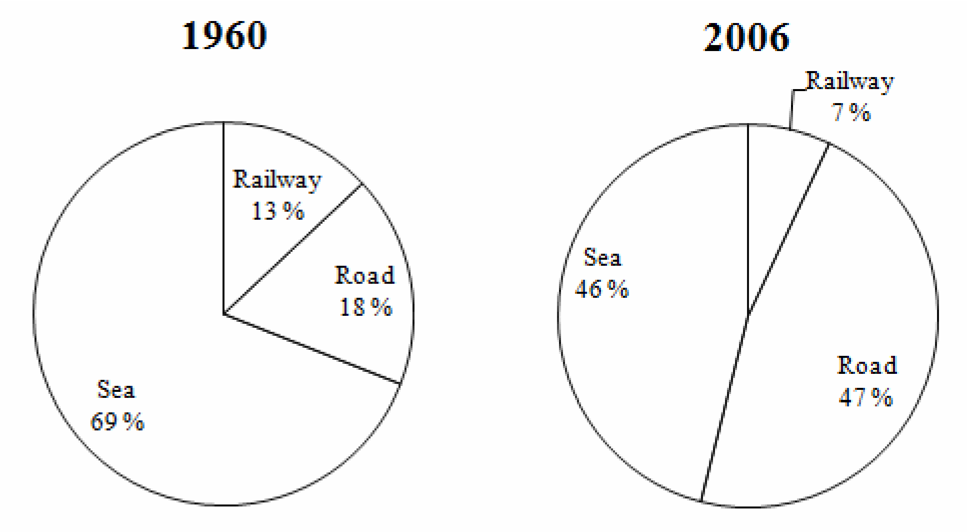


Figure 12: Domestic transport. Transportation work, goods, (measured in ton-kilometres) split on means of transport (percentage), 1960 and 2006. Source: Monsrud 2009.

Figure 12 shows that there has been a growth on road transportation at the expense of both railway and sea transport. The road traffic has more than doubled since 1960, it has risen even more than predicted by the Ministry of Transport and Communication in 2004. Although railways and vessels load more goods per unite than before, the tendency towards road transport is obvious. This increase leads to heavy pressure on the road network (Monsrud, 2009).

3.1.5 The road network

The Norwegian road network, see figure 13, is characterized by innumerable bridges, tunnels and winding roads, all necessary to connect this country marked by mountains, fjords and scattered settlement. The Norwegian geography is associated with challenging construction work and high costs, combined with corrosive weather conditions does it make Norway to a rough road-country.

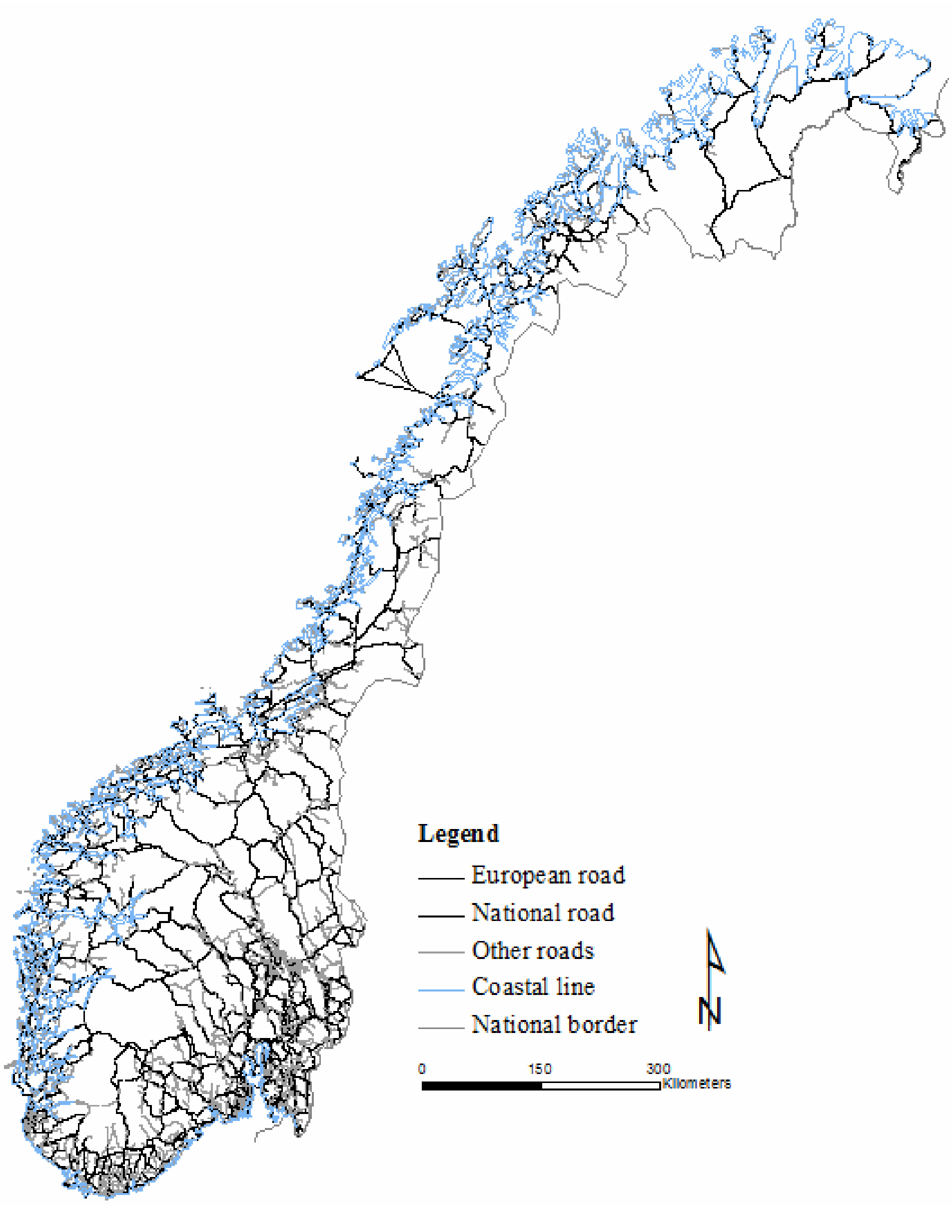


Figure 13: The national road network of Norway. The figure is based on data from Statens vegvesen

Norway had 93214 km of public road in 2008 relatively evenly distributed (Statens vegvesen – b, 2009). The road standard however has not kept up with the development in traffic loads. The road length has for example nearly stayed unchanged from 1990 to 2006, growing only 4,5%. There is an overhanging lag in maintenance, for example are 56 % of the trunk roads of non sufficient standard. Almost half of this insufficiency is due to problems with the road width, which is a problem of little importance for normal traffic, it may, however, be impassable for oversized transport (Samferdselsdepartementet, 2004).

After a long period with little focus, politicians have finally put the road network on the agenda. The Norwegian Public Roads Administration has put; road width, carrying capacity and bottlenecks on their priority list. A developed and maintained road network gives oversized transport improved possibilities to traverse.

Table 2: Road classes of the public road network in Norway. The table is based on information from Magerøy, 2009; Monsrud, 2009; Statens vegvesen – B, 2009.

Road class	Road length (km)	Description
European road (Europavei) - E	27463	Administrated by the NPRA and the Ministry of Transport and Communication.
National road (Riksvei) - R		Administrated by NPRA and the Ministry of Transport and Communication.
County road (Fylkesvei) - F	33926	Administrated by the County Executive Committee.
Municipal road (Kommunalvei) - K	38515	Administrated by the Municipal Executive Board
Private road	-	Roads on private land

The responsibility of road infrastructure, and thereby investment, in Norway is spread on different authority levels, see table 2. As the government is focusing on the road infrastructure the national roads are improved, as reflected in figure 14. This however does not imply that also county- and municipal authorities prioritise in the same way. By interpreting the graph a lower degree of investment in fact is identified. While the government invested around 13 billion NOK in national roads in 2008, county and municipalities invested together around 4 billion NOK.

This can be interpreted in two ways; either that the will of investment in road infrastructure is low in counties and municipalities, or that the overall investment has been so good that an all-out effort is not necessary. (Monsrud, 2009; Pham, 2009).

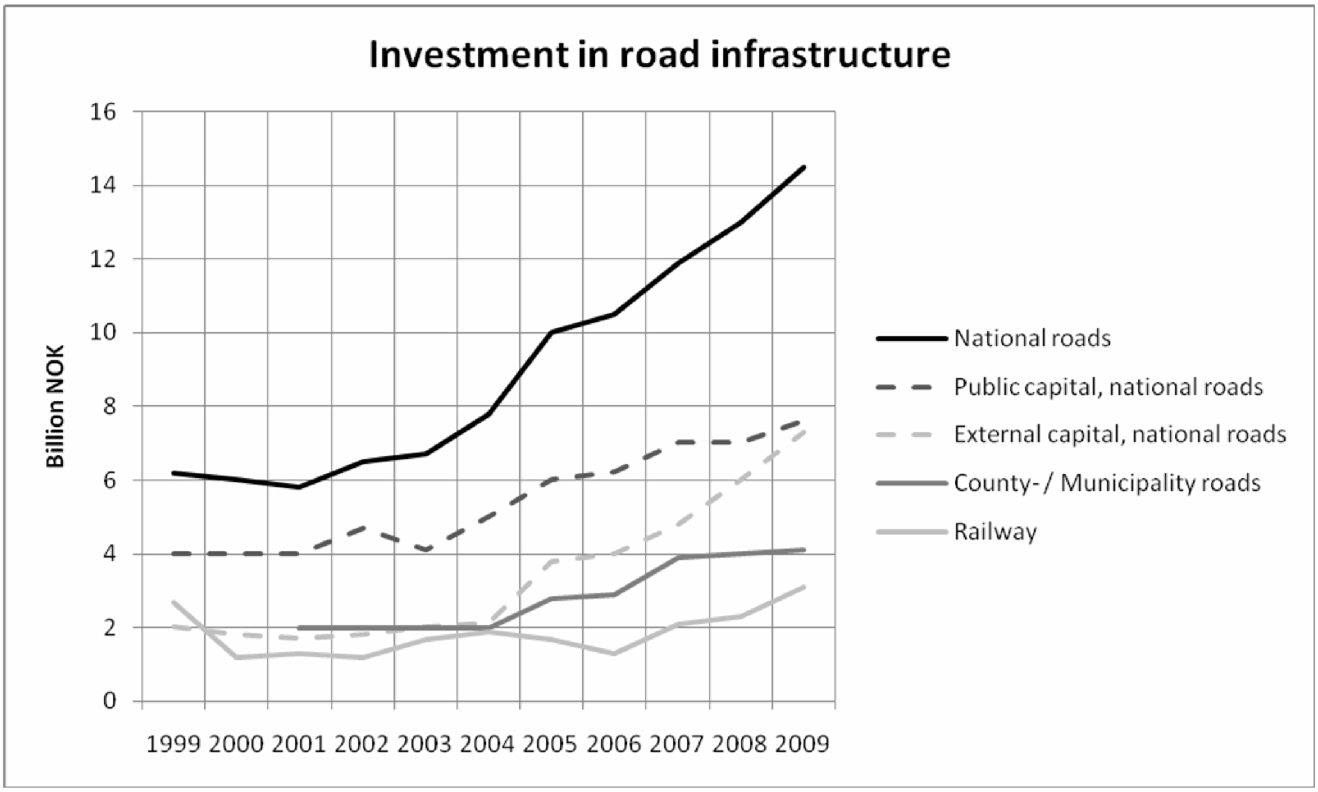


Figure 14: Investment in the road infrastructure, 1999 to 2009. Source: Pham, 2009 cited in SSB.

3.1.6 The sea network

For Norway the sea is and has been an enormously valuable means of transportation. To a large extent infrastructure and settlements are located along the cost. The infrastructure at sea includes ports, sea ways and navigation installations. The ongoing priority on strengthening maritime infrastructure will contribute to improved safety, navigability and reduced costs connected with sea transport. One of the measures implemented, is the creation of a trunk network at sea. Considerations made of settlement, transportation of goods and geographical location, amongst others, has led to the establishment of major ports with an connecting trunk network; Oslo, Grenland, Kristiansand, Stavanger/Sandnes, Karmsund, Bergen, Ålesund, Trondheim, Bodø, Tromsø, Borg, Drammen, Tønsberg, Larvik, Egersund, Flora, Molde, Kristiansund, Mo i Rana, Narvik, Hammerfest and Kirkenes.

Although there is a structure of lanes also at sea, see figure 15, travelling at sea is more unrestrained in comparison with road or railway, which is bound to special tracks. For example, it is possible to avoid queue formation as there is enough room for overtaking and the speed limitations are more flexible, contributing to an even transportation at sea. Traffic flow and safety is nevertheless as important at sea as on land.

The cost of maintenance of the sea ways, in relation to land transport is low. Except for general environmental protection, just a minimum of cost exists, such as building a sign or a beacon light. The basic element, water, is theoretically free of charge.

The sea network has an additional advantage. There are no dimensional limitations, as long as the vessel is designed to carry the goods, it will float. The topology and the depth of the seabed could moreover be a limitation.

Weather and banks or reefs seem to be the only real obstacle for a sea transport.

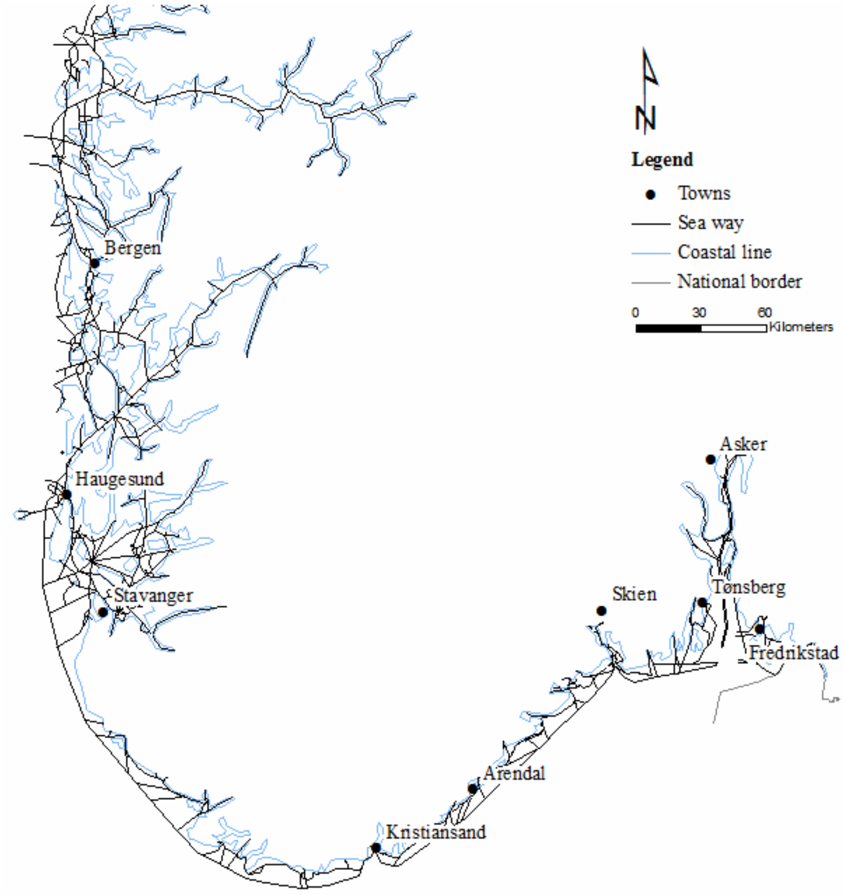


Figure 15: Some of the sea ways of southern Norway. The figure is based on data from Kystverket, 2005.

3.1.7 The railway network

Railway transport is superior to road transport regarding accident risk and pollution and at the same time is of no delay for other means of transportation. The railway has nevertheless not experienced a boom of passengers and freight transportation. Reasons can be that the traffic has been marked by poor signal systems, few developed double tracks, terminals that lack capacity and missing harmonisation and standardization (Monsrud, 2009).

As the graph in figure 14 illustrates, the investment in railways has been rising the last few years. Some more double tracks have been built, and lines have been extended. There have also been attempts to rationalize the system by restructuring the industry and closing some stations for faster conveyance. These implemented measures are good, though in order to compete with the sea or road net, the railway system has to be strengthened even more.

The railway industry is a future-oriented industry. At present more wishes and plans exist, than on-going construction.

Oversized transport on rail is seldom chosen because there are limitations on weight and the tunnels in the network are narrow. Furthermore the railway capacity is strained, which restricts the possibility to manoeuvre freely. Due to the low usage of railway in oversized transport, this means of transport is not included as an attribute in the case-study.

3.2 Data access layers

Pursuant to Sommer & Wade (2006) data is; *any collection of related facts arranged in a particular format; often the basic elements of information that are produced, stored, or processed by a computer.*

Right choice of data layers is fundamental to the result of analysis in Geographical information systems. This section presents the data layers included in the case study.

This study has demonstrated that almost all network attributes related to the analysis of oversized transport, have to be specially adapted. The data modification for adaptation to the special needs of oversized transport was therefore of utmost importance. Finding and deciding which data to include was one of the largest challenges during the case study.

All layers included in the analysis were adapted to fit five of the southernmost counties in Norway; Vest-Agder, Aust-Agder, Telemark, Buskerud and Vestfold. The road- and sea path network were the basis layers of the study. The road network alone contained 391910 road-line segments, all together 49696 km of road, and 352964 junctions.

3.2.1 Road related data

The national road database (NVDB), currently under development, will store information about all national-, county-, municipality-, private- and forest roads in Norway, all together more than 90 000 km of road. It covers basic data such as road type and road width and calculated data like annual daily traffic and environmental data such as pollution. The NVDB is meant to provide an effective information system and information dissemination, including everything concerning traffic.

The main objectives of the NVDB are (Statens vegvesen, 2008; Statens vegvesen - C, 2009) :

- To store correct data of the right quality
- To improve the user interface and ease access to important data, for internal and external users
- To improve the possibilities of variation in presentations and analysis
- To establish the use of a standard report-tool
- To establish a new data-model for the road network
- To create a new common feature catalogue

The Elveg – Electronical road-network dataset is an extraction of the NVDB and consist of road-network (vegnett), road-subject-data (vegfagdata), basis data (Bakgrunnsdata) and addresses. In the case study, only the road-network and road-subject-data have been utilised, and are the ones presented below.

The Road-network data is the geometrical aspect of the feature collection in Elveg. It includes the centre line for all road segments exceeding fifty meters length. The data is thematically organized based on road type. Additionally it holds some attributes for each road segment such as an unique identifier, road names and location through municipality number (Statens Kartverk & Statens vegvesen , 2009).

The road-subject data consists of thematically organised, attribute collections stored in ASCII files. Based on the primary key TRANSID, it is possible to join the road-network data with the attribute collections. The collections are; driving direction, axle load, speed limits, barriers, height restrictions and turn restrictions:

- *Driving direction:*

  - *The attribute*: Driving direction is an indication on the direction of traffic flow and which roads being limited by one-way restrictions. The driving direction attributes are stored based on their direction of digitalisation. For implementation in a network the column name “Oneway” is default.

  - *Case study adaptations:* To oversized transportation the driving direction attribute is not a necessity and therefore may be overruled. This is because special permissions for driving against the driving direction, avoiding other obstacles, normally are granted. The best thing for traffic flow is, however, that the common rule is adhered to and this was the reason to include the attribute in the case study.

- *Axle load:*

  - *The attribute*: The axel load attribute includes information related to weight restrictions on the road network, restrictions may vary with season. The values are given as maximum total weight of vehicle and not weight per axel. Referring to the introduction in section 3.1, the maximum road weight limitation in Norway is 60 tons. The highest value in the dataset used, was however 50 tons.

  - *Case study adaptations:* Oversized transports, as the name state, tend to weigh more than the maximum national standard allows. A consequence is that driving permissions have to be granted by local authorities and that calculation, particularly on bridges, has to be performed beforehand. This procedure has to be followed every time a new bridge, not calculated before, is planned into a route, or changes in the bridges are reported.

The axel load attribute is not adapted for usage of oversized transport, and therefore has only been used as a guiding line pointing out road segments with low carrying capacity. In particular has the axel load of bridges been utilized, due to special requirements for calculation and traverse.

Weight limitations have been calculated on actual routes before and driving permissions granted or rejected based on this information. Relevant historical information such as this has not been available during this case study. If actual collected bridge attribute data could be implemented and given special cost in the network dataset, the route calculations would become more realistic.

- *Speed*:

  - *The attribute*: Speed contains information about the maximum velocity on different road segments in the road network. Attribute values are given in kilometres per hour. The speed limit on a road additionally gives information about the road standard. For example there is a connection between high speeds and large road dimensions.

  - *Case study adaptations:* Oversized transport's velocity on road is between 5-15 kilometres per hour, the maximum speed limit is thereby not attained. Moreover will an oversized transport, due to low maximum speed, inflict limited traffic flow or even cause standstill.

    The relation of speed and road standard gave reason to include the attribute, as labels, in the case study, it was, however, of little use to the route solving.

- *Barrier*:

  - *The attribute*: Barrier attributes exist both in this barrier-ASCII file and are stored in the Elveg point layer. Barriers are physical obstacles such as road blocks or toll bar, which either have to be removed, for traffic to pass, or be driven around.

- *Case study adaptations:* Manoeuvring with an oversized transport vehicle in general is difficult, handling barriers can be even worse. To solve a barrier obstacle either is time consuming or not possible, resulting in a non traversable route. A toll bar typically is easy to solve by finding the right key, whereas to move poles dug down is a more comprehensive task.

  Barrier has been an essential attribute in the case study, in total 4263 barriers were included in the network.

- *Height*:

  - *The attribute*: The attribute stores all height restrictions that are signposted in reality. The height values are stored in meter.

  - *Case study adaptations:* For oversized transport this attribute was of great importance, as it together with the Barrier attributes formed physical obstacles implemented directly in the route solving. Every height attribute element was included as a barrier, because all height restrictions were stored whit a value lower than 4,5 meters. All together where 333 height restrictions included in the case study.

    Height obstacles too low for oversized transport may lead to time consuming detours or substantial interventions. To adapt this attribute further for oversized transport calculations, historical data as well as heights not signposted, could be included.

- *Turns*:

  - *The attribute*: Holds information about turning restrictions. To know where it is legal to turn is important for the flow of traffic.

  - *Case study adaptations:* Oversized transport has to turn where physically manageable, this attribute therefore was not included in the case study.

3.2.2 Sea ways

The sea way network data originate from the The Norwegian Coastal Administration (NCA). The main polyline of the sea network layer accompanies the coast line relatively evenly. The network is completed by shorter polylines going from the main polyline towards land, in a relatively unstructured manner, see figure 15. Sea ways are modelled shipping lanes which are recommended being followed at sea. It will always be up to the captain to decide on the actual course, the sea ways are however good guiding lines. The fact that sea ways do not coincide exactly with real sailing routes results in distance and durability calculations which are only approximately correct.

The network was kept original, except from some weak points which had to be adapted. This is because it was assumed that the data layer has been built with the knowledge of where trunk courses, streams, banks and shallows are located. It was assumed that obstacles are avoided in the sea network, the layer has therefore not been joined with additional attributes.

3.2.3 Transformer stations

The transformer station data layer was found locally on Statnett SFs ArcSDE server, but it originates in the first place from NVE. The route calculated, and taken a closer look at, in this thesis runs between Sylling and Stølen. Those two transformer stations constituted therefore the transformer station layer.

The other transformer stations in southern Norway were not considered essential information for this analysis and were therefore not included in the layer. A new layer of Statnett SFs transformer stations is expected to be created after the data collection of exact coordinates, and will be possible to use as a future input in the GIS system.

3.2.4 Landfalls

The landfall dataset was established for this analysis. It was first and foremost established as a connecting point between road and sea in the multimodal network,. The dataset contains descriptive data about the physical installation as well as name and commodity use. The information was not important for the route calculation but may be interesting knowledge in a later study. The attribute data was therefore established together with the geometry.

The attribute “landfall standard” described the physical standard of the landfalls. 6 out of 16 landfalls were identified with substantial up-grading needs, docking consequently would not be possible right away. This information was not displayed and used in the case study since the landfall of Kristiansand and Drammen, used by the routes, were identified to be of good standard. However, this information is so important that, these six attributes, either should be included with graded costs in the network, signalling needs for preparation procedures, or should be excluded from the dataset as docking is not physically possible at present.

The transfer time from road to sea through a landfall takes approximately one hour (Nordskog, 2009). This cost was not included in the network. No costs related to preparatory work were included in the network, neither dismantling, transfer, nor set up.

3.3 Data quality

The geographical data must hold acceptable quality or the development of data based functions, methods or tools is of little sense. To be familiar with the implemented data and to accept the level of quality is important. Data quality is a very wide term, spanning from attribute completeness and choice of detail and attribute, too for example topological and spatial accuracy. SearchDataManagement (2009) defined data quality as *the reliability and effectiveness of data*. It is further stated that *maintaining data quality requires going through the data periodically and scrubbing it.* The data used during this thesis has undergone a quality control presented in the section to come. Different data quality aspects have been inspected, no full control has thus been performed. It has been assumed that the data is of good quality because most of the data collected originate from well-established institutions

3.3.1 Conversion quality

In order to use the network analyst extension of the ArcGIS software, the original SOSI files[1] of the road network dataset (Elveg) had to be converted to the Shapefile[2] format. This was done without extensive problems.

After the conversion a sampling test was performed on the municipality 602 in the county of Buskerud. The SOSI-file is built up of hierarchical organized elements each containing all attribute information of one road segment, including a counter. Consequently by finding the counter of the last line segment the number of total elements of the data layer is found. In the data layer of municipality 602, that number was found to be 3035.

The same result was found when counting the number of the unique field TransID in the same file through a python code (see appendix VII).

[1] Norwegian standard format for digital geographical data, for more information see http://www.statkart.no/nor/SOSI/SOSI_in_English/
[2] A format made by ESRI for storage of digital geographical data, for more information see http://www.esri.com/library/whitepapers/pdfs/shapefile.pdf

After the conversion, the numbers of road segments were counted in the resulting shapefile. The result number was 3035 elements based on the selection; "KOMM" = 602. The amounts of geometrical road segments before and after the conversion were, in other words, the same. The quality of the output geometry was thereby found to be as good as the input, in other words loss did not occur during conversion.

3.3.2 Quality of the road network

Elveg is based on the work of the Norwegian Mapping and Cadastre Authority (NMCA), The Norwegian Public Roads Administration (NPRA), The Ministry of Transport and Communication and municipality- and county-administrations.

A weak point of Elveg is the amount of data supplying parties. The completeness and quality of the data deliverance depends highly on the regional- and local authorities' resources and priority-settings in relation to geographical data.

Due to lack of resources or lag in data delivery, newly built areas are not always up to date in the database. To optimize such a data process is challenging. The NMCA has nevertheless founded a project to update the road network data by comparing the existing network with orthophotos. As much as 15% of new roads per municipality were found (Abelvik, 2008).

A small study comparing map and orthophoto was also performed during this case study on several locations in the county of Rogaland. The overall completeness was good, only very few and seemingly unimportant roads where visible on the orthophoto but not retrieved in the digital road data. One of the comparisons, Havsøya in the municipality of Eigersund, is displayed in figure 16.

Figure 16: Comparison between digital road data (map) and orthophoto on Havsøya, Eigersund. Source: Norge digitalt - B, 2009; Statens vegvesen- D, 2009.

The roads found on both figures (map and orthophoto) were the same, which is natural as they originate from the same source, the NVDB. There were however some small roads visible on the orthophoto which had not been digitized. The reason for this may have been that they were relatively newly constructed and therefore had not been updated, or they could have been given a low priority because of their road class; walk- and bike-ways.

Small roads may be of high importance to for example ambulance personnel, but for oversized transport seeking the largest roads, they are of little importance. The only small or private roads that are of importance to oversized transport, are mostly those close to the destination or departure locations. In relation to transformer transport, this point is illustrated by the example of Nesflaten in Rogaland, shown in figure 17. Several small roads are not found in Elveg and may potentially cause problems in route solving. Generally, however, the local area around a transformer station is well known, reducing the problems concerning non-digitized roads.

Figure 17: The transformer station in Nesflaten, lack of digitized roads. Source: Norge digitalt- B, 2009.

The topology of Elveg has been easy to work with following the download from Norway digital. The implementation of Elveg into the network dataset was operational straight away. Only two changes were made to adapt the topology data of Elveg. First of all Ferry segments were deleted as oversized transport need special vessels at sea, secondly the Elveg geometry was extended with small segments connecting this layer with the landfall layer.

3.3.3 Quality of the road attributes

A difference between the SOSI-format and the network analyst data model is that SOSI allows several attributes connected to the one and same line-segment or TransID, dynamic segmentation, hence network analyst only allows one attribute connected to the same line-segment, static segmentation (Pedersen, 2009). That led to a problem when road-subject data had to be joined with road geometry data during the case study. By implementing an outer-join, keeping all of the records in the input layer (the road geometry) with the attribute data, several attribute records were lost. The loss was a result of exclusion, only the first attribute related to the TransID in the road-subject table was joined into the shapefile. All other attributes connected to the same TransID were lost.

A result of this process was reduced attribute data quality in the network dataset. In Buskerud county for example were 17067 out of 92238 elements lost during the join to Elveg. That meant that about 2% of the attribute data elements were connected as attribute two, three or more onto the same TransID.

The preservation of the attribute data left out of the join was questioned several times during the case study. Ideas of giving the dataset a new unique key, split road segments to fit the road attributes or performing special joins on line-segments registered with several attributes were thought through, but not implemented.

The final decision to accept data with subperfect quality and completeness was due to several reasons;

- The first reason was due to the strong wish of retaining TransID as a unique key, TransID is always the key for new Elveg updates or calculations done on the data.

- The second reason was that everything related to road data will probably be purchased and not self prepared when implementing this case study method in a later project.

- The third reason was that although a loss in completeness quality is never preferable, a calculated route would generally avoid a road segment with an obstacle, regardless of whether there were one or more obstacles. In that aspect the loss of data seems easier to operate with.

- The fourth and final reason was the preference of keeping original data. The reasoning being that all attribute data connected to the same TransID could be merged in some way, for example, based on the mean, average, highest or lowest number calculations. With such an exchange of data, the quality would reflect all values in the dataset, but at the same time loos the original data quality.

The data quality and completeness of the attributes is mostly reliable. Some room for improvement does, however, exist, for example when it comes to height restriction and speed limit data. In the height layer, information is stored only where actual signposts exist on the road, although all existing height limitations are relevant for route analysis. Moreover, in the point layer of the geometry file there are stored some elements characterized as road beneath railway. These do not have any height information connected to them, though it is clear that they must have a height limitation in reality.

In the speed limitation data some attribute data is missing, for example, 9604 of the elements in the Speed dataset are registered with a speed of zero kilometres per hour. Most of these elements are walkways, private roads or forest roads, places where speed is either not set or of little importance, however there are also some E, F and K roads with missing values.

3.3.4 Quality of Sea ways map layer

The sea way network consisted of 146 line segments and was decidedly smaller than the road network, but equally important.

At first sight the sea way network looked fine, but by taking a closer look, weaknesseses were found. The most serious challenge was missing connections between line segments; the topology had an infirmity. The topology therefore had to be repaired by removing certain dangles before it was put into the multimodal network. By accomplishing the topology, the connectivity to the multimodal network had to be established. Line-segments from the sea ways layer to the landfall layer was digitized.

The quality was never as realistic at sea as on land, because vehicles have to trace the roads exactly, in contrast to vessels which can deviate from the sea way. The length of real sailing courses and the sea ways therefore differ a bit. This quality incompatibility was nevertheless not perceived as very important to the study.

3.3.5 Quality of Landfalls map layer

The landfall layer was created for this case study and was an essential part as it connected roads and sea ways to become multimodal. The layer was established based on a document containing simple tables. The table was scarce on information about spatial reference of the different landfalls, and the geographically distributed points therefore had to be placed by using a combination of the information from the table, logical thinking and some orientation on orthophotos. Furthermore the locations were found in longitude and latitude coordinates and had to be converted to UTM X and Y coordinates in order to be displayed on the map.

The imperfect spatial quality caused no great problems. The route calculations may have differed slightly from reality at areas close to the landfalls, but the overall picture was not affected.

The layer was created to be good enough for this case study, for use in other projects with stricter quality rules, collecting exact coordinates is recommended.

3.3.6 Quality of Transformer stations map layer

In the actual layer which turned out to be implemented in the case study, only two transformer stations were included. The reason for such a limited layer was that the case study would be studying the transport between Syllingen and Stølen, and therefore not needed further transformer station elements. The layer was only used for guidance in relation to placing destination and departure nodes in the network. In the cases where more data is needed, further information can be extracted from the original layer of all Norwegian power stations published by NVE.

A quality program was undergone in the county of Rogaland and although the results were not quite pleasing, an extract of the transformer stations dataset of Norway (Sylling and Stølen) was used during the case study.

In Rogaland there are seven transformer stations. Two out of these seven stations turned out to be not properly displayed on the map. One of the transformer stations was not part of the dataset and had to be added. The other one did not hold the right spatial values, see figure 18. In the latter case, the point would in any way be connected to the right road, as there was no other alternative. Good data quality would however not be honoured.

Figure 18: Display of the variance between the actual transformer station (north) and the related transformer station point (south). The example is taken from Førre, Rogaland (Scale 1: 3256). Source: Statnett SF - C, 2009.

3.4 Route solving

Transportation features (TFs) are like strings of pasta. A bowl of spaghetti contains TFs of all types: freeways, arterials, local roads, alleys, paths and trails, airports, pipelines, and railways. Users identify the type of TF they want and select from the bowl those pieces needed for vehicle navigation, emergency dispatch, pizza delivery, walking, or bicycling. Then, using a "clean and build" procedure, users can construct application-specific networks (Dueker & Butler, 2000).

During the case study, a GIS-tool based on network analysis was sought created. The "spaghetti bowl" created and structured was based on a multimodal and hierarchical network with roads, landfalls and sea ways as the main pieces. The network built was located in southern Norway and based on an actual transport distance going from Sylling to Stølen.

3.4.1 The Network Analyst

Network analysis represents transport infrastructure, in this case roads and sea ways, by links and nodes forming a network topology of their mutual relationship. The link (line segment) connects two nodes (points), hence two nodes connects three links. The links are either directed (arcs) or undirected (edges) related to the movement in the network (Bell & Iida, 1997). Route calculations are performed based on the values assigned to the links and nodes. By varying the attribute weights in a network, the result can be a different choice of route. The sensitivity of the system indicates that the consideration of weighting is essential; small changes in attribute cost will possibly have huge influence on the analysis (Frank et al., 2000).

Network analyses are very specialized and as pointed out by Goodchild (1998) as cited in Thill (2000), extensions are needed in order to handle particular structures; he recognized meaningful extensions as, for example, planar versus non-planar models, turn tables and specific traffic lane topology. In the ArcGIS software every function handling any aspect of network analysis is placed into the Network Analyst extension. This extension has been the base of the work done to develop a method for oversized transport.

3.4.2 Preparing the network

In order to be able to perform network analysis the data layers had to be prepared and a network dataset established. For preparation, input data had to be collected and cost attributes established. It was also essential to make sure that the topology was functioning and coherent. Line segments had, for example, to meet in order to form a network. Z-elevation values on line end-points had to be given to indicate whether the lines were connected and if they passed over or under each other.

To make the work run smoothly it was advantageous to assign the cost attributes predefined column names, which are stored in the network wizard's library. The wizard detects the common fields, such as meters or drivetime, and places them as evaluators of the attributes.

Before the network dataset could be built, all properties had to be assigned. This was done via the help of the network dataset wizard. Sources, connectivity and attributes were set. In order to get the network dataset to function, minimum one source and one cost attribute had to be assigned. For this network the sources were roads, sea ways and landfalls (see appendix III). Transformer stations were only visualized on the map.

A multimodal network was established with roads and sea ways as connectivity groups and landfalls as the point of transfer. The roads were connected by the end point policy noting that roads were only connected to each other at the end of the line-segments. Sea ways were comprised by the "any vertex" policy. A landfall as a point of transfer overrode these rules if necessary.

The fundamental attributes of the route calculation were; Drivetime and Driving direction. Drivetime was calculated in minutes per meter, based on the different road classes (Vegkategor). Driving direction was prepared by the numbers 0, 1 and 2, representing respectively not directed, FromTo and ToFrom, all directing the traffic flow. Other attributes were; speed, height, weight road medium and road blocks.

The attributes were all prepared by more or less the same method. First the ASCII-files, downloaded by municipality, were joined together to a county collection and the semicolon separation replaced by tabulator separation, supported by ArcMap. A join was thereafter made between the table and the Elveg road geometry based on the key TransID.

Some of the attributes such as speed and weight were further labelled and displayed in a map. The driving direction attribute got a oneway column added which was used as a restriction in the network. The road block- and height attributes were assigned spatial point references to the start, middle or end section of the belonging line-segment. The point calculation was based on information from the columns Fra and Til. The point layers were loaded into the network as barriers.

The routes were in the end calculated and the attributes infliction on the route selection analysed. A closer description of the method is found in the appendices III and VI.

3.4.3 Analysing the network:

Several tools were available for the analysis of the network. The network dataset had to be loaded into a map view and a new route created. Routes could be altered as many times as desired by changing properties or attributes. Route locations and barriers were either manually assigned or uploaded from a point layer. The route solving tool always began to calculate from the nearest point of the location, see figure 19. Through the network analyst property window, simple changes in the dataset, or calculation specifications were set. In the network analyst map, the departure and destination nodes were placed based on the transformer station layer; Syllingen – Stølen. The road restrictions height and barriers were uploaded through the network analyst window.

Figure 19: Placement of node points for route solving in network analyst. The route is calculated from the closest link of the node.

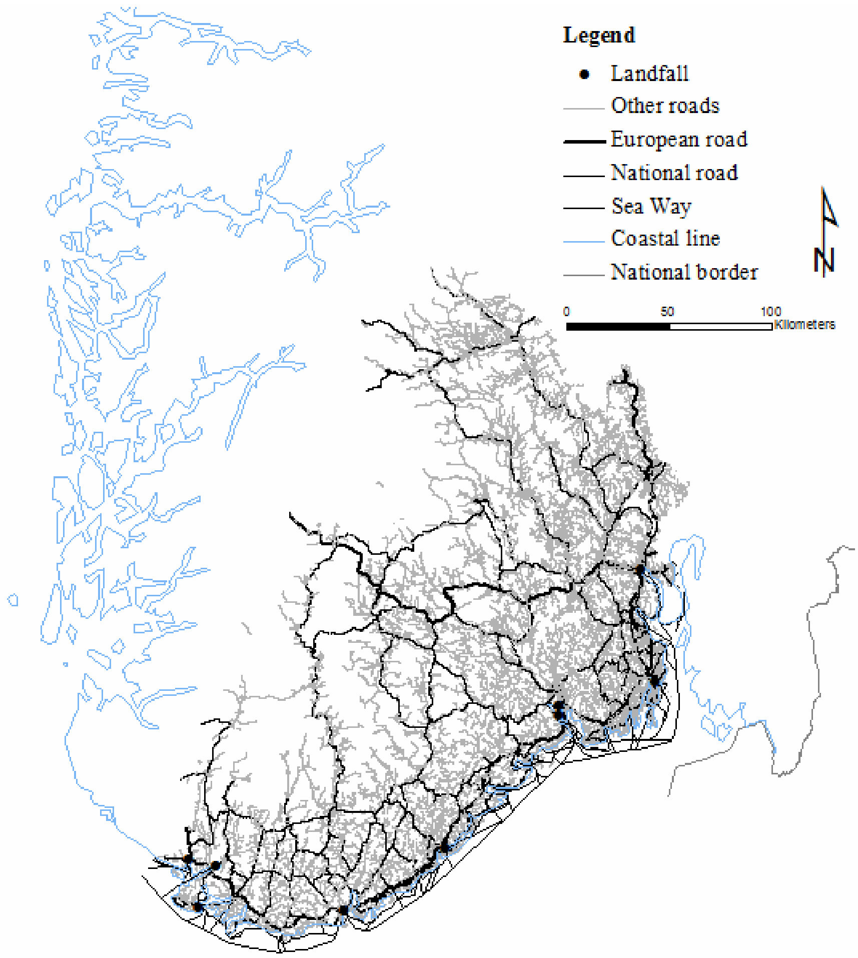
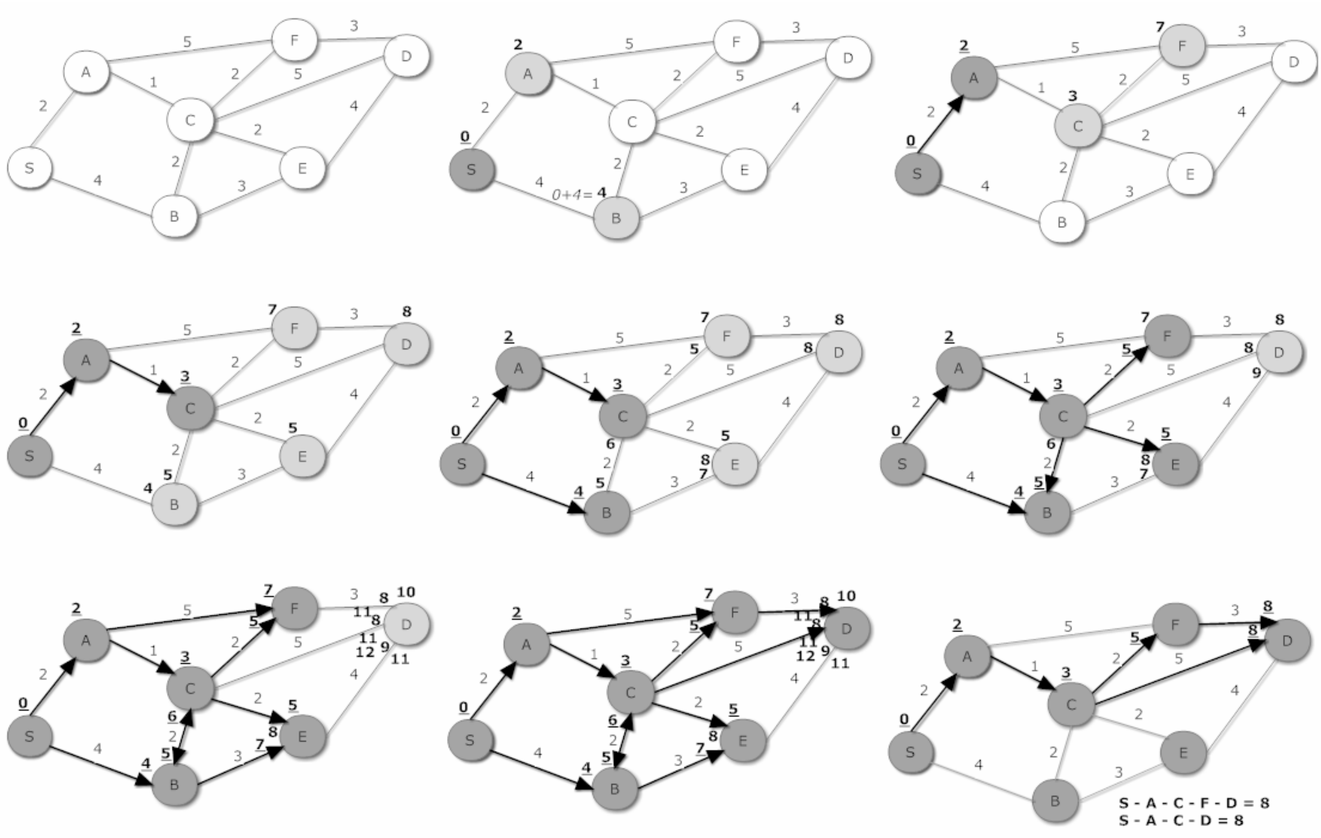


Figure 20: The network for oversized transport established during the case study.

3.4.4 Dijkstras shortest path algorithm

The underlying algorithm used by the ArcGIS network analyst, for route calculation, is the Dijkstras shortest path algorithm (ESRI, 2009).



Figur 21: Example of the flow in Dijkstras algorithm. The figure is based on information from Kinahan & Pryor 2009.

The Dijkstra algorithm is based on weighted graphs in which edge graphs are non-negative, which is normally no problem since travel time costs rarely are negative. The algorithm calculates the shortest path from one node to another, traversing the network through the path that gives least resistance. This includes searching for edge values all the time, and updating the system on which path that is the shortest, for every step (Dijkstra, 1959 cited in Worboys & Duckham, 2004). An example of a random network with seven nodes and belonging edges is displayed in figure 21 above. The edges are given costs, whereas the nodes are set to infinite or nothing. In this case the shortest path from start S to destination D is to be found. In network number two, the node S is set to zero, because it is zero nodes from the origin. A and B are labelled with the length to the node from the origin, path + new edge, for example 0 + 4 =4 (S – B). The cost of two is the lower of the two possible paths, the algorithm decides therefore on going to node A and marking it as visited (dark grey). Thereby all unsolved nodes, directly connected to A, are located as neighbours. The value of the nearest neighbours, the length value of the next node added to the traversed route, is further found every time a new node is visited.

Calculating the path on the run, the algorithm is stepping further and further into the network until the destination node D is marked as visited. Finally after having visited A, B, C, E and F the shortest path from S to D is found. In this example two routes turned out to have the same cost distance, the path S – A – C – D and S – A – C – D – F, with the cost of eight. Nevertheless S – A – C – D is obviously shorter than S – A – C – D – F.

More technically the Dijkstras algorithm is written as in the table 3.

Table 3: Dijkstras algorithm for scripting, Source: Worboys & Duckham, 2004.

Dijkstras algorithm	Comments/Explanation
Input: Undirected simple connected graph G = (N,E), Starting node s ∈ N, weighting function w: E → $\mathbb{R}^+$, target weighting function t : N → $\mathbb{R}^+$	w = weighting function, E = set of edges, $\mathbb{R}^+$ = positive reals, t : N → $\mathbb{R}^+$ = target weighting function, used to store the minimum distance from the start node s, to each node in the graph
1: initialize t(n) ← ∞ for all n ∈ N, visited node set V ← {s}	Set all target weights (nodes) to infinity, set starting node as visited
2: set t(s) ← 0	Starting node is set to zero
3: **for all** n ∈ N such that edges sn ∈ E **do**	For all nodes that are neighbours of s do
4: set t(n) ← w(sn)	Set target node to weighted (least cost) neighbour
5: **while** N ≠ V **do**	While the nodes are not marked as visited do
6: find, by sorting, n ∈ N\V such that t(n) is minimized	Sort the unvisited nodes such that the smallest value node is found (at every step)
7: add n to V	Add node (lowest weight at that moment) to visited
8: **for all** m ∈ N\V such that nm ∈ E **do**	For all nodes that are visited and their belonging edges do:
9: t(m) ← min(t(m),t(n), + w(nm))	Calculate the minimum target weight
Output: Graph weights t: N → $\mathbb{R}^+$	Stores the shortest path

Dijkstras algorithm is able to map a whole network. However in most cases the goal node is explicitly known and just some parts of the network are searched through, before finding the shortest path. If a node is known, the node is the starting point from which the algorithm works onward, through the network, to the goal node. It is also possible to conduct a search backwards, from the goal node to the starting node, reversing the initial steps. The outcome will be the same by traversing forward as backward. Combining these two algorithms to a bidirectional search is an advantage. The reason is that search trees grow exponentially. Two shorter search diameters will generate fewer branches, than a single longer diameter tree, making the algorithm more efficient. This is however provided that the two search trees do not traverse past each other (Pohl, 1971).

Dijkstras shortest path algorithm is widely used, as the network analyst tool is an example of. It suffers nevertheless from a slow time complexity of $O(n^2)$. This means that the processing time will increase exponentially in relation to the input n, number of nodes. In a network, as displayed in figure 21, where all nodes are visited during the calculation the time complexity $O(n^2)$ is met. If the algorithm is brought to a halt before all nodes are visited, however, time will be saved. This can be attained in a case where the shortest path is found before the whole network is traversed. By implementing directed, bidirectional or hierarchical search functions, or a combination of these, the clever qualities of the Dijkstras algorithm will be obtained, hence the processing time improved (Worboys & Duckham, 2004).

3.4.5 Hierarchical routing

Hierarchical routing is a property which is possible to insert in the network dataset. A hierarchy in the context of communication is an ordered set of line-segments in a network, for example roads (Universitetet i Oslo, 2008). Hierarchy cannot calculate a route alone, and is therefore dependent on other impedance. A time-based attribute is the most reasonable impedance to connect to a hierarchy. A hierarchy is created when a larger road such as an European road, is favoured over a smaller municipality road. The main idea of this system is faster performance on search in the network. This is done by decreasing the amount of edges that need to be searched through. By favouring a higher order of hierarchy, the impedance is minimized. The route solver is thereby always searching for a transition to a higher road class as long as this is cost effective. Hierarchical routing is based on a modified bidirectional Dijkstras algorithm. When the highest hierarchical level is reached, the search path traverses only on the highest level until the path from the origin meets the path from the destination, see figure 22. Thereby the route is created. Hierarchical routing, however, does not assure the shortest route, but moreover fast calculations and good route choices. A hierarchical route reflects in greater extent the way people normally drive (ESRI, 2009).

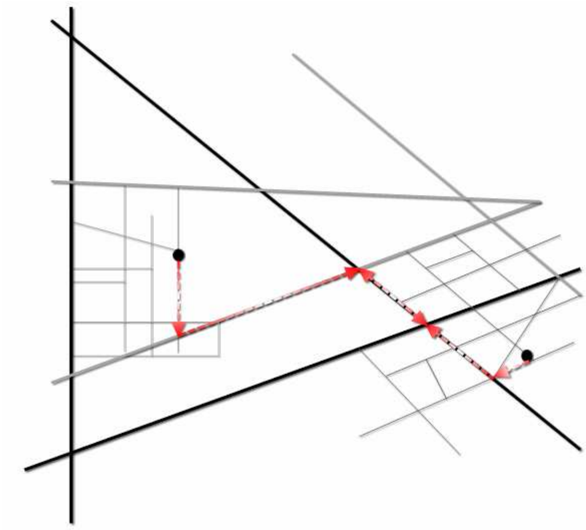


Figure 22: Hierarchical levels in a road network, bidirectional traverse.

In the case of barriers the solver tries to find an alternative route either by descending and ascending in the hierarchy to find a way around, or by finding a completely different path. If a detour is not found, the route remains unsolved. The same is the case if the line-segments of the highest class are not connected. The system assumes that they always are.

The dimension of oversized transport trucks implicate that large roads are always of preference. The reason for this is that larger roads are wider, giving more space for manoeuvring. It also makes passing traffic possible, avoiding closed roads or night-time transportation. Moreover larger roads tend to be straighter and with fewer intersections leading to higher driving speeds. The most important factor is that larger roads are dimensioned for heavy traffic (both weight and quantity), and therefore hold a relatively good standard of maintenance, increasing safety and making the consent to an oversized transportation more feasible. In Norway typical large roads would be European roads, National roads and to some extent County roads. This varies however from region to region all depending on resources, political will and geographical location.

To make the GIS tool of the case study as realistic as possible, a hierarchy based on the road class attribute was established (se appendix III). A hierarchy column was therefore created changing the road class strings; E, R, F, K, P, S, G to integers to suite the ranges in the network dataset wizard. In order not to favour roads over sea ways, owing to the fact that the model was multimodal, the same was done in the latter dataset, assigning all elements of sea ways to the highest hierarchy rank.

The road hierarchy was successfully implemented. It turned however out that, even if the wizard accepted both sources to have a hierarchy, it did not become reflected in the route solving. A node located on a road resulted nearly always in a road traversing route. The sea ways were ignored. Even if the cost of roads was put unreasonably high, roads were still prioritised. The study indicated thereby that hierarchy is not supported in a multimodal network in the ESRI Network Analyst.

For the sake of keeping both the multimodal network as well as a sort of hierarchy, the attribute drivetime was upgraded. The network dataset hierarchy was deleted, and a cost based on different road classes (vegkategor) was created. The drivetime was calculated as presented in table 4.

Table 4: Calculation of the attribute column Drivetime.

Attribute	Speed	Calculation
Vegkategor E – European road	15 km per hour	(Shape_Length * 60 / 15000)
Vegkategor R & F – National- and County road	10 km per hour	(Shape_Length * 60 / 10000)
Vegkategor K, P & S – Municipality-, Private- and Forest road	5 km per hour	(Shape_Length * 60 / 5000)
Vegkategor G – Walk- and cycleway	No driving	-1
Sea ways	20 km per hour	(Shape_Length * 60 / 20000)

The combination of the fastest and shortest path is preferred by the network route solver. A hierarchy is therefore built by assigning varied speeds to different road classes and sea ways. This hierarchy reflects the reality of an oversized transport as the speed is higher on larger roads and at sea. Walk- and cycleways are assigned the constant of minus one which is perceived as restricted. The placement of the route node on a “G”-road produces thereby an error.

The consequence of establishing a non-standardized hierarchy, as was done in the case study, is that the processing time, an advantage of the hierarchy, is lost. Nevertheless the outcome of a functioning network is preferable, despite increased processing time.

3.5 About DraGIS

The aim of the case study was to develop a GIS tool based on network analysis, with the emphasis to simplify the transport of oversized goods. The study has used an example in Statnett SFs transformer transport to point out obstacles and challenges in relation to oversized transport. In this section the GIS tool of the case study has been associated with DraGIS created by Kraftdragarna.

Kraftdragarna is a Swedish company responsible for immediate special transport as part of the management of the electricity supply (Kraftdragarna, 2009), in other words a Swedish version of Statnett Transport. Kraftdragarna have already pursued with GIS and developed the tool DraGIS.

3.5.1 The work flow of Kraftdragarna

The tool is first and foremost intended to search for information stored in a database, but is also used as a support tool for route solving. The map will, in addition to background information, display transport infrastructure, the location of goods, transfer stations and obstacles. The user interface makes search functions, distance calculations and route calculations available, in addition to standard functions like print, zoom etc.

At the moment the spatial data and enterprise specific data is saved as files on a file server. The information is available through GIS-applications which are installed on several personal computers. In the future, the object is to connect this information to both an ArcSDE server and to the computer network of Svenska Kraftnät.

DraGIS is designed to be as user friendly as possible; relevance, efficiency, attitude and readability are of importance. The development to improve this is still going on (Härdelin et al., 2004).

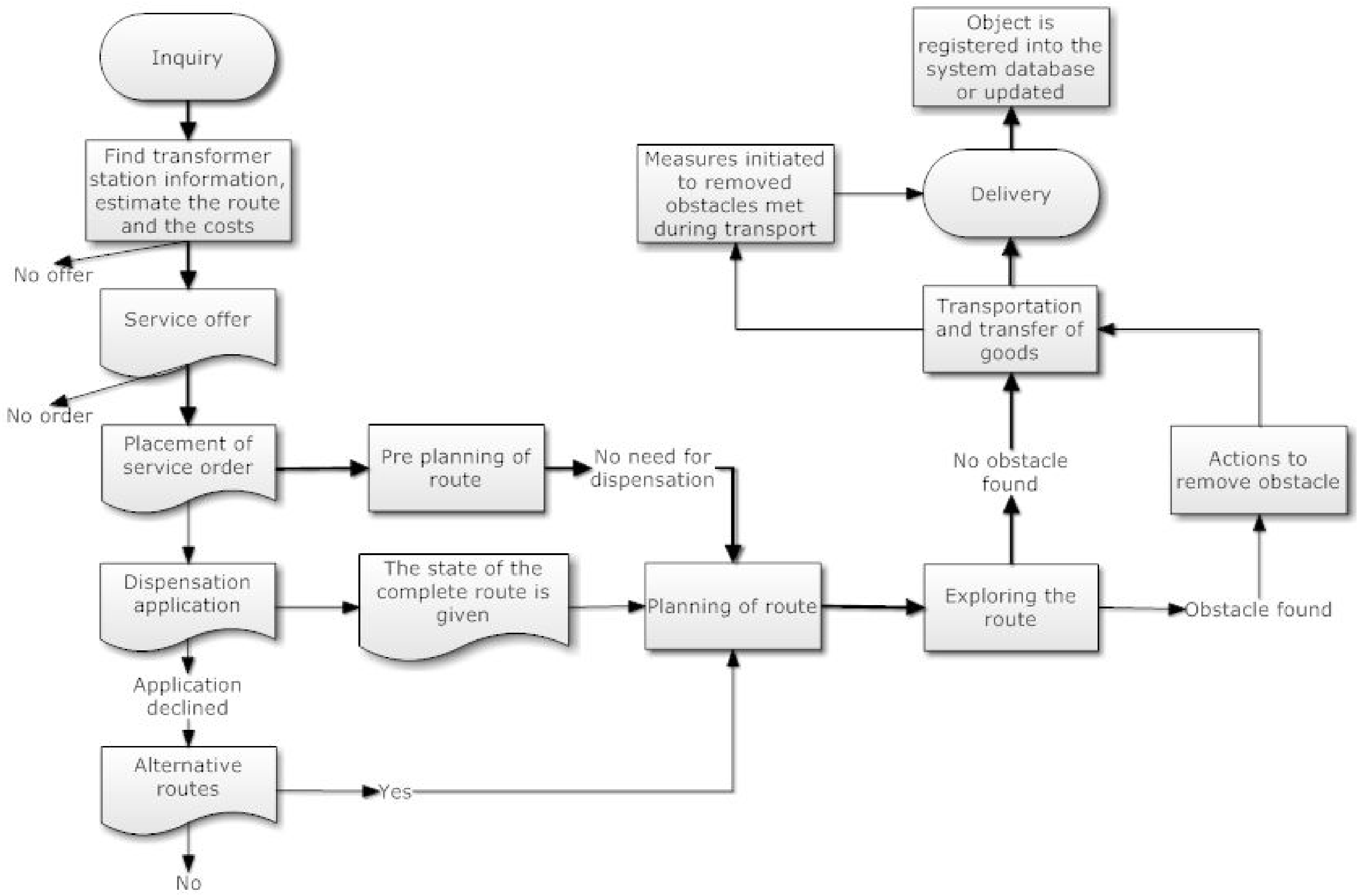


Figure 23: The work flow of Kraftdragarnas transport routines. Source: Härdelin et al., 2004.

By comparing figure 23 above with figure 11 in section 3.1.2, the transport routines of overdimensioned goods in Norway and Sweden seem to coincide well. In the figure of Statnett Transport AS the choices and dead ends are not presented as well as in the figure of Kraftdragarna. The routines, despite some difference in detail, are nevertheless the same.

Table 5: The workflow of Kraftdragarna and the relation to DraGIS. The table is based on information from Härdelin et al., 2004.

Scenario work flow	Possible relation to DraGIS
Incoming inquiry of a transport – A rough planning and cost estimation is brought about.	Search for relevant stations to plan for means of transportation
Placement of service order – Finding information and pre-planning of the good, means of transport, capacity and network. Decision of means of transportation.	Control of what transfer stations that exist and state information (including historical data) about both stations. Finding possible travelling route.
Hand in of a dispensation application(s) – in the case were official limitations are exceeded.	Map of the planned route or the problem area might be included in the application
Dispensation - is granted or declined and restrictions registered	Restrictions have to be put into the map. If the dispensation is declined a new route has to be found.
Planning of the route – the final route is planned in detail	Visualisation and road description
Exploring of the route –make sure that the planned route is passable (or not) and as many obstacles as possible are removed or adapted.	Register obstacles
Transportation and transfer of the good – the goods are picked up and delivered as agreed.	Route saved for eventual later use
Delivery and registration – the transport order is brought to a close	Storing of data

3.5.2 Comparison of DraGIS with the transformer transport tool of the case study

The transformer transport-tool's (TT-tool) largest difference to DraGIS is the focus on route finding. DraGIS is first and foremost a tool for visualization of database information, whereas the TT-tool first and foremost is a route calculating tool. The technical data and the data related to specific transformer transports are stored in different locations in Norway, while everything is stored all together in Sweden. Besides this, many similarities are found. Both tools present information in a user friendly way, present as much useful information as possible and seek to store all histories of performed transportation.

At the moment the TT-tool is saved as files in a file database, but for more extended use in the network system of both Statnett SF and Statnett Transport AS the objective, as in Sweden, is a set up of a connection to an ArcSDE server in a common secure network.

The data elements that are made use of in the GIS-tools both in Sweden and in Norway originate from different sources, however the contents are mostly the same; roads, sea ways, landfalls, vegetation, water, borders and built-up areas. The data elements which differ the most are the obstacle attributes such as driving direction, height- and weight limitations. In table 6 some of the different advantages and challenges of Sweden and Norway, related to oversized transport, are listed.

Table 6: Transportation in Sweden and Norway, a comparison. The table is based on information from Monsrud, 2009; Pham 2009; Statistisk centralbyrån 2009; Statistisk sentralbyrå – B, 2009.

Sweden	Norway
The glaciers have not made Sweden's terrain as topographically changing as Norway.	Relatively high mountains with perforating valleys or fjords leading to many tunnels, bridges and twisted roads
Have large possibilities by boat, but not perforating fjords leading in to the country.	A large part of the country is accessible by boat, especially because of the many fjords.

Has 1600 kilometres with good highway (per 2003) spread through the country, although a large share is situated in the most populated areas in the south. Generally the road standard is better than in Norway.	Has 253 km with highways (per 2008), a large share of them are located in the south-eastern part of the country.
The railway is not developed as much as in central- Europe, the length of track is 9899 km.	The railway tracks are little developed since 1946, the length is of only 4100 kilometres. In general the tracks grow older and older, this results in maximum weight limitations decreasing, in order to reduce strain.
The population is 9,2 million which implies for an oversized transport that: 1) There are a lot of populated areas to drive through which implies more traffic, smaller roads and generally more obstacles. 2) Because there are many relatively large settlements, the road infrastructure is well developed between these nodes.	The population is 4,8 million which implies for an oversized transport that; 1) There are a lot of populated areas to drive through which implies more traffic, smaller roads and generally more obstacles. 2) There are many medium or small settlements, the traffic is limited between settled areas and because of challenging topography, the dimension and standard of the roads can be problematic for oversized transport.

What we can see of the table is that obstacles or challenges are present in both countries. Each benefit from a long costal line and suffer under a little developed railway sector. It seems however that Sweden benefits from a much better road network and a more even topography than Norway. As Sweden needs to supply electricity to almost double the number of people in Norway, and additionally to industry, the power grid is presumably of a larger dimension than in Norway. This of course gives Sweden more to develop and maintain.

Additionally is there an aspect which has not been mentioned in the table. Both countries have large amounts of forest areas and wilderness without road infrastructure, making oversized transport naturally more difficult.

4 Results

4.1 Route analysis

4.1.1 The route

The duration of the final modelled route between Sylling and Stølen was calculated to be approximately 20 hours. The distance Sylling – Drammen took 2 hours by road, Drammen – Kristiansand 15 hours (at sea) and Kristiansand – Stølen 3 hours by road. Hans Nordskog in Statnett Transport AS stated that the duration of the undertaken transport was 21 hours, hence with a slight different distribution of 5 + 12 + 4 hours. The difference between calculation and reality was only one hour, a very acceptable divergence.

The small difference in durations seems like a coincidence as the actual route calculated on the criteria's of the case study deviates from the route of the undertaken transport. This is displayed and discussed in tables 7 and in the next section.

Table 7: Modelled and actual route from Sylling to Stølen, calculated in ArcGIS and driven by Statnett Transport AS. The table is based on information from Statnett SF – D, 2009.

Obstacle nr.	Modelled route	Comment	Actual route	Comment
	The transformer station Sylling		The transformer station Sylling	
1 / 1	Svarthavnveien	It would have been desirable if the modelled route travelled right to Vestsideveien. This road has a locked bar, probably owned by Statnett SF	Svarthavnveien	Through-transport was prohibited by a locked bar, probably owned by Statnett SF.
1 / 8	Ned Bråtaasen	This road had weight restrictions	Vestsideveien F21 northwards and eastwards	The route travels over a river, on a bridge that is not given as a road medium.

1	Gifstadbakken	This road had weight restrictions	Modumveien R284	
2	Vestsideveien - F21 southwards to Lierbyen	There was a bridge on this road which had to be calculated in relation to axel load.	-	-
3 / 3, 4, 9 & 10	Ringeriksveien – R285 southwards to E18 at Åby	The road passed under a road bridge, the height was not given.	Ringeriksveien R285 southwards to Lyngakrysset	Three bridges and one underpass are travelled on this section. Obstacle number 10 is not stored as a road medium.
4 & 5 & 6	E18 southwards to Brakerøya	The road passed beneath a road bridge twice and over it once, the height restrictions were not given.	Lierbakkene R282 southwards parallell with the E18	
7 / 11 & 12	Strandveien - R282	After driving off the E18 an underpass, crossing under E18 is travelled	Strandveien R282	The route is passing under two bridges, the height is not given.
	Jacob Borchs gate		Jacob Borchs gate	
	Drammen landfall		Drammen landfall	
	Sea way: Guldholmen – Drammen	←→	Sea way	Information about the exact sea way, from the actual transport, was not given. The transfer at sea should approximately have followed the path described for the modelled route.
	Dyna – Hallangstangen			
	Færder – Langesundsbukta			
	Langesundsbukta – Jomfrulandsrevet			

	Jomfrulandsrevet – Oksø			
	Kristiansandsfjorden			
	Kristiansand landfall		Kristiansand landfall	
	Lagmannsholmen		Lagmannsholmen	
	Gravane		Gravane	
	Vestre Strandgata - R471		Henrik Wergelands gate	
13	Dronningensgate – R471	There was a bridge on this road (road medium L) which would have to be calculated in relation to axel load.	Møllevannsveien F30 northwest to Krossen	
	Østerveien – R471		-	-
14	Torridalsveien – F1 north-west to Mosby, øvre.	There was a tunnel with a given height restriction of 4, 3 meters in Mosbyen, therefore a detour northwards on Venneslaveien was driven instead of a more direct route towards south-west.	-	-
	Venneslaveien - R405 northwards to Vennesla		-	-
15	Drivenesveien – F7	There was a bridge on this road which would have to be calculated in relation to axel load.	-	-
	Ravnåsveien - F7 to Mosby, øvre		-	-
	Venneslaveien - R405 south-westwards		-	-

16 / 18	Setesdalsveien – R9 north-westwards	The route traversed a bridge before travelling along with the actual route in the roundabout.	Setesdalsveien R9 northward passing Mosby	This road had a height barrier which excluded the modelled route from driving there, the actual route however did traverse barrier nr 18.
17 / 17	F75, Eptesvannsheia to Stølen	The transport had to go through a tunnel, the height restriction was not given.	F75, Eptesvannsheia to Stølen	The transport had to go through a tunnel, the height restriction was not given.
	The transformer station Stølen		The transformer station Stølen	

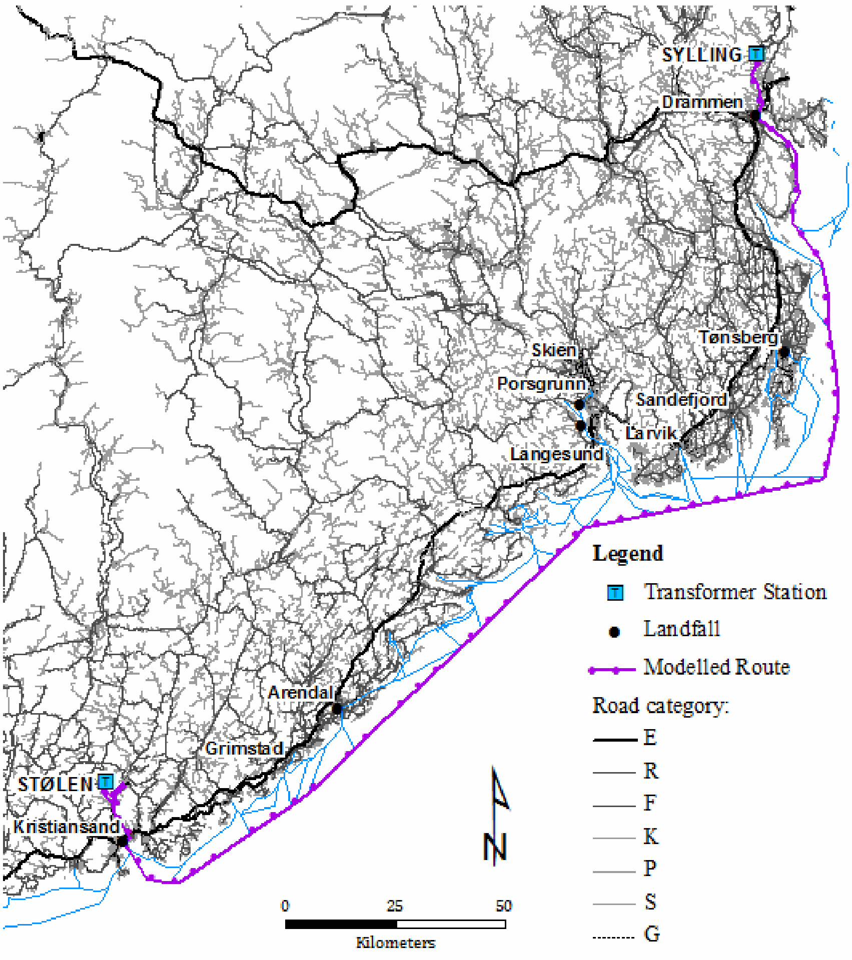


Figure 24: The final modelled route, Sylling to Stølen.

4.1.2 Comparison of the actual and the modelled transport routes

Except for the sea ways which have been difficult to compare exactly, the routes by road turned out to be quite different, even though the total time frames were almost equal.

On the stretch Sylling – Drammen, figure 25, the time difference, between the modelled route and the time given by Nordskog (2009), was as much as 3 hours. The main explanation for that was that the actual route was longer than the modelled route. Furthermore there were probably challenges on the route, resulting in slower speed. The actual route calculated through the same method as the modelled route gave interestingly three hours of transport. This implies that, given that the numbers are right, approximately two hours (5 hours – 3 hours) were used for problem solving and slow driving.

The reason for the actual route taking a longer path than the modelled route was because the modelled route had an overall lower road standard (roads and bridges), was more trafficated (E18) and was not consented by the NPRA (Nordskog, 2009). This was despite the fact that the modelled route had a shorter travelling length and fewer obstacles, 6 versus 8. Considerations made, based on data that has not been included in the case study, may have caused the difference in route.

The overall result, based on the premises made use of in this study, was that the modelled route was better than the actual one. Given that the route would have been approved by the authorities, several hours could be saved in transport. Even if two hours of challenges, calculated for the actual route, were added on to the time of the modelled route, the latter would still be better. In such case the oversized transport time between Sylling and Drammen would decrease with approximately one hour; from 5 hours to 4 hours.

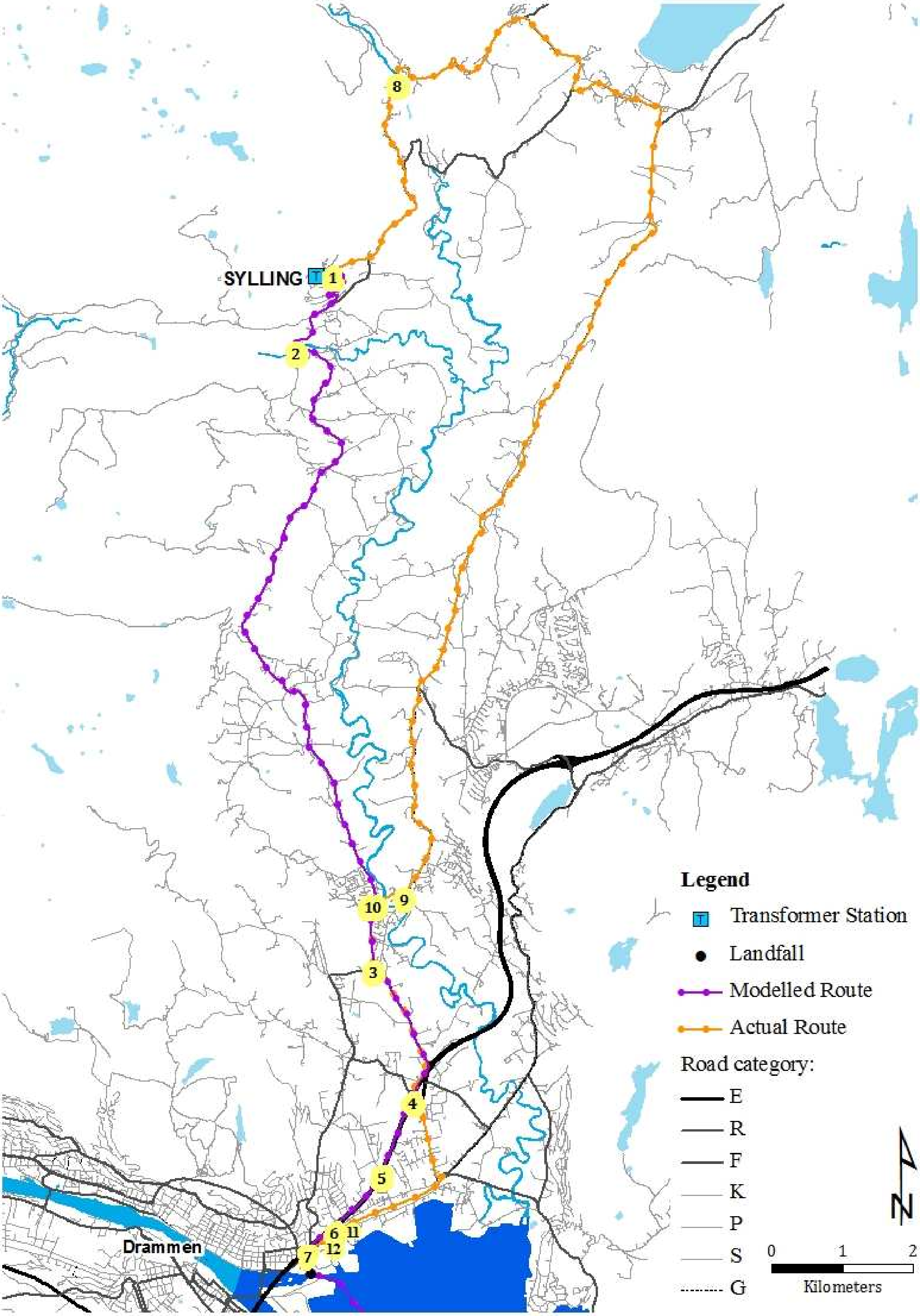


Figure 25: The modelled and actual routes between the transformer station Sylling and the landfall at Drammen harbour. The marked numbers represent obstacles.

On the sea ways distance between Drammen and Kristiansand the difference between the modelled route and the actual route was 3 hours. The modelled route followed given sea ways, whereas the undertaken route might have deviated from that shipping lane. By deviating from the shipping lanes, some time could have been saved by sailing closer to land or navigating smoother seas than the sea ways designated in the study. Nevertheless the exact sailing route has not been available, and further comparison has therefore not been possible.

On the stretch Kristiansand – Stølen, see figure 26, only one hour separated the two routes in time. The time difference in favour of the modelled route was despite a detour which the modelled route was forced to take due to a barrier (nr. 18). The duration of the actual route was given to be four hours, whereas based on the premises of the case study, the time aspect was down to two hours. Two hours stands more in relation with the three hours calculated for the modelled route. Despite the detour, the routes traverse pretty much the same spatial area, just on opposite sides of the river Otra. If the time aspect of two hours driving is correct, problem solving and slow driving would account for two hours on the actual route. If those two hours were to be added on to the modelled route, the time aspect would be approximately five hours. That sounds logical, as the indifference between the modelled route included additional obstacle time and the actual time could be explained by the detour.

The modelled route was not an ideal route, as it had to cross three bridges and drive through two tunnels, in contrast to the actual routes height obstacles. It was however positive to see that impassable barriers were avoided, demonstrating that the network was indeed functioning. Nevertheless was it interesting to note, that before the barriers were implemented in the network dataset, the modelled route was solved in about the same way as the actual route. The obstacle that made the two routes so different was a height barrier at R9 at Krossen. The barrier was set to be 4, 3 meters high in the dataset from the NPRA, which is normally too low for an oversized transformer transport. Before the undertaken transport, however, the survey team measured this underpass to have an actual height of 4640 mm. This was high enough for the transport which measured 4470 mm. on that actual transport. The modelled route would in other words be different if the given data sources had been more accurate. The modelled route could thereby have had two obstacles instead of five.

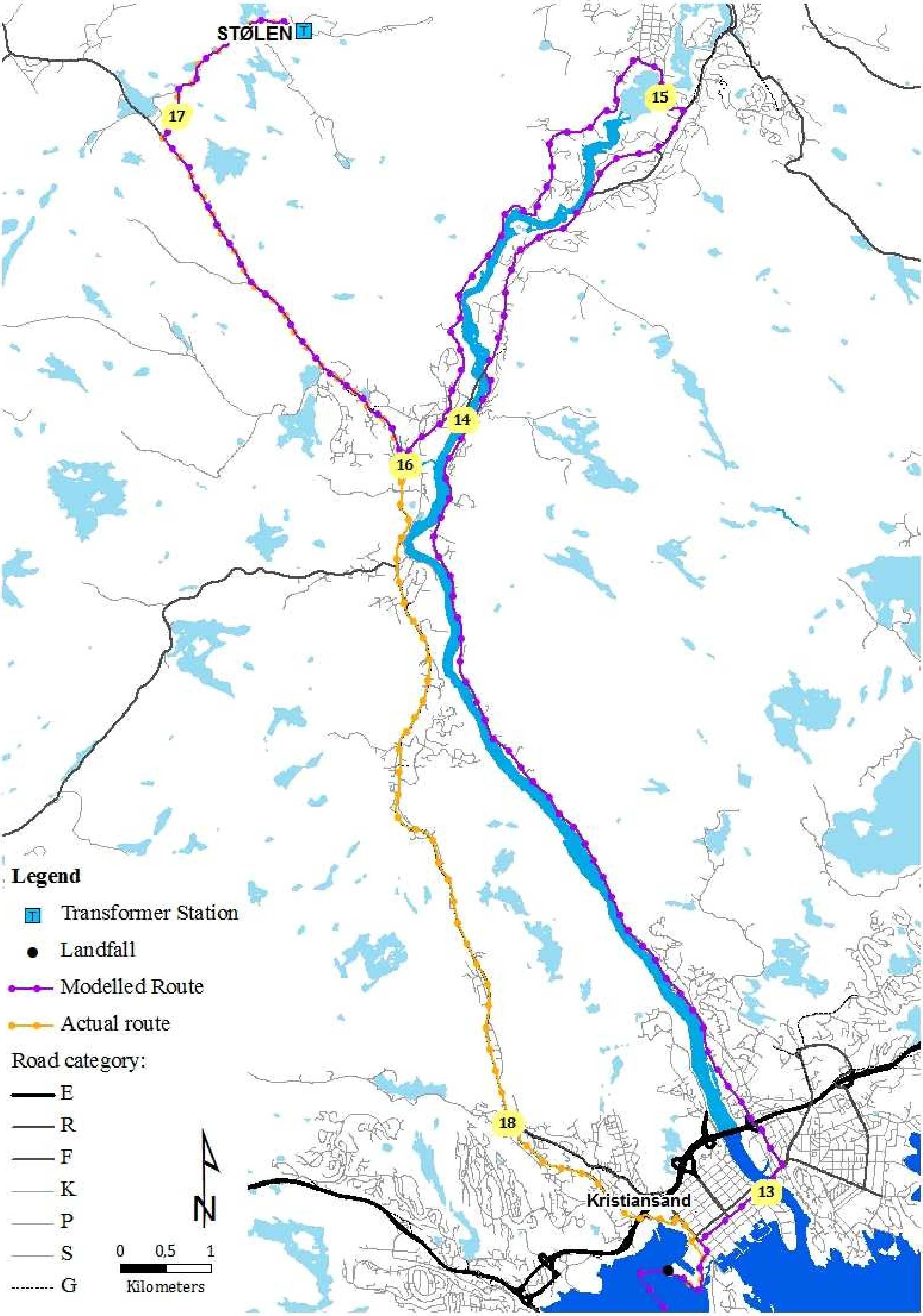


Figure 26: The modelled and actual routes between the landfall at Kristiansand harbour and the transformer station Sylling. The marked numbers represent obstacles.

4.1.3 Obstacles found on the routes

The obstacles described in the former section 4.1.2 are displayed and commented below. They are numbered based on the yellow circular labels in the figures 25 and 26.

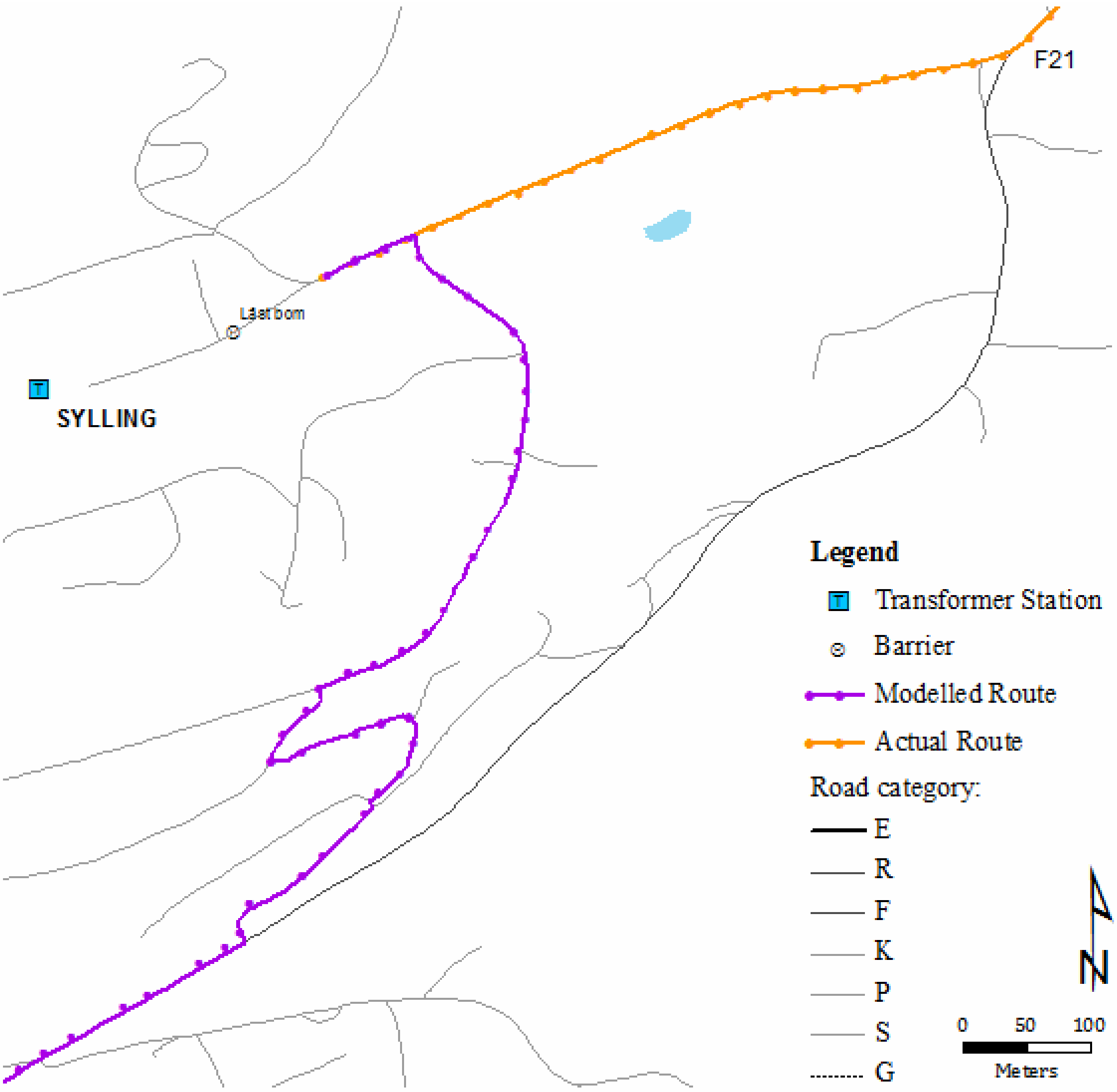


Figure 27: Obstacle nr. 1, locked bar and curvy slope, Sylling

1. The route chose to take local roads down a curvy slope, instead of running straight to the County road F21 as the actual route does. The network did, however, neither know that the road was steep and had weight limitations, nor was the costs of the hierarchy high enough to overrule the advantage of the shortest route.

There was also a locked bar just before the transformer station of Sylling, a barrier set to non-traversable. On that location however, one could assume that the locked bar was the security gate to the station and that admission was of no further problem.

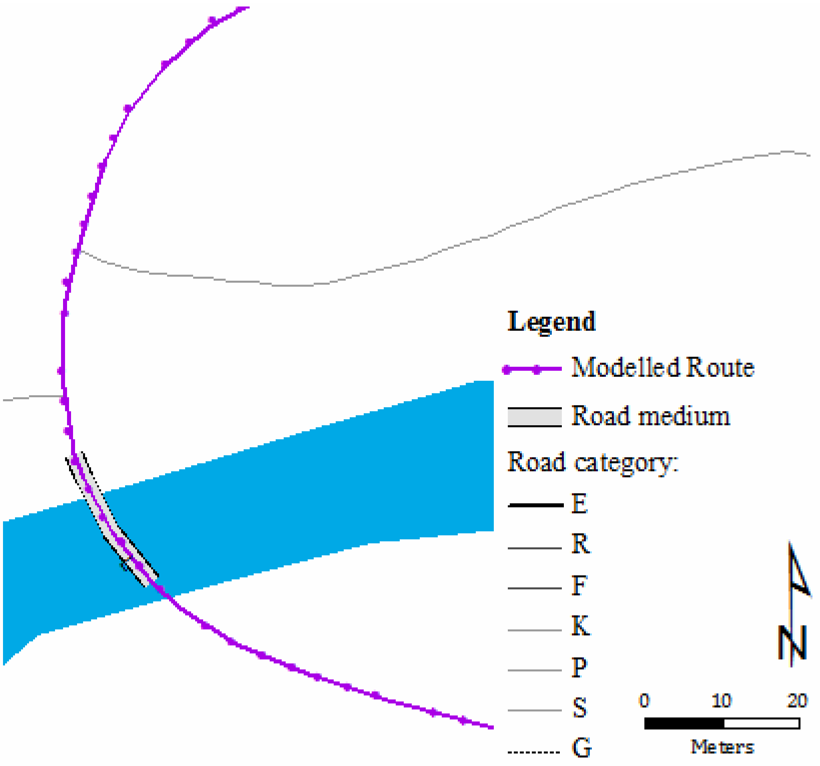


Figure 28: Obstacle nr. 2, bridge, Vestsideveien (F21)

2. A bridge above a river. The axel load limitation was set to 50, the highest possible in the dataset. The bridge has nevertheless to be calculated before any real transport is allowed to traverse.

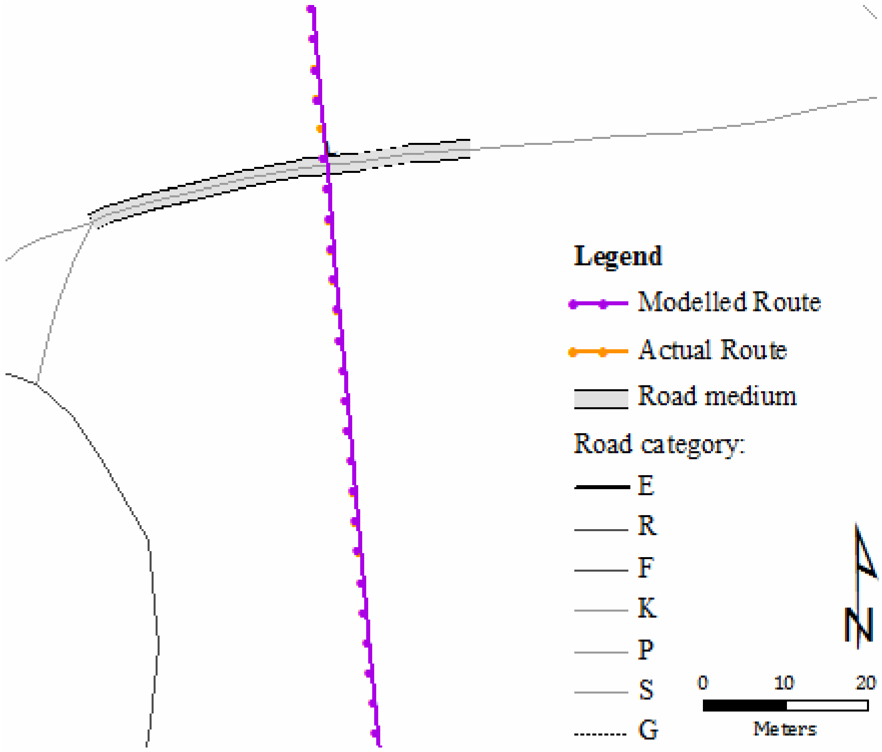


Figure 29: Obstacle nr. 3, bridge, Ringeriksveien (R285)

3. Ringeriksveien is the stretch where the actual and modelled routes for a distance travel the same path. Through the attribute Road medium of Elveg, bridges (L), tunnels (U) and constructions (B) were labelled in the road network. A bridge was therefore found crossing the route, indicating that the route travelled beneath it. Information about the height from the road surface and up to the bridge was not given. To get this information, a survey would have had to be undertaken or detailed measurement in orthophotos performed.

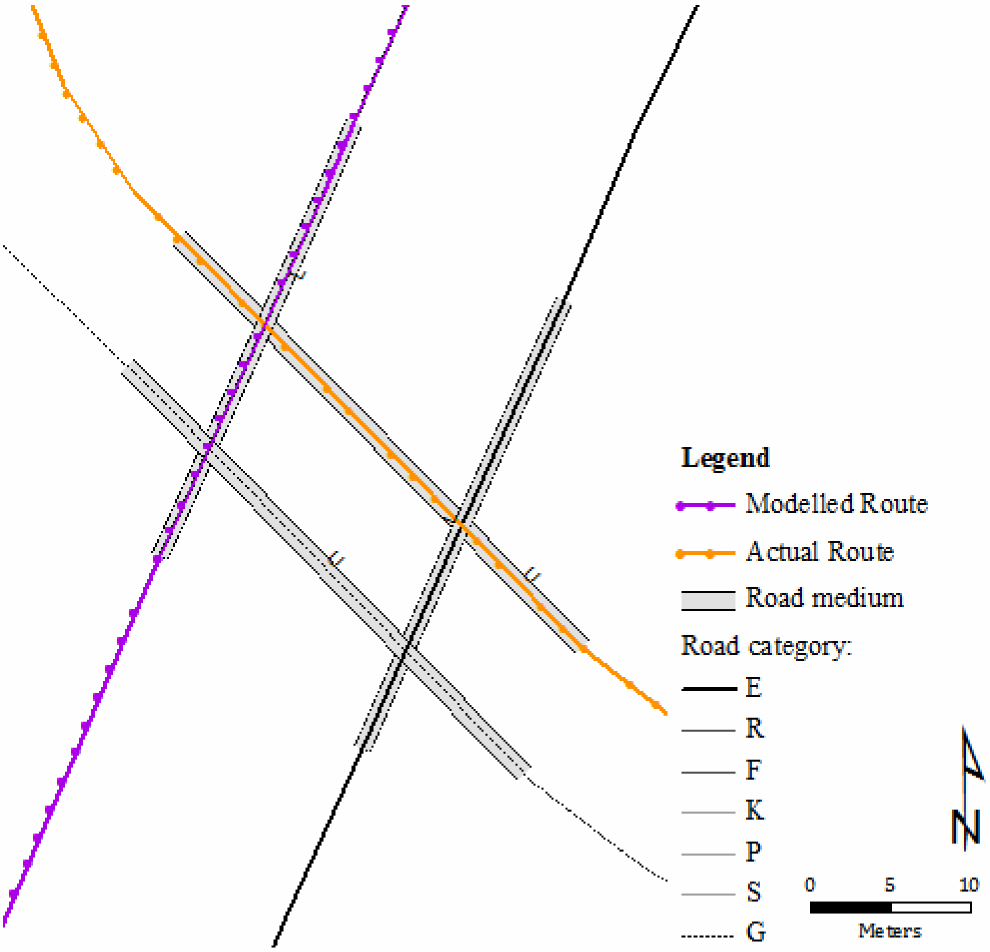


Figure 30: Obstacle nr. 4, bridge & underpass, E18 & Ringeriksveien (R285)

4. In this section a bridge and an underpass were marked by the Road Medium attribute. The height would not play any negative role to the modelled route, as the route was travelling on the bridge, hence could play a role to the actual route passing under. The bridge would have to be calculated before driving permission could be received.

Figure 31: Obstacle nr. 5, bridge, E18

5. Another Medium L was found on the European road E18. In the dataset the total vehicle weight was set to 50 tons, the highest possible.

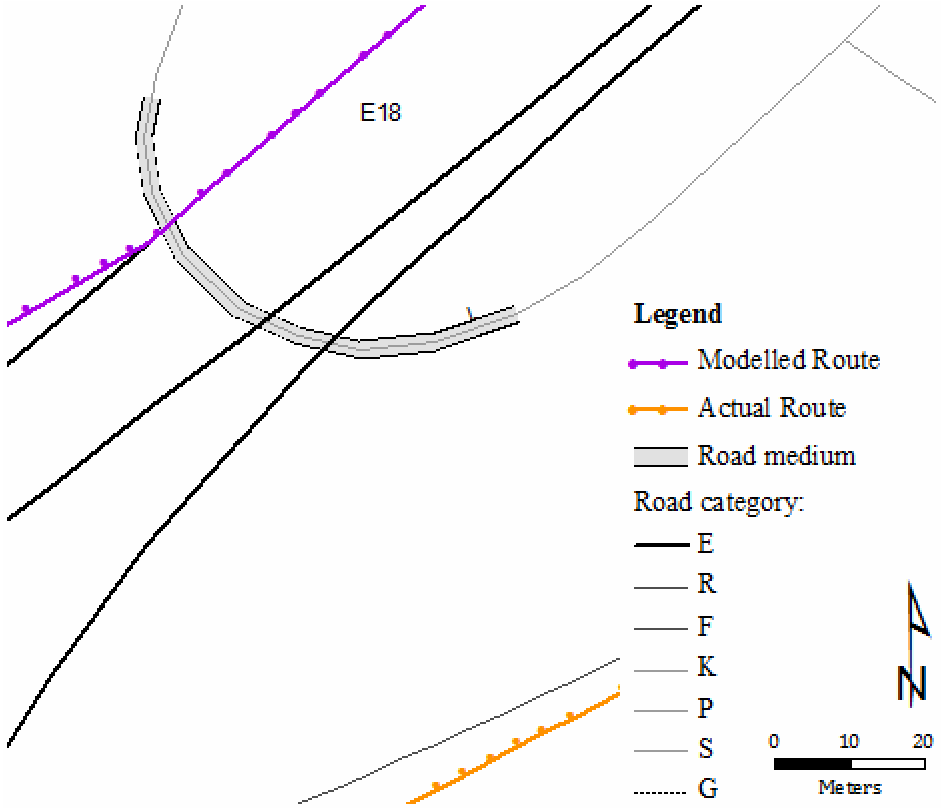


Figure 32: Obstacle nr. 6, underpass, E18

6. This map displays a typical underpass which was not registered with a height restriction in the dataset. It was neither registered as a Medium U, indicating that the road on the route passed below an installation, nor as a height barrier. It could possibly be an obstacle for an oversized transport if the height beneath the bridge, passing over, were too low. The height information was regardless not given, and therefore this possible obstacle was only commented and not included as a barrier in the network. The actual route travels parallel to E18 on Strandveien in the lower right corner of the figure.

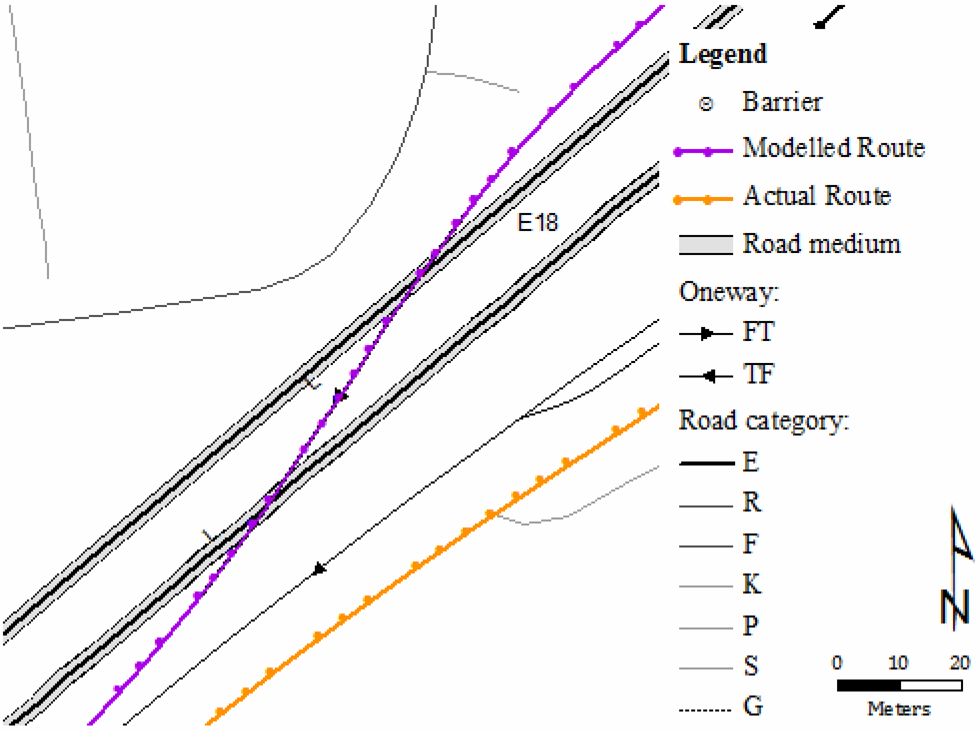


Figure 33: Obstacle nr. 7, underpass, E18

7. The modelled route has to travel under the E18 bridge, road medium L, in order to arrive at the landfall in Drammen. The height is not given. The actual route is travelling on a local road, Strandveien, beside.

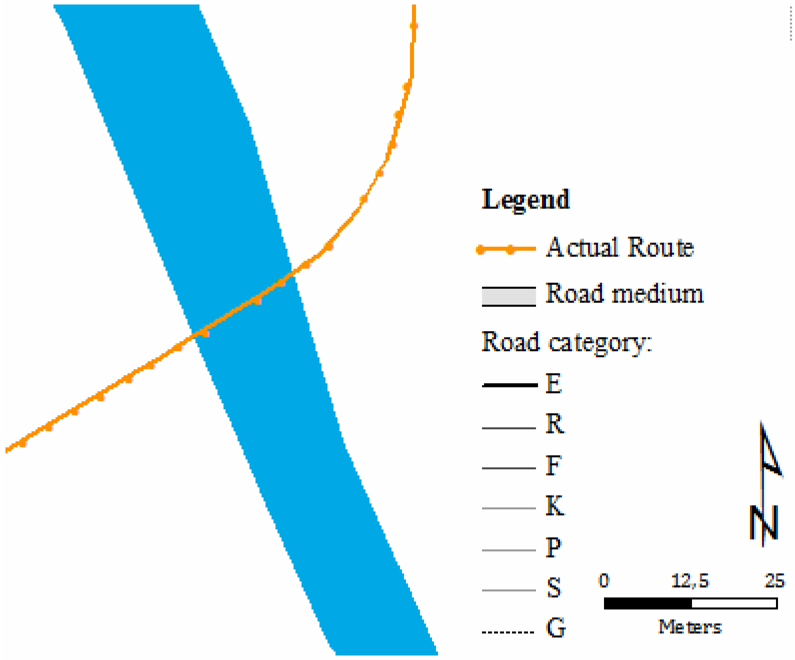


Figure 34: Obstacle nr. 8, bridge, Vestsideveien (F21)

8. A bridge had to be traversed across a river hence no further information about the obstacle was available. Although there is no road medium indicating a bridge, the map uncovers the fact, which is in correspondence with words by Hans Nordskog.

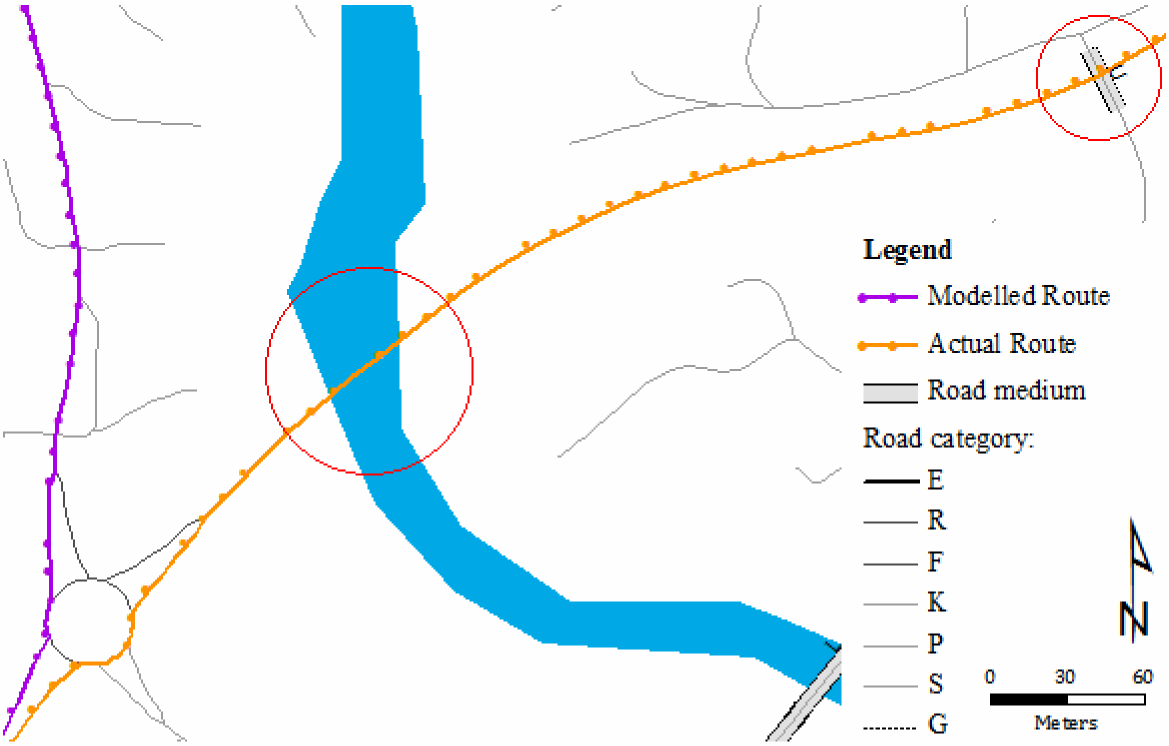


Figure 35: Obstacle nr. 9 & 10, bridges, Ringeriksveien (R285)

9, 10. Before the modelled and actual route meet in the roundabout, the actual route encounter two possible obstacles. At obstacle nine, a road medium U is crossing under the actual route indicating that the route is travelling on a small bridge. Obstacle number ten, such as number eight, is a point where the actual route is crossing a river. No height or road medium is given, but as the route is crossing the river, there has to be a bridge at that specific point.

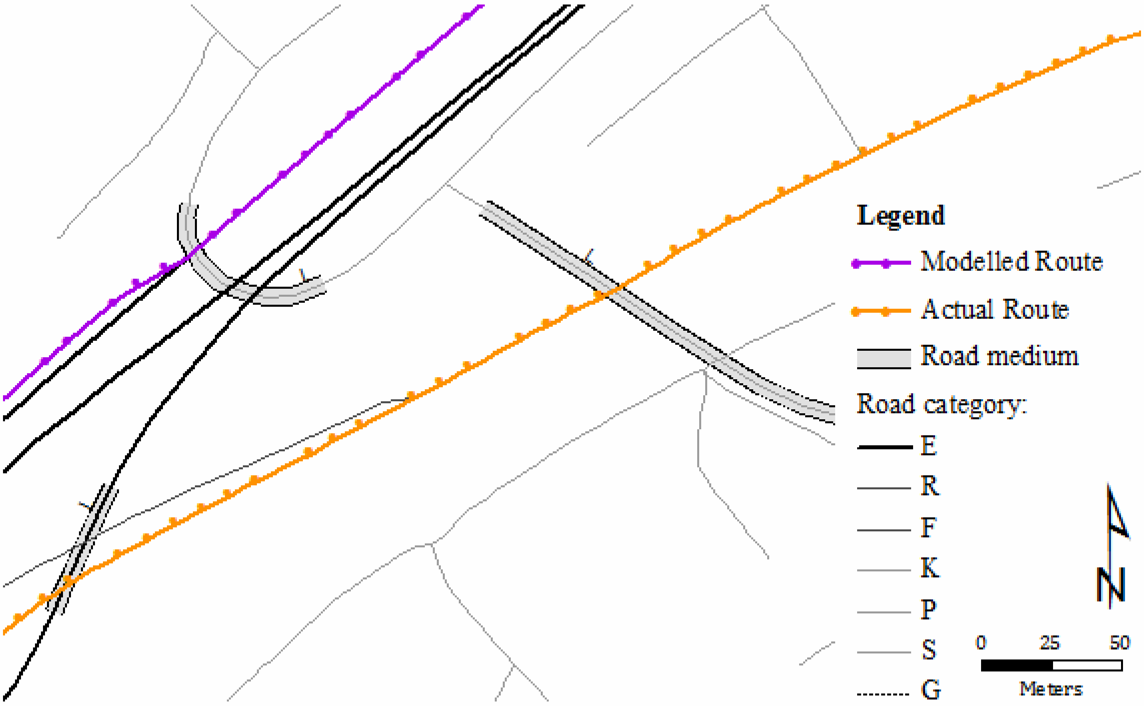


Figure 36: Obstacle nr. 11 & 12 (with nr. 6 above), underpasses, Strandveien (R282)

11, 12. The actual route is driving on the national road nr 282 in order to get to the landfall in Drammen. As the actual route and Strandveien is crossing two bridges it is to assume that this is done beneath. Two underpasses are thereby found, although the height is not given. The height is however probably of no problem because the actual route has been travelling there in reality.

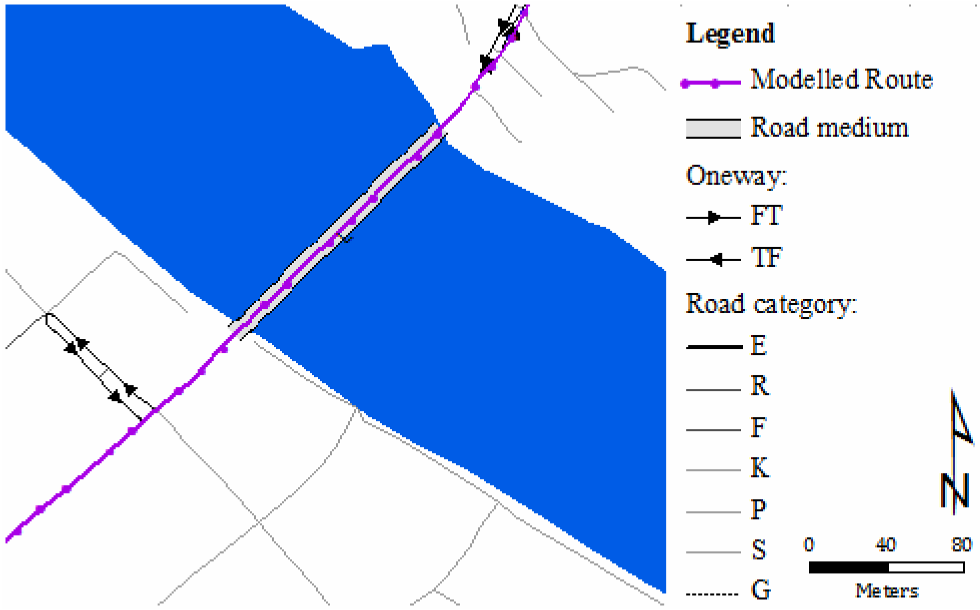


Figure 37: Obstacle nr. 13, bridge, Dronningensgate (R471)

13. This bridge, coded as medium L, was a relatively big bridge. It was assigned the highest total vehicle weight of 50 tons. Calculations and authority consent would be needed before usage.

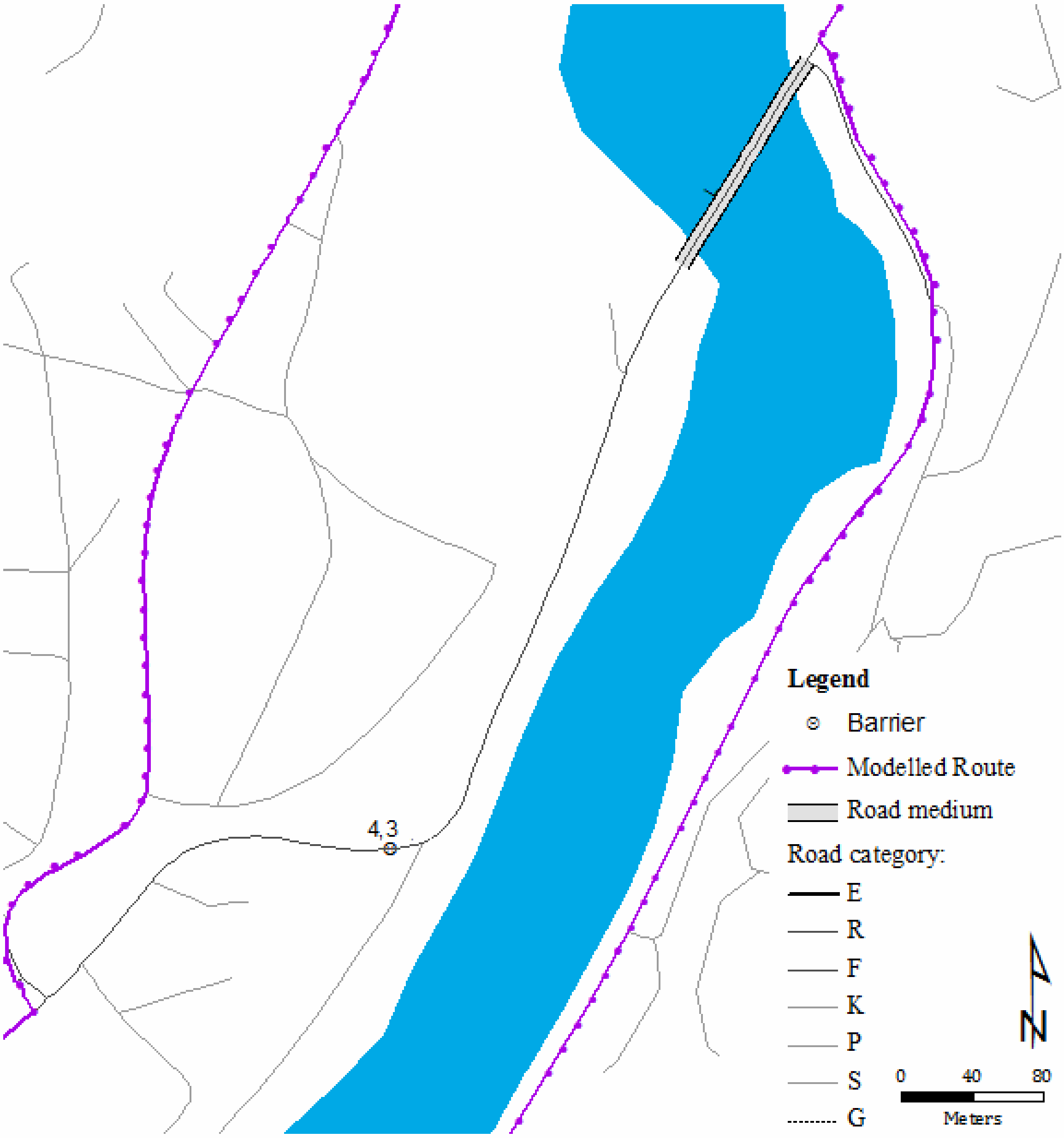


Figure 38: Obstacle nr. 14, bridge and height barrier, Venneslaveien (R405)

14. At Mosby, there were both a height restriction and a weight restriction (50 tons) causing the modelled route to make a detour around the problem area. In fact it was the height barrier that caused the detour. Although the bridge might have been an impassable barrier, it would not have been known for sure before the axel load was calculated. The bridge was therefore only set as a label and not a barrier in the map analysis.

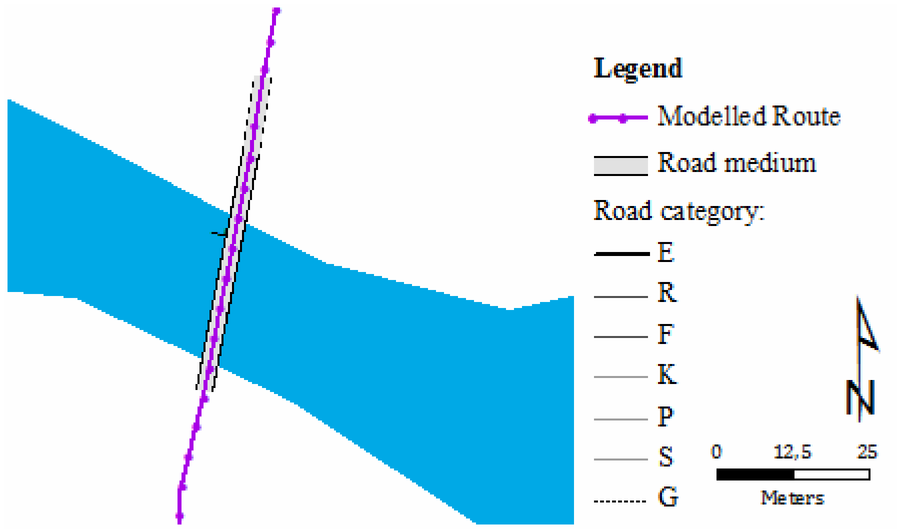


Figure 39: Obstacle nr. 15, bridge, Drivnesveien (F7)

15. On the detour another bridge had to be passed. The weight restriction was registered to 50 tons, calculations would be required.

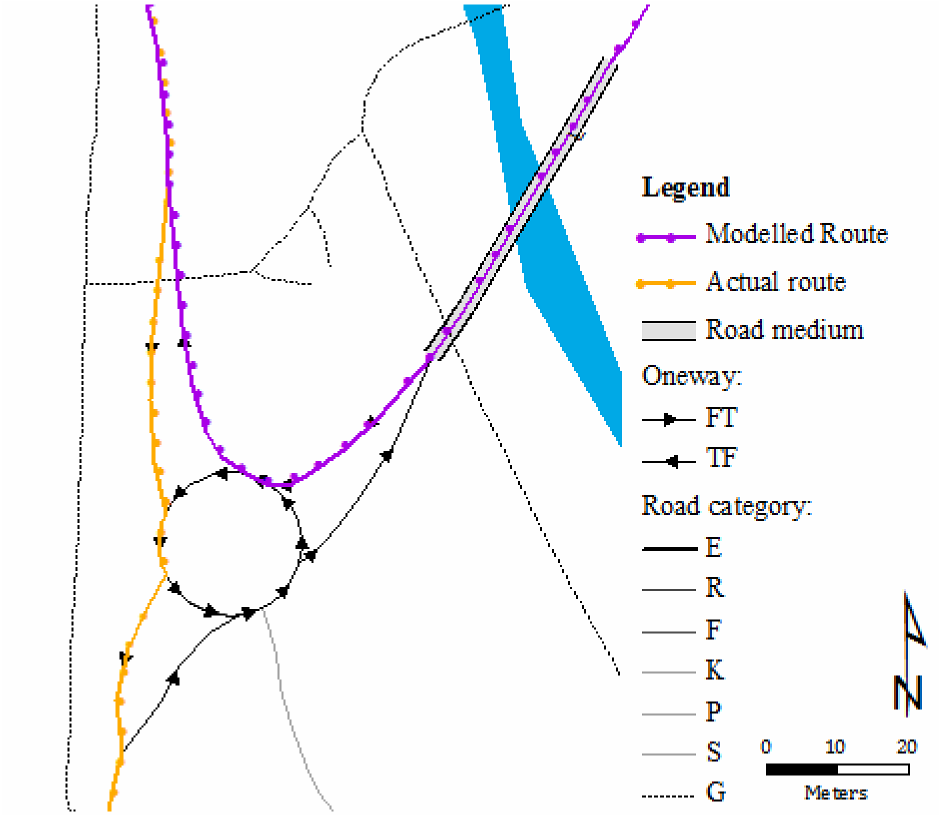


Figure 40: Obstacle nr. 16, bridge and roundabout, Setesdalsveien (R9)

16. At this point the modelled and the actual route joined together to travel the same path to the transformer station of Stølen. The modelled route came from north-east and had to cross a bridge (50 tons) before going towards the north on R9, as opposed to the actual route which came from the south on R9. Both routes would have to drive into the roundabout.

Figure 41: Obstacle nr. 17, tunnel, F75

17. On the last road section before ending at the transformer station of Stølen a tunnel, Medium U, was reached. The height was not given, moreover it was assumed it would not cause any difficulties as transportations occur there from time to time. As a routine the height should of course be controlled.

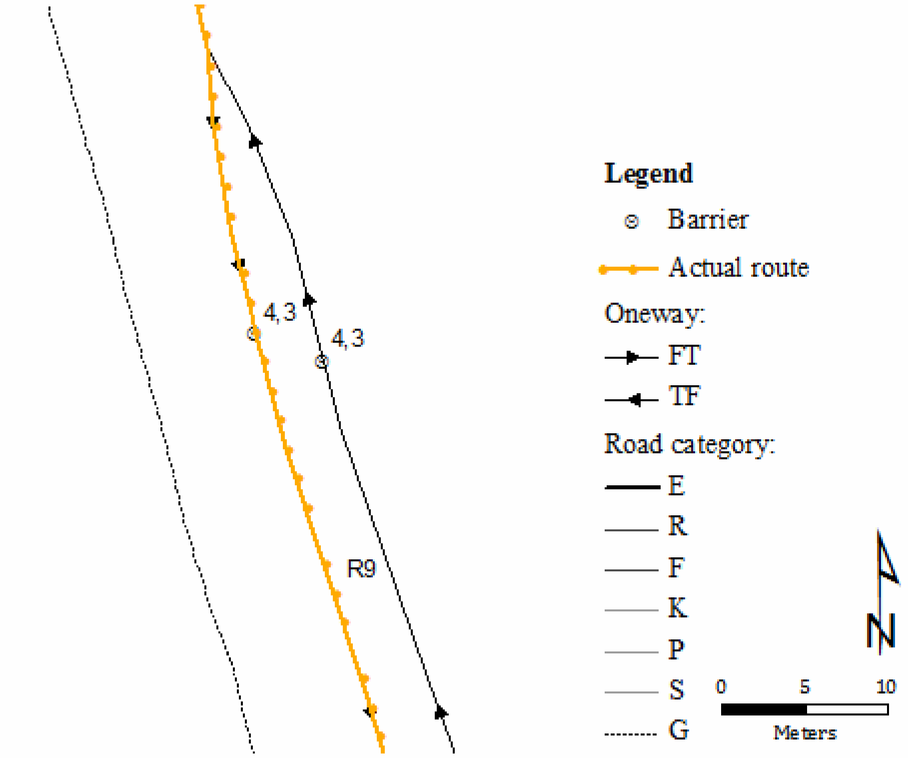


Figure 42: Obstacle nr. 18, height barrier, Setesdalsveien (R9)

18. This is the height restriction on R9 at Krossen. As one can see, the barrier was impassable for the modelled route, because the height was set to be 4, 3 meters. In reality however it was measured to be 4, 64 meters, making the barrier a manageable transport challenge. A barrier could here have been exchanged with some time impedance if the accuracy in the data had been better, or information from the actual transport had been organised and implemented in a dataset.

4.2 Method development

4.2.1 The method development process

Throughout the study several ideas and theories were tested and mistakes corrected, the final result however was an outcome of the method flow presented in figure 43.

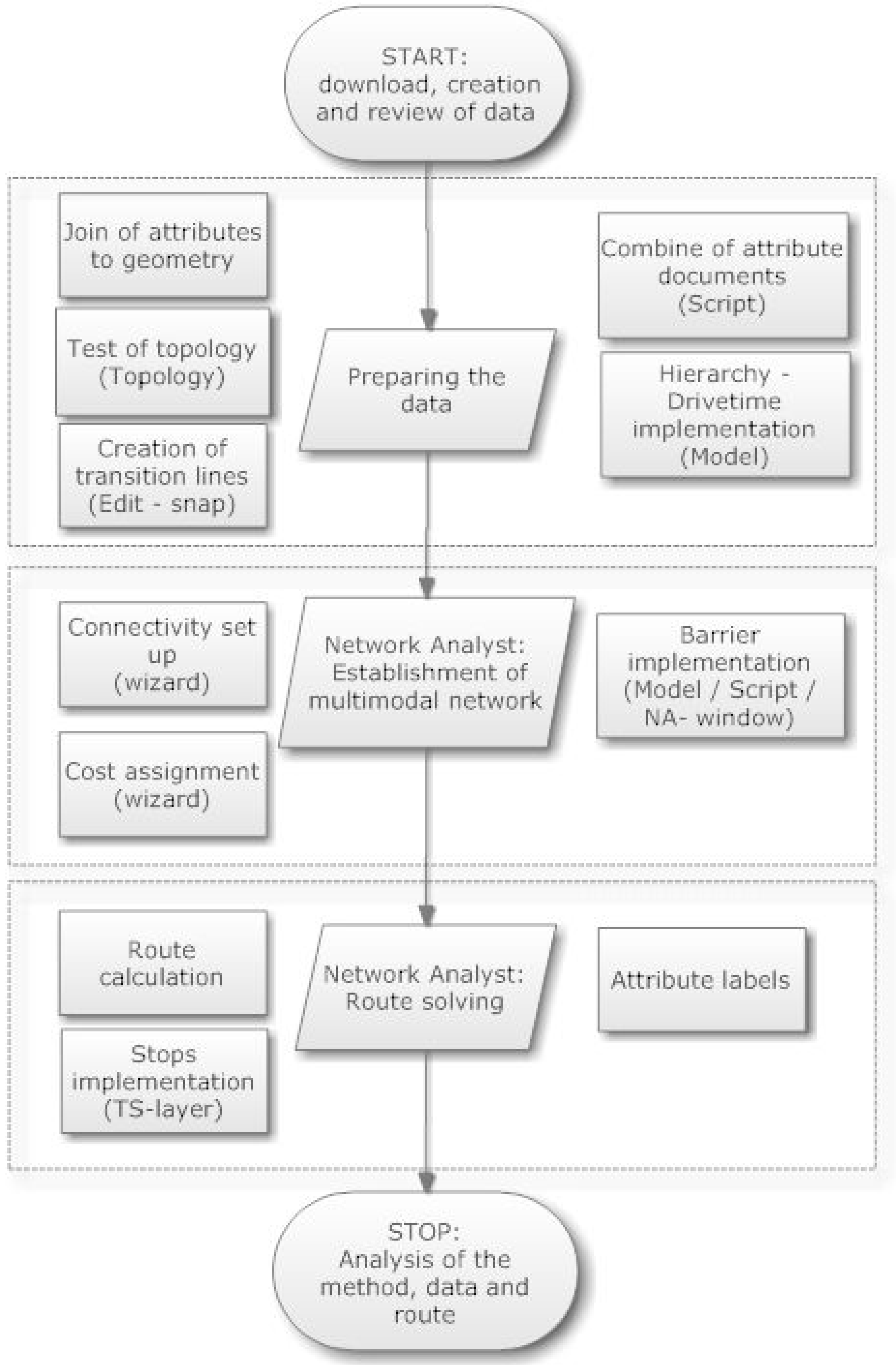


Figure 43: Method flow diagram.

The creation of a route finding GIS tool had many different combinations of elements during the case study, the final relation among the elements is however presented in figure 44. The last and at present well working combination was built based on three sources of data; NVE via Statnett, self-created and Norway digital. The output from those sources were six layers; Transformer station, Landfall, Sea way, Background data (several layers as water, borders etc.) and the Electronical road-net. The Electronical road-net was the fundament of the barriers; road block, height, driving direction, road medium, weight and speed. The hierarchy and multimodal connection was based on the layers; Landfall, Sea way and road-network.

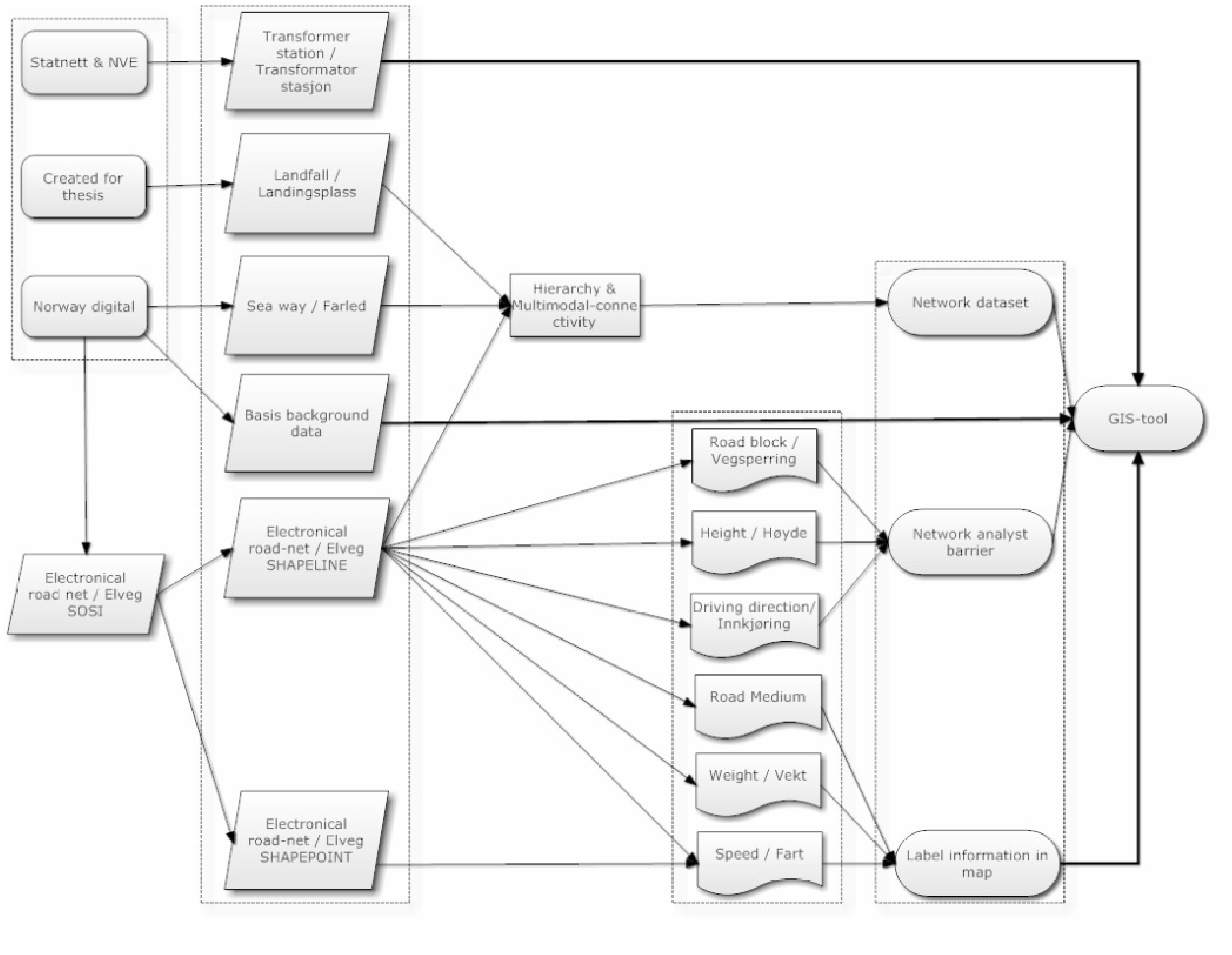


Figure 44: The method development process, flow chart

The method developed is a good basis for a professional tool, hence before such an implementation could take place, a unified storage policy would have to be implemented, data would have to be included for the whole country, the attribute data's completeness improved and the data given better accuracy. This method development was however a good contribution towards improving preparedness of oversized transport by visualizing and calculating routes and obstacles, by collecting data and by simply focusing on the theme.

5 Discussion

The transport of oversized goods is a highly specialized business. Local conditions and regulations play a very important role, making comparison to other transport businesses hard. Research in this field is therefore not very widespread. Moreover reuse of methods is difficult. Literature may give a pointer to fundamental elements to include in an analysis of oversized transport, but are seldom in direct accordance.

As literature was relatively scarce on the subject, the starting point of the study was to get an overview of how the transport is carried out at present, which obstacles that are problematic and to what extent the obstacles are. Accompanying an actual oversized transport and conversations with the manager for Land Transport in Statnett Transport AS, Hans Nordskog, was therefore relevant. The information gained on the field trip has influenced the decisions made throughout the study. There is the risk that too much of the method development and final result has been based on the impressions gained on the field trip and the general collaboration with Statnett SF. On the other hand, this knowledge has lead to understanding and insight.

The developed method does not change the way of transport, but introduces ideas for re-organisation and the adoption of new technology. The recommendations given or results found cannot be imposed on anybody. In order for the thesis results to become of value, people in the oversized transport business have to make use of these conclusions, and develop them further into their own product and for their own needs. Nevertheless the hope is there that awareness on this subject has risen with this thesis and that new insight or inspiration is obtained by the reader or the business.

The transformer transport of Statnett Transport AS is considered to be a good example of oversized transport, due to the dimensions of such a transport and because the combination of vehicles used is unique in Norway. Larger transport by road or railway in Norway is not possible. By creating a method for road calculations based on those dimensions, method re-use is made possible as the data input adaptation from larger to smaller transport is assumed to be easier than the other way around.

The aim of this thesis is to develop and present a GIS tool based on network analysis, with the emphasis on simplifying the transport of oversized goods. In that respect it must however be mentioned that there already exist procedures and plans for both planning and implementation of oversized transport. Several people work on this daily. This thesis has in that manner not been innovating, nor was it intended to be so. This study is an opportunity for re-thinking and re-structuring of existing routines. It does not imply that the organisation of today is poor. Rather it implies that the work done today is good, but could be even better.

The input of data in the case study is based on the student's considerations and the available data. The current combination of layers and attributes was found best at the moment of consideration and has lead to interesting results. Much information was however discovered during the development process, if they had been discovered earlier on, other considerations would possibly have been made. Examples of possible data input are seasonal changes, cable-spans crossing roads or working hours and resting restrictions (Hasle et al., 2007). In later processes the decisions made in this study may be overruled by new knowledge or aspects. One must however keep in mind that the broad option of input is both an advantage and disadvantage.

As Bella and Iida, 1997, state; *Choices made today, depend on costs yesterday!* The data that is collected will, put in another way, never be up to date, because reality has already changed even before the newest data is implemented. An oversized transport is therefore likely to meet unexpected obstacles on any route. Due to the change of reality, it is not possible to prevent obstacles, but it is possible to reduce the probability of them occuring. Furthermore this statement of Bella and Iida does not imply that newly collected data has poor quality. It does however emphasize the vulnerability connected to the presentation of reality. They recommend that considerations, of the relationship between presentation and reality, should be made before data are combined and employed.

The data employed during this case study was sufficient for this method development, for prospective professional use however the quality has to be re-considered. In the course of this study, by testing and reviewing the data, several drawbacks were found. For example height limitations on roads are incomplete and inaccurate, the landfall data suffer from inaccurate coordinates, while sea ways experience some trouble with presenting actually driven routes.

Moreover various information were left out of the case study, for example topography, due to unavailable sources.

A longer project period and more resources could probably have solved the issue of unavailability. The transition between sufficient and abundant information is however very fine, more information would not necessarily improve the analysis, but only improve the option of input. As Frank et al. (2000) states; *Usually there is no "best" route. Minimizing one criterion typically conflicts with minimizing another. By an iterative process of displaying routes, using different solution methods and creating detours, a compromise route can be developed.*

If the method is further developed an improved input option would be preferable, in so doing adaptation for special needs would be extended. In such a case one analysis could be carried out on the physical route obstacles, while another on road environment and location. In fact that was more or less the goal at the beginning of this project. By mapping the whole country several comparisons on calculated routes, road conditions and special regional adaptations could have been performed. The project had, however, to be narrowed down as especially data collection and data preparation turned out to be very time consuming.

At present the data used and referred to in this project, is stored and managed by several parties. Some data is stored with the NPRA, some at the Statistics of Norway, other data at NVE and NCA, some are stored on different database locations at Statnett SF and of course some data is stored only in people's minds. Luckily several data have been available through the cooperation Norway digital, making orientation easier.

A positive thing is that several parties are interested in establishing and managing geographical data. Moreover different data are stored at several enterprises, limiting the consequences of break-down or administrative errors. On the other hand can this lead to redundancy, unavailability and even high purchasing costs. The Norway digital cooperation is an excellent initiative to avoid many of these problems. Nevertheless not all data is available there, and not all companies or organisations are invited to join the cooperation. In addition much interesting data exists on unstructured and non spatial format. Thereby data availability and data preparation has been and can become a challenge.

Based on the time difference between the modelled and actual route found in the results, hours of transport can potentially be saved. Assuming that the modelled route is true on the road network and the actual route true on the sea network, the trip would take 17 hours (2 + 12 + 3). That would be a total improvement of four hours (21 – 17). Such an improvement is presumably not realistic however it does bear witness to the potential of saving some time. Even if it is impossible to save time on the route, the tool may contribute in planning.

The result is dependent on the case study's relation to reality. There is no assurance to say that the modelled route actually is driveable, for instance in relation to permissions by local authorities. In fact has Nordskog (2009) stated that the road and bridge standard on the path of the modelled route is too poor to be travelled. Nevertheless, the modelled and actual routes are even if one takes a broad view on the duration and number of obstacles (between Sylling and Stølen), securing that the result of the modelled route is not too unrealistic, in relation to the implemented premises.

The most interesting part of the analysis, except duration, is the choice of route. On the stretch Stølen – Kristiansand the actual route seems to be the most rational, especially when taking into consideration the detour the modelled route is forced to take. When it comes to the shipping lanes, no extensive comparison could be made, but by looking at the sea way network, it becomes clear that a shorter and thereby faster route can be possible to find. The stretch Drammen – Sylling is maybe the most interesting part of the route to discuss, as the divergence between the routes is quite large.

It is difficult to conclude why the actual route between Sylling and Drammen diverge from the modelled route. The modelled route is both shorter and experience fewer potentially obstacles. On the other hand, if a premise, not given in this case study, leads to the conclusion that the modelled route is impassable, the next best route seems to be the actual route. Then although the actual route is longer and potentially will meet more obstacles, the road class or road standard is nearly the same. The actual routes avoidance of the European road may in fact be an advantage in relation to traffic.

Nordskog (2009) states that, the modelled route is impossible to travel because of the road standard. The road width, surfacing and the bridges carrying capacity is too low to be an option for transformer transport. This information leads to two aspects on the quality of the input data in this case study. Firstly that the road class attributes not reflect the road standard good enough and secondly that bridges carrying capacity is much more important for route analysis, than expected.

The different road classes are set by the NPRA. The roads are maintained and built based on the same regulations and by the same public entity and developers across the country. Some uniformity of the road standard is therefore natural to assume. This case study has however proven that the connection between road class and road standard is of little value to route analysis, at least for oversized transport. Roads marked with the same road class may in reality hold different road standard. A more specified road standard attribute with the combination of road width, hard shoulders, road class and speed is maybe a solution for future studies.

The bridges carrying capacity has proven to be a very important obstacle for oversized transport. This attribute should probably have been put as a barrier in the analysis. The challenge would however be to differentiate the drivable- from the non drivable bridges in the data layer. Carrying capacity of bridges is influenced by different elements; the length (in relation to the total weight loaded on the bridge at a time), the weight, building material, the dimensioning, age and former strains. If all these elements were available and could be included in an analysis it would probably result in a good bridge layer benefitting route solving. Nevertheless would it be difficult to decide on how the costs should be weighted. Generally it would be a challenge to display and implement such an element, so complex in reality.

It has been difficult to test the network on other undergone routes because there are no other routes in the mapped area of southern Norway. More extensive comparisons are therefore natural if this project were to be extended to include the whole country. Nevertheless, as mentioned, is the solved route only a representation of reality and will only reflect the quality of the input data.

An objective at the beginning of this process was to develop an extremely user friendly tool, suitable for people with little knowledge in the field. During the study however the process of method development has been put higher on the priority list than the design of a user interface. Simple use with available GIS-software is possible on the present data. To alter, extend or calculate the data however, requires more knowledge.

On one hand it is favourable to leave the tool on this user level, as it to some extent assures the user's knowledge of GIS and cartography. On the other hand inexperienced users should also be able to handle the tool, to make it more available and usable. A future solution is to give different users different access possibilities ensuring, user-friendliness, the quality of the calculations or tool, and securing the safety of the data content (Hansen & Mallaug, 2003).

In order to improve a future method for oversized transport, several actions can be taken. First and foremost the accuracy of several layers has to be improved and the case history of both transformer- transport and other transport has to be stored. In addition, the structuring of different data and the organisation of all data into one database, at least the data of Statnett SF, would improve the GIS-work.

Further objectives are;

- To make orthophotos and other pictures more visible by connecting them to their spatial location and making it possible to display them on maps, for example as background material.

- To imply route directions on future solved routes making navigability easier.

- To include information about which transformer that can replace another transformer into the method development and analysis.

- To display non-sensitive self-prepared data and route solutions in Norway digital.

- To improve the availability of transport maps for Statnett Transport AS, both to make it possible to include easily understandable maps with dispensation applications to local authorities and to be able to measure and inspect sites on the computer. The idea being to visualize plans in better ways, decreasing the processing times of the application and thereby the transport.

The implementation of a GIS-based tool has the potential to improve preparedness and decrease the time spent on planning and carrying out a transport by visualization and mapping of transportation routes, decreasing on-site surveys, and by storing, displaying and calculating obstacle information. What the GIS-tool however is not possible to refine is the efficiency of landing-, preparing- or dismantling the oversized goods.

Preparedness is a fundamental part of oversized transport. All equipment, transport plans, and people need to be in place. Furthermore the transportation is dependent on many other parties of society and co-operation is therefore fundamental. Norges offentlige utredninger, 2006 has recommended that *the Ministry of Transport and Communication, the Ministry of Trade and Industry, the Ministry of Fisheries and Coastal Affairs and the Ministry of Justice and the Police, cooperate in order to clarify the need for choosing the safest conveying path and transport method to enterprises that require transport of dangerous goods.*

The co-operation of many of these parties is also important for the coordination of oversized goods, or goods critically important for society. Normally, bureaucracy is set aside in difficult situations. However to have a good communication when not engaged in emergency situations is advantageous. The co-operation between Statnett SF and Statnett Transport AS is essential to the preparedness in the power-unit transport. To take care of all collaboration with other enterprises and authorities, but especially the relationship to Statnett Transport AS, and to share thoughts and ideas will be important also in the future.

6 Conclusions and final remarks

The aim of this thesis has been to develop and present a GIS tool based on network analysis, with the emphasis on simplifying the transport of oversized goods, i.e. power transformers, and thereby contribute to the preparedness in the power industry.

Throughout the thesis, analysis in relation to oversized routing and transport preparedness has been performed. There has been no attempt made to adapt existing preparedness regulations on any level, but to contribute to the overall preparedness of the power industry by looking at an efficiency improvement of special transports.

The power industry is a vulnerable infrastructure and is therefore often described in legislations and regulations. The aspect of transport preparedness, excepting dangerous goods, has been more or less a missing subject in preparedness plans or other written documents. Nevertheless oversized transport has been accomplished whenever required.

During the study on this subject a need for uniformity in preparedness of oversized transport has been found, both in planning and storing of data.

The case study was set in southern Norway, more exactly between the transformer stations Sylling and Stølen. A suitable transportation route was found in the multimodal network which consisted of road and sea ways with landfalls as points of connection. The attributes restricting the modelled route were based on communication with people employed at Statnett SF and Statnett Transport AS, as well as impressions gained on a field trip. The selection of attributes were height, road-block, weight, distance, speed and driving direction, which reflected the obstacles of oversized transportation well. The accuracy of the attributes, especially height and weight, their cost weighting and their implementation into the network has refinement potential, mainly due to the special requirements of data for oversized transport and data transformation processes.

A method, aimed at the routing of oversized goods, has been developed. The method included finding, preparing and implementing data in order to find and visualise the best route. A route solving tool was not developed as intended, rather methods and models were established. The method developed has been based on the ArcGIS, network analyst extension and the entry level was therefore set higher than expected. Despite the weakness that multimodal networks do not support built-in hierarchy functions, the software has been a good tool for the handling and calculation of data in this process.

Maps of the distribution of oversized units, routes and infrastructure, were produced for the analysis. However no maps were produced for direct use in the power business as the data has to be improved before professional usage. Implementation of maps in public dispensation applications and in preparedness plans has been recommended through this thesis. Case study data have been stored in a database, ready for inspection and limited use.

The results of the route analysis demonstrate that there potentially was time to be saved on oversized transport by the use of network analysis. On the route Sylling – Stølen the potential of improvement was from one to four hours. The result has however two factors of uncertainty; firstly that the route has not been driven and therefore there is an uncertainty whether a driving permission will be granted or not, and secondly the modelled route is just a representation of the reality which makes it dependent on the quality of input. The better the data becomes, the better the result will be. If the method be employed, the amount of on-site surveys will decrease and the time of planning reduced.

7 References

Abelvik, Tore. 2008. *Norge digitalt (ppt presentation).* Hønefoss : Statens kartverk, 2008.

AREALIS. 2002. Faktaark farled. [Online] 2002. [Cited: 20. Octobre 2009.] http://www.statkart.no/arealis/tema/faktaark/Kyst_fiskeri/Faktaark_FAR.pdf.

Ask - B. 2009. Dictionary.com. *Transformer.* [Online] 2009. [Cited: 12. June 2009.] http://dictionary.reference.com/browse/transformer.

Ask- A. 2009. Dictionary. com. *Volt.* [Online] 2009. [Cited: 20. October 2009.] http://dictionary.reference.com/browse/volt.

Bakke, Kjerstin. 2009. *Om N-1 regelen.* [E-mail] Oslo : Statnett SF, 14. August 2009.

Barstad, Odd. 2009. *Information on road challenges.* [Email] Oslo : Statens vegvesen, 22. July 2009.

Bell, Michael G. H. & Iida, Yasunori. 1997. *Transportation network analysis.* Chichester : Wiley, 1997. p. 40.

Bysveen, Steinar. 2006. *Hva slags nett vil du ha?* [Online] KraftNytt, 2006. [Cited: 19. May 2009.] http://www.kraftnytt.no/default.asp?page=21877&article=34891.

Caplex. 2009. *Kongeriket Norge.* [Online] Cappelen, 2009. [Cited: 19. November 2009.] http://www.caplex.no/Web/ArticleView.aspx?id=9325043.

Christopherson, Robert W. 2006. *Geosystems - An Introduction to Physical Geography.* 6. edition. Upper Saddle River : Pearson Prentice Hall, 2006.

Climate-zone. 2004. *Norway.* [Online] Climate-zone.com, 2004. [Cited: 19. November 2009.] http://www.climate-zone.com/climate/norway/.

Dueker J. Kenneth & Butler, J. Allison. 2000. *A geographic information system framework for transportation data sharing.* USA : Elsevier Science Ltd, 2000. p. 14.

Energibedriftenes landsforening. 2005. *Kraftnettet fornyes ikke raskt nok.* [Online] Energibedriftenes landsforening, 2005. [Cited: 27. October 2009.] http://www.ebl.no/article.php?articleID=386&categoryID=6.

ESRI. 1998. *ESRI Shapefile Technical Description.* [Online] 1998. http://www.esri.com/library/whitepapers/pdfs/shapefile.pdf.

—. 2009. ArcGIS Desktop 9.3 Help. *Algorithms used by Network Analyst.* [Online] 2009. [Cited: 23 November 2009.] http://webhelp.esri.com/arcgisdesktop/9.3/index.cfm?id=4364&pid=4349&topicname=Algorithms_used_by_Network_Analyst.

Fornybar. 2009. *Viktig med kunnskap om fornybar energi.* [Online] Norges vassdrags- og energidirektorat, Enova, Innovasjon Norge, Forskningsrådet, 2009. [Cited: 22. October 2009.] http://www.fornybar.no/sitepageview.aspx?sitePageID=1004.

Frank, William C., Thill, Jean-Claude & Battam Rajan. 2000. *Spatial decision support system for hazardous material truck routing.* USA : Elsevier Science Ltd, 2000. p. 341.

—. 2000. *Spatial decision support system for hazardous material truck routing.* USA : Elsevier Science Ltd, 2000.

Friedheim, Håvard, Hagen, Janne & Henriksen, Stein. 2001. *En sårbar kraftforsyning, sluttrapport etter BAS3.* Kjeller : Forsvarets forskningsintstitutt, 2001. FFI/RAPPORT-2001/02381.

Grønås, Sigbjørn, Kvamme, Dag & Teigen, Roar. 2005. Cicerone. *Norklima - Og regnet strømmet ned på jorden.* [Online] 2005. [Cited: 15. 12. 2009.] http://regclim.met.no/cicerone_artikler/cic05-01-side_24-26.pdf.

Hansen, Kjell Toft & Mallaug, Tore. 2003. *Databaser.* Oslo : TISIP Gyldendal, 2003.

Hasle, Geir, Lie, Knut.Andreas & Quak, Ewald (eds.). 2007. *Geometric Modelling, Numerical Simulation, and Optimization: Applied Mathematics at SINTEF.* s.l. : Springer & Sintef, 2007. pp. 391 - 427.

Henriksen, Stein. 2001. *Samfunnsmessige konsekvenser av bortfall av elektrisk kraft - Hva skjer med oss når strømmen blir borte?* Kjeller : Forsvarets forskningsinstitutt, 2001.

Härdelin, Yvonne, Bjursell, Conny, Eriksson, Håkan & Andersson, Lars-Göran (eds.). 2004. *DraGIS - Kravspesification - Version 2.1.* s.l. : Svenska Kraftnät, 2004. Made available by Mathias Rönbeck [E-mail 01. June 2009], Svenska Kraftnät.

Justis- og politidepartementet. 2002. *Samfunnssikkerhet - Veien til et mindre sårbart samfunn.* Oslo : Justis- og politidepartementet, 2002.

Kinahan, Kelly & Pryor, Jennifer. 2009. *Dijkstras Algorithm for Shortest Route Problem.* [Online] 2009. [Cited: 13. July 2009.] http://optlab-server.sce.carleton.ca/POAnimations2007/DijkstrasAlgo.html.

Kraftdragarna. 2009. *About Kraftdragarna AB.* [Online] Kraftdragarna Ab, 2009. [Cited: 20 July 2009.] http://www.kraftdragarna.se/Kraftdragarna1.asp.

Kystverket. 2005. Farled. [Data layer]. Haugesund : Kystverket, 2005.

Lie, Halvor. 2009. *Nyinvestering i Statnetteiet nett siden 1963.* [E-mail]. Oslo : Statnett SF, 15 September 2009. Based on information from Statistics Norway.

Magerøy, Risa. 2009. *Terminology information.* [Email] Oslo : The Norwegian Public Roads Administration's head office library, 11. September 2009.

Monsrud, Jan (ed). 2009. *Transport i Norge.* Kongsvinger : Statistisk sentralbyrå, 2009. p 12.

Nordskog, Hans. 2009. Diverse communication throughout the study period. [E-mail & personal communication]. Oslo : Statnett Transport AS, 2009.

Norge digitalt - A. 2009. Norway Digital - the national geographical infrastructure. [Online] 2009. [Cited: 19. May 2009.] http://www.statkart.no/Norge_digitalt/Engelsk/About_Norway_Digital/.

Norge digitalt - B. 2009. *Norge i bilder.* [Online] Norge digitalt, 2009. http://www.norgeibilder.no/.

Norges offentlige utredninger. 2000. *Et sårbart samfunn - Utfordringer for sikkerhets- og beredskapsarbeidet i samfunnet 2000:24.* Oslo : Justis- og Politidepartementet, 2000.

—. 2006. *Når sikkerhet er viktigst - Beskyttelse av landets kritiske infrastrukturer og kritiske samfunnsfunksjoner 2006:6.* Oslo : Justis- og politidepartementet, 2006. pp. 16, 25, 35.

Norges vassdrags- og energidirektorat - A. 2009. *Fyllingsgrad magasiner.* [Online] Norges vassdrags- og energidirektorat, 2009. http://www5.nve.no/magasinfylling/MagfyllTbl_AlleAar.aspx?Tidsenhet=Uke&Omr=NO.

Norges vassdrags- og energidirektorat - B. 2009. *Energiforsyningen påvirkes.* [Online] Norges vassdrag- og energidirektorat, 2009. [Cited: 23. October 2009.] http://www.nve.no/no/Vann-og-vassdrag/Tilpasning-til-et-endret-klima/Energiforsyningen-pavirkes/.

Norges vassdrags- og energidirektorat. Elektriskedata - Stasjon & Ledning. [Data Layer]. s.l. : Norges vassdrags- og energidirektorat.

Olje- og energidepartementet. 2009. *Ot. prep. nr. 62 (2008 - 2009) - Om lov om endringer i energiloven.* Oslo : Olje- og energidepartementet, 2009.

—. 2001. *St. meld. nr. 37 (2000 - 2001) - Om vasskrafta og kraftbalansen.* Oslo : Olje- og energidepartementet, 2001. p 46.

Pedersen, Karl John. 2009. Network analyst spørsmål. [E-mail]. Oslo : Geodata, 13. November 2009.

Pham, Hong. 2009. *Vekst i vei og jernbane.* [Online] forskning.no, 2009. [Cited: 18. September 2009.] http://www.forskning.no/artikler/2009/september/228037.

Pohl, Ira. 1971. *Bi-directional Search, in Machine Intelligence.* [ed.] Bernhard & Michie, Donald Meltzer. vol. 6. s.l. : Edinburgh University Press, 1971.

Samferdselsdepartementet. 2009. *Forskrift om endring i forskrift om nærmere bestemmelser om tillatte vekter og dimensjoner for offentlig veg.* [Online] 2009. http://www.lovdata.no/cgiwift/wiftldles?doc=/usr/www/lovdata/ltavd1/filer/sf-20090724-1013.html&emne=20%20januar*%202009%20nr*%2078&. FOR-2009-07-24-1013 .

—. 2004. *St. meld. nr. 24 (2003 - 2004) - Nasjonal transportplan 2006 - 2015.* Oslo : Samferdselsdepartementet, 2004.

SearchDataManagement. 2009. *Data quality definition.* [Online] Whatis.com, 2009. [Cited: 20. November 2009.] http://searchdatamanagement.techtarget.com/sDefinition/0,,sid91_gci1007547,00.html.

SeNorge. *Vær & Klima.* [Online] Norges vassdrags- og energidirektorat, Meteorologisk institutt & Statens kartverk .[Cited: 15. November 2009r.] http://www.senorge.no/mapPage.aspx.

Skaansar, Ellen (ed). 2009. *Energistatus 2008.* [Online] 2009. http://www.nve.no/no/Energistatus-2008/.

Sommer, Shelly & Wade, Tasha (eds.). 2006. *A to Z GIS.* USA : ESRI Press, 2006. 9781589481404.

Statens kartverk. 2009. *Om SOSI.* [Online] Statens Kartverk, 2009. [Cited: 4. June 2009.] http://www.statkart.no/nor/SOSI/SOSI-standarden/.

Statens kartverk & Statens vegvesen. 2009. Elveg produktark. [Online] 2009. [Cited: 30. September 2009.] http://www.statkart.no/filestore/Landdivisjonen_ny/Kart_og_produkter/eVeidata/Elveg_produktark.pdf.

Statens vegvesen. 2007. *Høring vedrørende prøveordning om å tillate modulvogntog med lengde inntil 25,25 og med totalvekt opp til 60 tonn i Norge.* [Online] 2007. http://www.vegvesen.no/binary?id=3331.

—. 2008. *Nasjonal vegdatabank - Vegen inn på skrivebordet.* [Online] 2008. http://www.vegvesen.no/binary?id=14452.

Statens vegvesen - A. 2009. *Vegliste.* [Online] 2009. [Cited: 2. April 2009.] http://www.vegvesen.no/Kjoretoy/Yrkestransport/Veglister+og+dispensasjoner/Vegliste+riksveger+2009.

Statens vegvesen - B. 2009. *Key figures 2009 - annual report.* Oslo : Statens vegvesen, 2009. p 9-10.

Statens vegvesen - C. 2009. *The national road database.* [Online] 2009. [Cited: 3. June 2009.] http://www.vegvesen.no/Fag/Teknologi/Nasjonal+vegdatabank/In+English.

Statens vegvesen - D. 2009. Elveg. [data layer]. Oslo : Statens vegvesen, 2009.

Statens vegvesen. VBASE. [Data layer]. s.l. : Statens vegvesen.

Statistisk centralbyrån. 2009. *Folkmängd.* [Online] 2009. [Cited: 1. May 2009.] http://www.scb.se/.

Statistisk sentralbyrå. 2009. *Gjennomsnittlig lufttemperatur og nedbør i ulike årstider .* [Online] 2009. [Cited: 05 12 2009.] http://www.ssb.no/emner/historisk_statistikk/tabeller/2-9.html.

Statistisk sentralbyrå - A. 2009. *Elektrisisetsbalanse etter år/kvartal. 1994 - 2007. GWh.* [Online] 2009. [Cited: 14. September 2009.] http://www.ssb.no/emner/10/08/10/elektrisitetaar/tab-2009-05-28-13.html.

Statistisk sentralbyrå - B. 2009. *Dette er Norge.* Oslo/Kongsvinger : Statistisk sentralbyrå, 2009.

Statnett SF - A. 2009. *Årsrapport 2008.* Oslo : Statnett SF, 2009. p 10, 32.

Statnett SF - B. 2009. *Hva er N-1?* [Online] Statnett SF, 2009. [Cited: 18. November 2009.] http://www.statnett.no/no/Nyheter-og-media/Nyhetsarkiv/Nyhetsarkiv-2009/Hva-er-N-1/.

Statnett SF - C. 2009. Laser data ledning. [Data layer]. s.l. : Statnett SF, 2009.

Statnett SF - D. 2009. *Transportplan for Sylling og Stølen.* [Word-document]. Oslo : Statnett SF, 2009. J:\Transpplaner.

Statnett SF. 2008. About Statnett. [Online] May 2008. [Cited: 27. May 2009.] http://www.statnett.no/en/The-power-system/About-the-power-system/The-power-grid/.

Statnett Transport AS. 2009. About Statnett Transport. [Online] 2009. [Cited: 27. May 2009.] http://www.statnett-transport.com/about_statnett_transport.

Store norske leksikon. 2009. Flesaker. [Online] Store Norske leksikon, 2009. [Cited: 19. October 2009.] http://www.snl.no/Flesaker.

Strømme, Helge & Alvestad, Rolf. 1997. *Elektrisk energi - Produksjon, overføring og fordeling.* Oslo : Universitetsforlaget, 1997.

Sund, Pål Herman. 2009. Diverse communication during the master thesis. [personal communication]. Oslo : s.n., 2009.

Sveaas, Hege Fadum (ed). 2009. *Avbruddsstatistikk 2008.* Oslo : Norges vassdrags- og energidirektorat, 2009.

Thill, Jean-Claude (ed). 2001. *Geographical Information Systems in transportation Research.* s.l. : Pergamon, 2001. pp. 3-12.

Thill, Jean-Claude. 2000. *Geographical information systems for transportation in perspective.* USA : Elsevier Science Ltd, 2000. pp 3 - 12.

Universitetet i Oslo. 2008. *Hierarki.* [electronical dictionary] Oslo : Universitetet i Oslo, 2008.

Wikipedia. 2009. *Norges klima.* [Online] 2009. [Cited: 19. November 2009.] http://no.wikipedia.org/wiki/Norges_klima.

Worboys, Michael & Duckham, Matt. 2004. *GIS - A computing perspective.* 2. edition. Florida : CRC Press, 2004.

Østby, Erik, Hagen, Janne Merete & Nystuen, Kjell Olav. 2000. *Finansiering og organisering av beredskap innen telekommunikasjon og kraftforsyning.* Kjeller : Forsvarets forskningsinstitutt, 2000. FFI/RAPPORT-2000/00131.

8 Appendices

8.1 Appendix I: Attribute layer information

Elveg – Roads		
OBJECTID_1	Object ID	ArcGIS ID
Shape	Geometry	Polyline
OBJECTID	Long Integer	ArcGIS ID
LENGTH	Double	Length of the line segment
OPPR	Short Integer	
KOORDH	Double	Coordinat height (Z-value)
TRANSID	Long Integer	The road segments ID, unique
VFRDATO	Date	The road segments last update/validation
OBJTYPE	Text	Object type; road or side walk
GATENAVN	Text	The road name
GATENR	Long Integer	The road number
MEDIUM	Text	The object location (L = bridge, U = tunnel, B = construction)
VKJORFLT	Text	Direction of lane (odd number = lane direction with the digitalization direction # even number = lane direction against the digitalization direction)
VEGKATEGOR	Text	Road category (E = European road, R = National road, F = County road, K = Municipality road, P = Private road, G = Cycle way and Pedestrian walk)
HOVEDPARSE	Short Integer	
METER_FRA	Long Integer	Start point of obstacle/barrier
METER_TIL	Long Integer	End point of obstacle/barrier
KOMM	Short Integer	Municipality number
DATFGSTDAT	Text	Date of the registration
Hierarki	Short Integer	Value in the road network hierarchy (1 = highest ranked)
Shape_Length	Double	Length of the line segment
Oneway	Text	Driving direction ToFrom (TF), FromTo (FT) and Not directed (B)
Drivetime	Double	LENGTH*60/speed

Farled – Sea way		
OBJECTID	Object ID	ArcGIS ID
Shape	Geometry	Polyline
OBJTYPE	Text	Object type
LTEMA	Short Integer	Layer theme
OPPHAV	Text	Producer
DATO	Long Integer	Date of last update
KOMM	Text	Municipality
KVALITET	Text	Quality
DIGMOSTOKK	Short Integer	Digitizing scale
KYSTDISTRI	Short Integer	Costal district number
FARLED_TYP	Short Integer	Type of sea way
FARLED_BRU	Short Integer	Bridge (0 = no, 1 = yes)
FARLED_NAV	Text	Navigational name
FARLED_NUM	Short Integer	Number of the sea way
FARLED_STR	Text	Name of the path
FARLED_DEL	Short Integer	Part of the sea way
Shape_length	Double	Length of the line segment
Hierarki	Short Integer	Value in the hierarchy 1 = highest rank (higher than the roads)
Drivetime	Double	LENGTH*60/speed

Landingsplass - Landfall		
OBJECTID_1	Object ID	ArcGIS ID
Shape	Geometry	Point
OBJECTID	Long Integer	ArcGIS ID
FID_	Double	Counting number of ArcGIS
TrafoID	Text	ID of the related transformer(s)
LPLNavn	Text	Name of the landfall
Long_	Text	Longitude
Lat	Text	Latitude
NordY	Double	Y-coordinate
ØstX	Double	X-coordinate
Standard	Double	The condition of the landfall (1 = ready for use, 2 = preparation needed)
Kommentar	Text	Comment (quality and accessibility of the landfall)
AnlEier	Text	Owner of the landfall
Trafolast	Text	Transformers of possible transport
Annenlast	Text	Commodities of possible transport

Sylling_Stoelen – Transformer station		
OBJECTID_1	Object ID	ArcGIS ID
Shape	Geometry	Point
OBJECTID	Double	ArcGIS ID
ID	Double	Unit number ID
KVALITET	Text	Quality
BYGGEAAR	Text	Year of construction
FYLKE	Text	County
KOMTYP	Text	Component type
KONSESJON	Text	Concession
OBJNR	Text	Unit number
PLASSERING	Text	Location
SPENNING	Text	Voltage
STATUS	Text	State
TYPE_STASJ	Text	Type of station

Sperring_soerlandet - Barriers		
OBJECTID	Object ID	ARCGIS ID
Shape	Geometry	Point
OPPR	Short Integer	
KOORDH	Double	Coordinat height (Z-value)
VFRDATO	Date	The road segments last update/validation
MALEMETODE	Short Integer	Measuring method
NOYAKTIGHET	Long Integer	Accuracy
SYNBARHET	Short Integer	Visuality
OBJTYPE	Text	Type of object; Roadblock
VKJORFLT	Text	Direction of lane (odd number = lane direction with the digitalization direction # even number = lane direction against the digitalization direction)
VEGSPERRIN	Text	Description of the object type; concrete cone, car block, buss lock, locked bar, New Jersey, pipe railing, stone block, guard stone
VEGKATEGOR	Text	Road category (E = European road, R = National road, F = County road, K = Municipality road, P = Private road, G = Cycle way and Pedestrian walk)
VEGSTATUS	Text	State of the road
VEGNUMMER	Long Integer	Road number
HOVEDPARSE	Short Integer	Main parcel
METER_FRA	Long Integer	Start point of obstacle/barrier
METER_TIL	Long Integer	End point of obstacle/barrier
KOMM	Short Integer	Municipality number

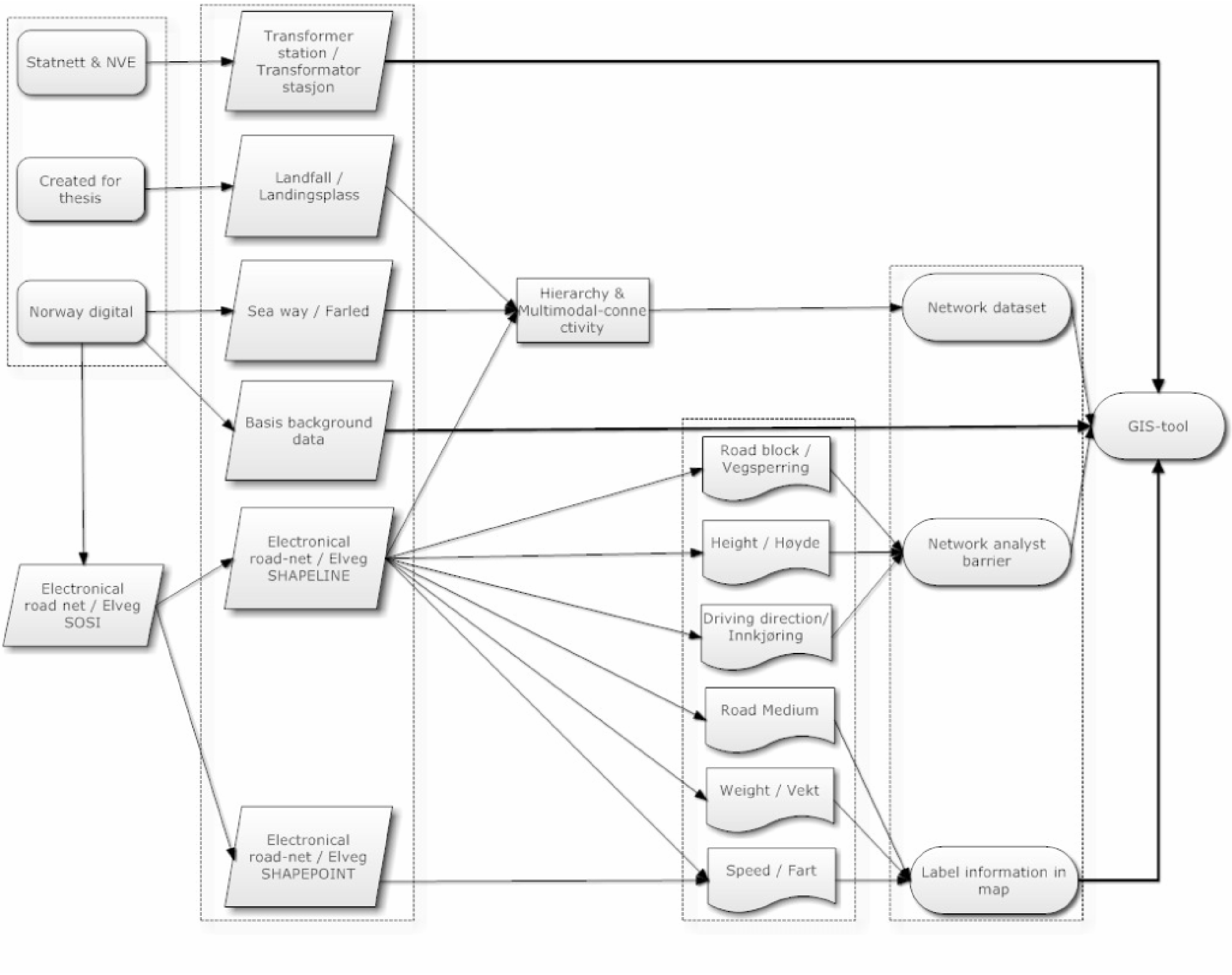
DATFGSTDAT	Text	Date of the registration
LENGTH	Double	Length of the line segment
TRANSID	Long Integer	The road segments ID, unique
MEDIUM	Text	The object location (L = bridge, U = tunnel, B = construction)

Fart(ASCII) - Speed		
Komm	Double	Municipality number
TransID	Double	The road segments ID
kode	Double	Code, tells which part of the element the attribute describes. 1 = the whole element
Fra	Double	Starting point of the speed attribute on the road-line segment
Til	Double	Ending point of the speed attribute on the road-line segment
felt	Text	Lanes (1#2 = one lane in each direction)
Fart	Double	Speed given in km per hour

Høyde(ASCII) - Hight		
Komm	Double	Municipality number
TransID	Double	The road segments ID
kode	Double	Code, tells which part of the element the attribute describes. 1 = the whole element
Fra	Double	Starting point of the attribute on the road-line segment
Til	Double	Ending point of the attribute on the road-line segment
felt	Text	Lanes (1#2 = one lane in each direction)
Høyde	Double	Height limitations measured in meter on the segment

Innkjoring(ASCII) – Driving direction		
Komm	Double	Municipality number
TransID	Double	The road segments ID
Kode	Double	Code, tells which part of the element the attribute describes. 1 = the whole element
Fra	Double	Starting point of the attribute on the road-line segment
Til	Double	Ending point of the attribute on the road-line segment
Felt	Text	Lanes (1#2 = one lane in each direction)
Retning	Double	Driving direction, 2 = drive in forbidden against the coordinate order, 1 = drive in forbidden with the coordinate order

8.2 Appendix II: The method development process



8.3 Appendix III: Network analyst procedures

Procedure:

1) Download data from Norway digital:
   a. Road - Elveg
   b. Sea way - Farled
2) Create data, based on Statnetts SDE server:
   a. Transformer stations
   b. Landfall

Table I: Data layer preparation procedures.

Road	- Download - Transform to shapefile format. - Check topology and completeness - If necessary merge layers (see appendix VI) - Insert transition lines between roads and landfalls - Remove ferries - Join with obstacle attributes (road block, height, driving direction, speed and weight) - Implement the columns Fartsgrense and Drivetime - Incorporate roads into the multimodal network
Sea way	- Download - Check topology - Remove dangles - Insert transition lines between Sea ways and Landfalls - Implement the columns Fartsgrense and Drivetime - Incorporate sea ways into the multimodal network

Transformer stations	- Select the Statnett SF operated stations from the NVE layer Elektriske data - transformator stasjoner. - Validate the station positions by comparing with scanned picture data - Move the points to the right position if necessary - Add missing stations by editing
Landfalls	- If no coordinates are given, find the place-names and add them by digitalization - Establish attribute data in the layers attribute table which are given in the source document - Incorporate the layer into the multimodal network

3) Preparing the data

General: The information needed as cost attributes in the network dataset has to be included in the layer as information in different columns before the layer is inserted into the network dataset wizard. If changes are done later on, the network has to be re-built in order to become updated.

It is advantageous to name the columns with standard names which the network dataset wizard automatically recognises, for example Drivetime, Hierarchy, Meter, Oneway etc.

In order to get the best result it is clever to explore the data before using it in any analysis. For example it is important to know whether length is saved in meters or kilometres.

All features have to be stored in the same feature class and geodatabase.

Table II: The data layers included in the network dataset.

SOURCES		
Name	**Element Type**	**Type**
Elveg	Edge	Edge Feature
Sea way	Edge	Edge Feature
Landfall	Junction	Junction Feature
Multimodal	*Junction*	*System Junction*

a. Implementation of Drivetime columns

A multimodal network does not support the built-in hierarchy function. The hierarchy cost was therefore calculated in new columns in the questioned layers; Sea way and road. The formula used was (Length*60/speed), the speed was changed based on class values. The calculated column was named Drivetime.

Table III: Calculation of the column Drivetime included into the road-network.

DRIVETIME		
Network class	**Speed (km/h)**	**Calculation** (Length*hour/speed in meter)
E	15	(Road segment length * 60/15000)
R & F	10	(Road segment length * 60 / 10000)
K, P, S	5	(Road segment length * 60 / 5000)
G	0 (Restricted)	-1
Sea way	20	(Road segment length * 60 / 20000)

Before it was observed that multimodal networks do not support common hierarchy, such a hierarchy was created by naming a column, with assigned numbers related to the edges hierarchy level, Hierarchy. A tool was established to make this process easier. The tool consisted of these steps;

- START
- Add a new column called Hierarchy (Add field tool)
- New select where [VEGKATEGOR = K] for example (Select Layer by attribute tool)
- Calculate selected fields to be for example = 5 (Calculate field tool)
- STOP

The select was done on every road category class, resulting in a new column with new values. The hierarchy column was automatically recognised by the network analyst dataset wizard, so only the layers and different ranges of these; primary, secondary and local, had to be chosen.

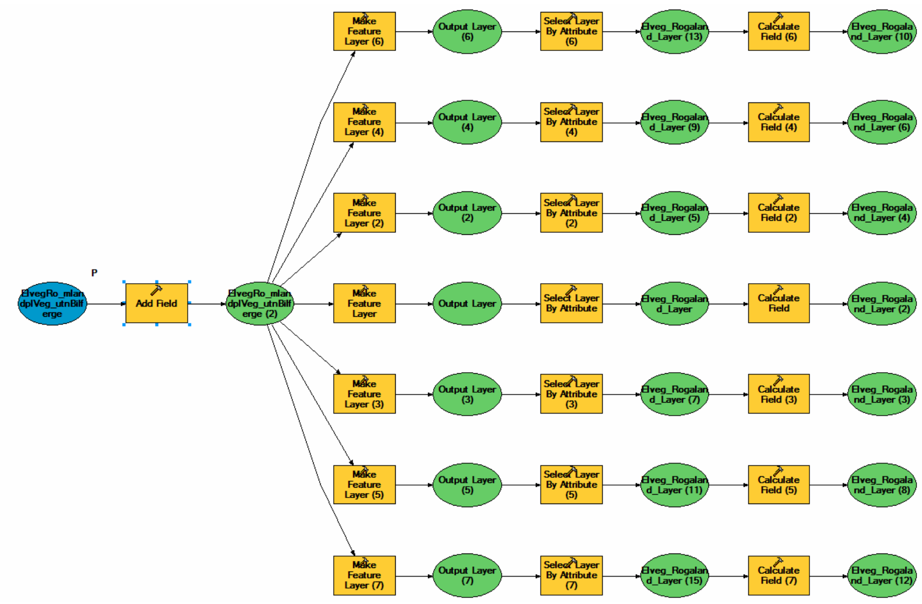


Figure I: Model preparing the data for the built-in hierarchy function of network analyst. Source: J:\GIS\Masteroppgave Transportplaner\rogaland\Obstacles\NewHierarki.

b. Topology testing

In order to navigate in a network the topology has to be right. The road layer had a good topology and could be directly implemented in the network dataset. The sea ways however had an unfinished topology, because most of the line segments were not connected properly. Therefore a new topology dataset was created based on the rule; Sea ways must not have dangles. The layer was validated and errors were inspected. The selected dangles were repaired by snapping within a certain tolerance.

c. Connectivity establishment

The point of connection between roads and sea ways are landfalls. Neither roads nor sea ways line segments are naturally connected to the landfalls. Transition lines had therefore to be created and implemented in the respective layers, for the sake of connectivity. In this case study these were digitized manually with the assistance of the snapping tool.

4) Multimodal network dataset

a. Connectivity

In the network dataset the connectivity has to be set up. For this study the set up was as presented in the table below.

End point = the line segments are only connected in the start and end part.

Any vertex = the line segments can be connected wherever there is a vertex.

Override = the layers policy is dependent of the intersecting layers policy. If no policy is given, in principle, every connection is allowed.

Table IV: Connectivity in the multimodal network.

CONNECTIVITY			
Source	**Connectivity Policy**	**Group 1**	**Group 2**
Elveg	End point	X	
Sea way	Any vertex		X
Landfall	Override	X	X

b. Attributes

The attributes included in the analysis were assigned in three different ways, through the network dataset wizard, through the layer property; barriers, or simply as labels in the map.

i. *Wizard:*

Drivetime which is based on speed and distance and Oneway which is based on the driving direction, were assigned through the network dataset wizard. Their properties are described in the tables below.

The expression of the value in Oneway is predefined and an automatically assigned VBscript of the network analyst. The expression looks like this;

restricted = False

Select Case UCase([Oneway])

Case "N", "TF", "T": restricted = True

End Select

Table V: Network dataset attributes

ATTRIBUTES			
Name	**Usage**	**Units**	**Data Type**
Drivetime	Cost	Minutes	Double
Oneway	Restriction	Unknown	Boolean

Table VI: The Drivetime attribute in the network dataset.

DRIVETIME				
Source	**Direction**	**Element**	**Type**	**Value**
Elveg	From-To	Edge	Field	Drivetime
Elveg	To-From	Edge	Field	Drivetime
Sea way	From-To	Edge	Field	Drivetime
Sea way	To- From	Edge	Field	Drivetime
Landfall		Junction		

Table VII: The Oneway attribute in the network dataset.

ONEWAY				
Source	**Direction**	**Element**	**Type**	**Value**
Elveg	From-To	Edge	Field	<expression>
Elveg	To-From	Edge	Field	<expression>
Sea way	From-To	Edge		
Sea way	To- From	Edge		
Landfall		Junction		

ii. Barrier

To make the most of the attributes height and road block they were implemented as barriers in the analysis. This was done by loading point locations through the barriers layer in the network analyst window. The challenge of this implementation was that the attributes originally had no spatial reference. This had to be assigned before the data could be uploaded.

The performing steps;

Tool 1:

- Indexing the Elveg file for better performance (Data Management tool)
- Deleting fields of no need from earlier merge (Data Management tool)
- Joining fields (default = outer join) from Elveg and the obstacle attribute based on the key-column TransID. (Data Management tool)

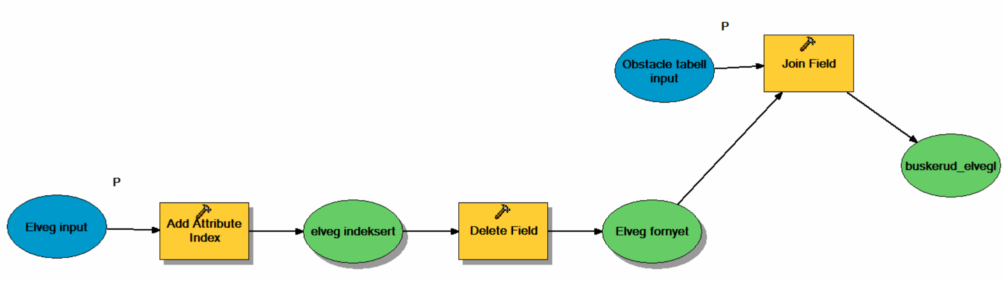


Figure II: Model that prepares the road attributes for use as barriers.

Tool 2:

- Deleting old data layers in the case that they already exist. This is done to make sure that there is no error or mistakes made with old data layers. (Data Management tool)

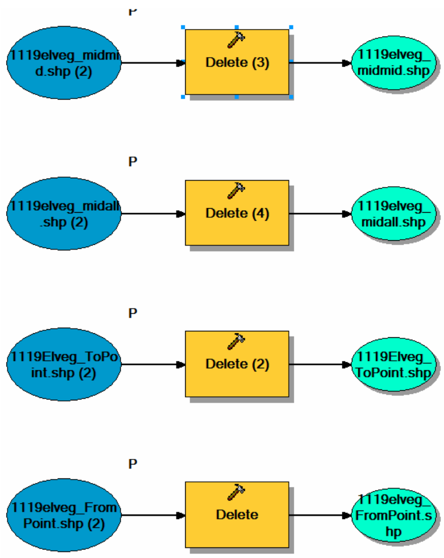


Figure III: Model that prepares the road attributes for use as barriers.

Tool 3:

- Selecting all the elements in the layer by making a new selection on TransID > 0

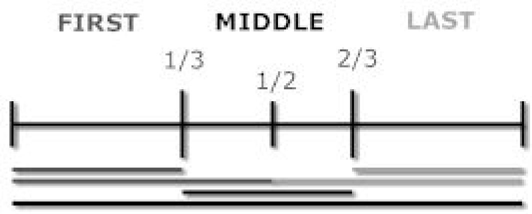
- Making six different subset selections based on SQL expressions and the column Fra (from) and Til (to). The selection is performed with the objective to find whether the obstacle lies in the first, middle or last part of the road line segment.

  - Elements located in the first part of the line segment:

    - "Fra" <("LENGTH" /3) AND "Til" >("LENGTH" /3) AND "Til" <("LENGTH" /2)

    - "Til" <("LENGTH" /3)

- Elements located in the middle part of the line segment:
  - "Fra" <("LENGTH" /3) AND "Til" > ("LENGTH" /2) OR "Fra" < ("LENGTH" /2) AND "Til" >(("LENGTH" /3)*2)
  - "Fra" >("LENGTH" /3) AND "Fra" <(("LENGTH" /3)*2) AND "Til" <(("LENGTH" /3)*2)
- Elements located in the last part of the line segment:
  - "Fra" >("LENGTH" /2) AND "Fra" <(("LENGTH" /3)*2) AND "Til" >(("LENGTH" /3)*2)
  - "Fra" >(("LENGTH"/3)*2)



- Creating new layers; First, Middle and Last (Feature class to feature class tool)
- Adding columns named; Position, X and Y, to every of the established new layers. (Add field tool)
- Storing some of the history. The column Position gets assigned the string FromPoint, ToPoint or MiddlePoint according to the position of the point on the related line segment. (calculating field tool)
- Calculating the X & Y fields with the VB-scripts found in appendix V. There are three different scripts locating coordinates to a line segment, based on the barrier point's position on the line.

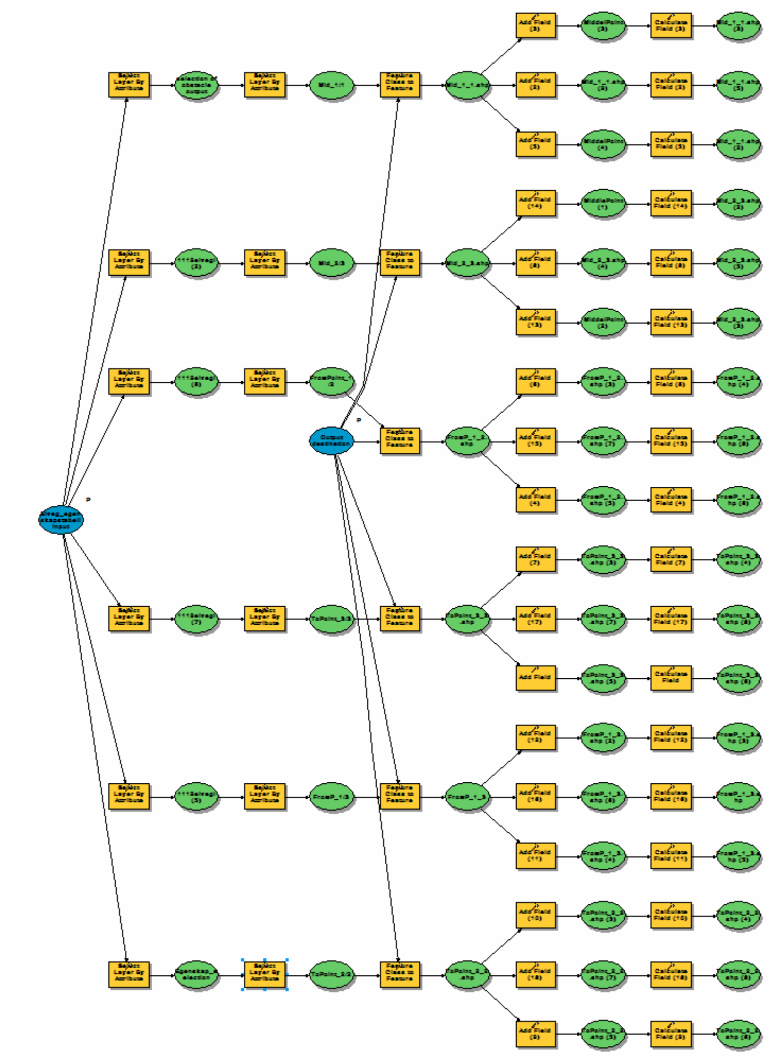


Figure IV: Model that prepares the road attributes for use as barriers. Source: J:\GIS\Masteroppgave Transportplaner\rogaland\Obstacles\Egenskaper_3

Tool 4:

- Finally the spatial location is found. The attributes have to be assigned as points with the help of the coordinates. (Make XY Event Layer tool)
- The information has to be stored in feature classes for protection. (Feature class to feature class tool)
- All layers; first, middle and last, are merged together to one layer. (Merge tool)
- Redundant attribute information, occurred through the process, is deleted. (Delete field tool)

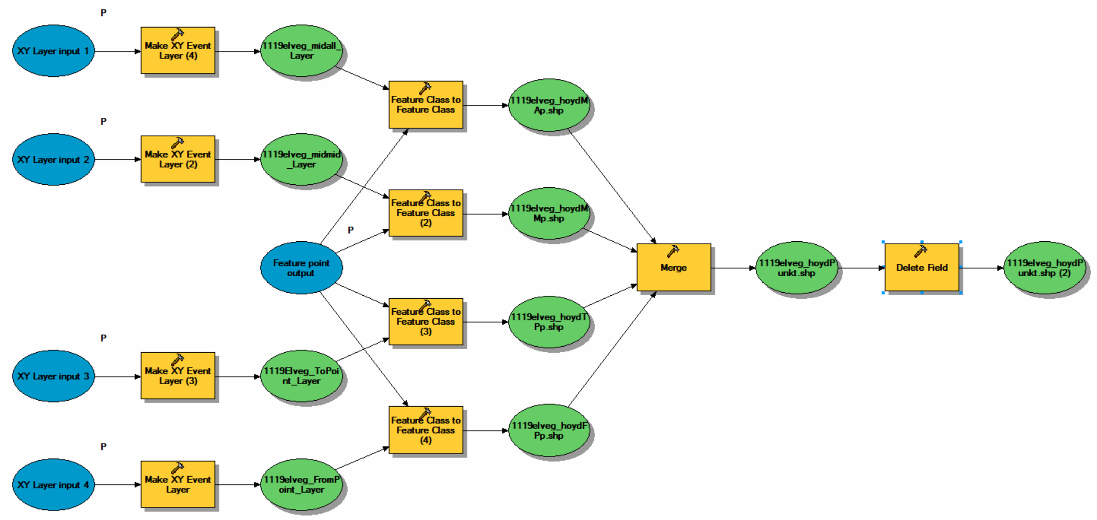


Figure V: Model that prepares the road attributes for use as barriers.

iii. Labels

Speed and to some extent weight limitations were displayed as labels on the map for guidance. This was done through the layer properties.

5) Route solving

Before the analysis can start a new route has to be created, this is easily done by selection in the network analyst toolbar. The next step is to create the network location points; departure and destination, on the map. The locations are based on the transformer station layer. The barrier points have to be up-loaded. When everything seems finished the solver button is pushed and the program starts calculating, finding the best route. Finally the analysis can begin.

If there is a problem with the network or there simply is no possible path accessible, an error message occurs. This happened several times during this project. The solution is to find the problem, change some attributes, re-calculate costs etc., before the network is attempted solved again.

8.4 Appendix IV: Example of Elveg road-network data in SOSI format

..OBJTYPE vegsenterlinje	Object type – road centre line
.. KVALITET 22 36	Quality, the assumed position in relation to reality - 22 (measuring method – analytical plotter) 36 (accuracy in cm)
..DATO 19970602	The date when the data was last verified to the real topography - 02. June 1997
..TRANSID 145266099	Unique identifier of the line segment 145266099
..GATENR 11023	Road number 11023
..GATENAVN ”CAMILLA COLLETTS VEI”	Road name “Camilla Collettsvei”
..ADR V 2 20 H 1 17	Address; Side of road (V = Left); housing nr 2-20 – Side of road (H = Right); housing nr 1-17
..KOMM 0301	Municipality 0301 (decoded: 03 = county of Oslo, 01 = municipality of Oslo)
..VNR K V 11023	VNR: - V: Road category (Road class) - N: State (construction, planned, existing etc) - R: Road class Here: - V = ‘K’ – Municipality road - N = ‘V’ – existing road - R = 11023 – road number
..VPA 1 0 348	Road parcel number – parcel 1, from 0 meters to 348 meters
..VKJORFLT 1#2	Driving direction and lane direction - to (odd number) # from (even number)
..VFRADATO 19500101	The date of the creation or last update - 01. January 1950 (default)

8.5 Appendix V: Spatial location on a line segment

Finding the X-coordinate of the start point of a line segment:

polyline_Get_X_FromPoint.cal

```
'=========================
'polyline_Get_X_FromPoint.cal
'Author: Ianko Tchoukanski
'http://www.ian-ko.com
'=========================
On Error Resume Next
Dim pMxDoc As IMxDocument
Dim pMap As IMap
Dim pCurve As ICurve
Dim pFromPoint As IPoint
Dim dXFrom As Double
Dim bSrefFromMap As Boolean
'=======================
'Adjust the parameter below
'bSrefFromMap = True ==> the coordinates will be calculated in the projection of the Map
'bSrefFromMap = False ==> the coordinates will be calculated in the projection of the data
bSrefFromMap = True
'=======================
If (Not IsNull([Shape])) Then
  Set pCurve = [Shape]
  If (Not pCurve.IsEmpty) Then
    If (bSrefFromMap) Then
```

```
    Set pMxDoc = ThisDocument
    Set pMap = pMxDoc.FocusMap
    pCurve.Project pMap.SpatialReference
  End If
  Set pFromPoint = pCurve.FromPoint
  dXFrom = pFromPoint.X
 End If
End If
```

Finding the X-coordinate of the middle point of a line segment:

polyline_Get_X_MiddlePoint.cal

```
'========================
'polyline_Get_X_MiddlePoint.cal
'Author: Ianko Tchoukanski
'http://www.ian-ko.com
'========================
On Error Resume Next
Dim pMxDoc As IMxDocument
Dim pMap As IMap
Dim pCurve As ICurve
Dim pMiddlePoint As IPoint
Dim dXMiddle As Double
Dim dDistance As Double
Dim bAsRatio As Boolean
Dim bSrefFromMap As Boolean
'======================
'adjust the parameters below
```

```
'bSrefFromMap = True ==> the coordinates will be calculated in the projection of the Map
'bSrefFromMap = False ==> the coordinates will be calculated in the projection of the data
bSrefFromMap = False
dDistance = 0.5 'when bAsRatio = True identifies the middle point of the polyline
bAsRatio = True
'=======================
If (Not IsNull([Shape])) Then
  Set pCurve = [Shape]
  If (Not pCurve.IsEmpty) Then
    If (bSrefFromMap) Then
      Set pMxDoc = ThisDocument
      Set pMap = pMxDoc.FocusMap
      pCurve.Project pMap.SpatialReference
    End If
    Set pMiddlePoint = New Point
    pCurve.QueryPoint 0, dDistance, bAsRatio, pMiddlePoint
    dXMiddle = pMiddlePoint.X
  End If
End If
```

Finding the X-coordinate of the end point of a line segment:
polyline_Get_X_ToPoint.cal

```
'========================

'polyline_Get_X_ToPoint.cal

'Author: Ianko Tchoukanski

'http://www.ian-ko.com

'========================

On Error Resume Next

Dim pMxDoc As IMxDocument

Dim pMap As IMap

Dim pCurve As ICurve

Dim pToPoint As IPoint

Dim dXTo As Double

Dim bSrefFromMap As Boolean

'======================

'Adjust the parameter below

'bSrefFromMap = True ==> the coordinates will be calculated in the projection of the Map

'bSrefFromMap = False ==> the coordinates will be calculated in the projection of the data

bSrefFromMap = True

'======================

If (Not IsNull([Shape])) Then

  Set pCurve = [Shape]

  If (Not pCurve.IsEmpty) Then

    If (bSrefFromMap) Then

      Set pMxDoc = ThisDocument

      Set pMap = pMxDoc.FocusMap

      pCurve.Project pMap.SpatialReference
```

```
    End If
    Set pToPoint = pCurve.ToPoint
    dXTo = pToPoint.X
  End If
End If
```

Finding the Y-coordinate of the start point of the line segment:

polyline_Get_Y_FromPoint.cal

```
'=========================
'polyline_Get_Y_FromPoint.cal
'Author: Ianko Tchoukanski
'http://www.ian-ko.com
'=========================
Dim pMxDoc As IMxDocument
Dim pMap As IMap
Dim pCurve As ICurve
Dim pFromPoint As IPoint
Dim dYFrom As Double
Dim bSrefFromMap As Boolean
'=======================
'Adjust the parameter below
'bSrefFromMap = True ==> the coordinates will be calculated in the projection of the Map
'bSrefFromMap = False ==> the coordinates will be calculated in the projection of the data
bSrefFromMap = True
'=======================
If (Not IsNull([Shape])) Then
  Set pCurve = [Shape]
```

```
  If (Not pCurve.IsEmpty) Then
    If (bSrefFromMap) Then
      Set pMxDoc = ThisDocument
      Set pMap = pMxDoc.FocusMap
      pCurve.Project pMap.SpatialReference
    End If
    Set pFromPoint = pCurve.FromPoint
    dYFrom = pFromPoint.Y
  End If
End If
```

Finding the Y-coordinate of the middle point of the line segment:

polyline_Get_Y_MiddlePoint.cal

```
'========================
'polyline_Get_Y_MiddlePoint.cal
'Author: Ianko Tchoukanski
'http://www.ian-ko.com
'========================
On Error Resume Next
Dim pMxDoc As IMxDocument
Dim pMap As IMap
Dim pCurve As ICurve
Dim pMiddlePoint As IPoint
Dim dYMiddle As Double
Dim dDistance As Double
Dim bAsRatio As Boolean
Dim bSrefFromMap As Boolean
```

```
'=======================
'adjust the parameters below
'bSrefFromMap = True ==> the coordinates will be calculated in the projection of the Map
'bSrefFromMap = False ==> the coordinates will be calculated in the projection of the data
bSrefFromMap = False
dDistance = 0.5 'when bAsRatio = True identifies the middle point of the polyline
bAsRatio = True
'========================
If (Not IsNull([Shape])) Then
  Set pCurve = [Shape]
  If (Not pCurve.IsEmpty) Then
    If (bSrefFromMap) Then
      Set pMxDoc = ThisDocument
      Set pMap = pMxDoc.FocusMap
      pCurve.Project pMap.SpatialReference
    End If
    Set pMiddlePoint = New Point
    pCurve.QueryPoint 0, dDistance, bAsRatio, pMiddlePoint
    dYMiddle = pMiddlePoint.Y
  End If
End If
```

Finding the Y-coordinate of the end point of the line segment:

polyline_Get_Y_ToPoint.cal

```
'=========================
'polyline_Get_Y_ToPoint.cal
'Author: Ianko Tchoukanski
```

```
'http://www.ian-ko.com
'=======================
On Error Resume Next
Dim pMxDoc As IMxDocument
Dim pMap As IMap
Dim pCurve As ICurve
Dim pToPoint As IPoint
Dim dYTo As Double
Dim bSrefFromMap As Boolean
'======================
'Adjust the parameter below
'bSrefFromMap = True ==> the coordinates will be calculated in the projection of the Map
'bSrefFromMap = False ==> the coordinates will be calculated in the projection of the data
bSrefFromMap = True
'======================
If (Not IsNull([Shape])) Then
  Set pCurve = [Shape]
  If (Not pCurve.IsEmpty) Then
    If (bSrefFromMap) Then
      Set pMxDoc = ThisDocument
      Set pMap = pMxDoc.FocusMap
      pCurve.Project pMap.SpatialReference
    End If
    Set pToPoint = pCurve.ToPoint
    dYTo = pToPoint.Y
  End If
End If
```

8.6 Appendix VI: Concatenating Elveg attribute files

The attribute ASCII-files from Elveg are available in Norway digital only split on municipality. To organize them county wise and to get them suited for use in ArcMap the attribute files had to be opened, the data of interest copied out and pasted into a new document representing the whole county. Additionally had the data to be saved with tabulator separation instead of semicolon.

Below an example of the script which was used to prepare the attribute ASCII-files (here aksel.txt). Only small changes had to be made in order to use the script on the other attribute files.

```
''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''
'Made by Siri Oestreich Waage & Are Shaw Waage
'11. August 2009
' Concatenates Elveg axle load attribute files and stores them for use in ArcMap
''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''
Option Explicit 'Man må deklarere alt i skriptet
'---Henter ut katalognavn (kommunenummer)
	dim fs,fo,x 'deklarerer tre variable
	set fs=CreateObject("Scripting.FileSystemObject") ' setter fs lik et objekt (med parameter)
	set fo=fs.GetFolder(".") ' setter fo lik fs sin gjeldende (der .vbs er lagret) katalog/folder

'Skriv katalognavn minus Elveg (kommunenummer) til Array.
	Dim arrKataloger() 'deklarerer en tom array
	Dim i
	i = 0 'counter
	for each x in fo.SubFolders 'for hver katalog som ligger i fo (subfolders av fo ".")
		If IsNumeric(Replace(x.Name, "Elveg", "")) Then 'Hvis du står igjen med et tall så går man inn i if-løkken, om ikke sjekker man neste katalog
```

```
            Redim Preserve arrKataloger(i) 'deklarerer arrayen med størrelse i (i tillegg til det som allerede måtte ligge inne)

            arrKataloger(i) = Replace(x.Name, "Elveg", "") 'gir arrayen i innholdet x.Name (katalognavn) og bytter elveg med ingenting (ergo sletter Elveg)

            i = i + 1 'øker counter, teller opp linjene i arrayen

        end if

    next


    set fo=nothing 'nuller ut objektet

    set fs=nothing ' nuller ut objektet ("går ut fra datamaskinen")


    'Oppretter/overskriver AkselAll.txt med første linje.

        Dim objFSO

        Const ForWriting = 2

        Const ForReading = 1 'deklarerer en konstant med gitt verdi

        Const ForAppending = 8 'deklarerer en konstant med gitt verdi


        Set objFSO = CreateObject("Scripting.FileSystemObject")

        Set objTextFile = objFSO.OpenTextFile (".\AkselAll.txt", ForWriting, True) 'Oppretter AkselAll for skriving. (overskriver/oppretter).

        objTextFile.WriteLine("Komm" & vbTab & "TransID" & vbTab & "kode" & vbTab & "Fra" & vbTab & "Til" & vbTab & "felt" & vbTab & "So" & vbTab & "Vi" & vbTab & "Tel" & vbTab & "Len" & vbTab & "Vekt" & vbTab & "Skilting") 'Hardkoder første linje av dokumentet

        objTextFile.Close


'---Åpner én og en xxxxAksel.txt

Dim ikatalog

For ikatalog=0 to Ubound(arrKataloger) 'Starter For-løkke som starter på 0 og går med default +1 opp til Ubound(arrKataloger) som er størrelsen på den endimensjonale arrayen.
```

```
        Dim ObjFile

        Set objFSO = CreateObject("Scripting.FileSystemObject") 'Setter objFSo til et filsystemobjekt

        Set objFile = objFSO.OpenTextFile(".\" & arrKataloger(ikatalog) & "Elveg\" & arrKataloger(ikatalog) & "Aksel.txt", ForReading) 'setter objFile=valgt filnavn (hjemkatalog\arraynr+Elveg\arraynr+Aksel.txt)



        'Leser til Array

        If IsArray(arrFileLines)=false then 'If-løkke sjekker om arrFileLines er en array, hvis det IKKE er en array så fortsetter den

                Dim arrFileLines() 'Deklarerer arrayen (det vil si at første gang den kjøres så blir den laget)

        end if



        i = 0

                Do Until objFile.AtEndOfStream 'Gjør intill den aktuelle filen objFile er ved endes (lest igjennom txt linjene for eksempel)

                ReDim Preserve arrFileLines(i) ' Redeklarerer arrayen

                arrFileLines(i) = objFile.ReadLine 'Setter arrayens linje i til å være filens (xxxxAksel.txt) n'te linje (readLine starter default å lese på filens første linje)

                i = i + 1

                Loop

        objFile.Close 'Lukker gjeldende fil/objekt



'---Åpner ny fil og skriver array.

        Dim objTextFile, iLinjer

        Set objFSO = CreateObject("Scripting.FileSystemObject")

        Set objTextFile = objFSO.OpenTextFile (".\AkselAll.txt", ForAppending) 'Oppretter AkselAll for tillegg (ikke sletting etc.)
```

```
    For iLinjer=5 to UBound(arrFileLines) 'Fra linje 6 til siste linje (linjene før er av liten interesse i og med at de inneholder informasjon og ikke dataene vi er ute etter)

    objTextFile.WriteLine(Left(Replace(arrFileLines(iLinjer),";",vbTab),Len(Replace(arrFileLines(iLinjer),";",vbTab))-1)) 'Skriver gjeldende array verdi inn i dokumentet

    Next

    objTextFile.Close

Next
```

8.7 Appendix VII: Counting numbers of segments in SOSI

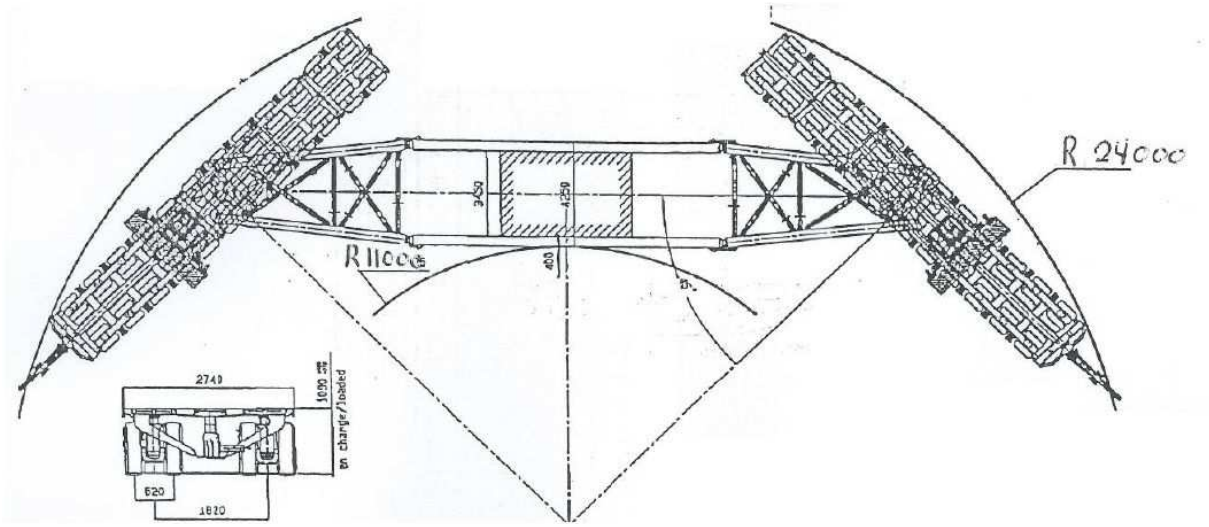
This small script counts the number of TransID occurring in a SOSI-file.

```
#Siri Oestreich Waage med hjelp fra http://www.daniweb.com/forums/thread128457.html#

#Opprettet for å telle SOSI innhold 25. September 2009

#string lagrer ordet som skal letes etter

string = "TRANSID"

#Åpner filen i lese modus

f = open("C:/temp/0602Elveg.txt","r")

#Leser inneholdet til variabelen contents

contents = f.read()

#lukker filen

f.close()

# Skriver ut verdien av antall ganger TransID forekommer i filen eller variabelen count

print "number of '"+ string + "'in your file is:", contents.count("TRANSID")
```

8.8 Appendix VIII: Example of transformer transport vehicle

Pictures taken during the field trip in Oslo, in commission of Hafslund.

A drawing of the turning radius of a transformer trailer.



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