Olav Vestøl

The impact of distance-based value of time on transport models and benefit-cost analyses: A Norwegian case study

Master's thesis in Civil and Environmental Engineering
Supervisor: Trude Tørset
June 2019

Master's thesis

NTNU
Norwegian University of Science and Technology
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Abstract

Transport infrastructure plays an important role for the well-functioning of economies. Whether it is roads, rail, air, sea or any other mode of transport, it is important and necessary in our globalized world that people and goods are transported efficiently and in a sustainable manner.

Decision making processes considering what infrastructure projects to implement are based on Benefit-Cost Analyses, where benefits and costs for different alternatives are compared. This thesis investigates one of the fundamental concepts of these analyses; the valuation of travel time savings for travelers in the network.

This master thesis includes a scientific paper and several attachments providing in-depth information about the most important aspects. The thesis investigates both how the general choice of value of time parameter as well as how a value of time model depending on travel distance, affects the calculated benefit from proposed infrastructure projects.

The work is divided into two parts. First, a sensitivity analysis considering the value of time parameter used in the transport models today is performed for two cases. This analysis tries to identify how the estimated benefit from infrastructure projects can be affected when the basic premises for the calculations change. Since the values used today are approximations and consequently associated with uncertainty, a sensitivity analysis will provide information about the consequences of using the wrong values. Second, the fact that value of time is known to increase with trip length is investigated by implementing a distance-dependent model for value of time. This means that longer trips will be higher valued compared to shorter trips in the network. This is only partly accounted for in the models today, and it is therefore interesting to see the effects of such a model on the estimated benefit.

The results show that the sensitivity of the transport models to changes in the input parameters for value of time vary between several attributes, such as calculation step in the models and type of project. This analysis reveals where the model is the most vulnerable to changes in the input parameters and hence where using the wrong values will impact the estimated results the most.

For the distance-dependent model, the results show that such a model might affect the total benefit in a significant way if implemented in the right calculation step in the model. Furthermore, the results also reveal that a distance-dependent model might not be necessary in all steps of the model.

The results in this study are interesting in several different ways. First, the sensitivity analysis reveals how much the estimation results differ from the basis scenarios when the input values for the value of time parameter is changed. This is useful e.g. to identify where a distance-dependent model should be implemented. Second, the distance dependent model might give a more realistic description of the actual situation and hence better estimate how the travelers perceive the improvements in the transport network. This might lead to changes in how benefit from infrastructure projects are measured and consequently how different projects are ranked against each other.

Sammendrag

I vår globaliserte verden er det viktig at både mennesker og gods transporteres på en effektiv og bærekraftig måte. Enten det er transport på vei, bane, sjø eller annen infrastruktur, spiller transportinfrastrukturen en viktig rolle for at samfunnet skal fungere på best mulig måte.

Beslutningsprosesser knyttet til hvilke infrastrukturprosjekter som skal bygges baserer seg på nytte-kostnadsanalyser hvor nytte og kostnad knyttet til ulike prosjekter er sammenlignet. Denne masteroppgaven undersøker en av de fundamentale ideene som ligger til grunn for disse analysene; hvordan tidsbesparelser i transport verdsettes.

Denne masteroppgaven er bygd opp av en fagartikkel og flere vedlegg som gir utfyllende informasjon om flere av de viktigste temaene i artikkelen. Oppgaven tar for seg hvordan en generell endring av tidsverdien i transportmodeller, samt hvordan en avstandsavhengig tidsverdifordeling påvirker den beregnede nytten fra infrastrukturprosjekter.

Oppgaven er delt inn i to deler. Første del omhandler en sensitivitetsanalyse av tidsverdiene som er brukt i transportmodellene i dag. Målet med denne analysen er å vise hvordan de beregnede resultatene påvirkes når grunnlaget for beregningene endres. Tidsverdiene som brukes i modellene i dag er estimerte verdier og det er følgelig knyttet usikkerhet til disse. Derfor er det interessant å vite mer om hvordan disse verdiene påvirker beregningsresultatene. Videre er tidsverdien kjent for å øke med reiselengden på turene, men dette er ikke tatt høyde for i dagens modeller i vesentlig grad. En avstandsavhengig tidsverdimodell er derfor implementert i transportmodellen for å se hvordan dette påvirker beregningsresultatene. Dette betyr at lengre turer vil bli verdsatt høyere enn korte turer og det er interessant å se hvordan dette kan påvirke nytten fra prosjekter.

Resultatene viser at sensitiviteten for endringer i verdsettingen av tid i modellen varierer med blant annet beregningssteg og type prosjekt. Resultatene viser hvilke beregningssteg som er mest sårbare for endringer i tidsverdien og følgelig hvor bruk av gale tidsverdier kan gjøre mest skade.

Resultatene fra den avstandsavhengige tidsverdimodellen viser at en den totale nytten beregnet fra prosjekter kan bli signifikant endret hvis modellen er implementert i riktig beregningssteg. Resultatene viser også at ikke alle stegene i transportmodellen nødvendigvis trenger en slik avstandsavhengig modell.

Funnene i denne oppgaven er interessante på flere måter. For det første viser sensitivitetsanalysen hvordan beregningsresultatene endrer seg fra basisscenarioet når inputverdiene for tidsverdien endres. Dettee kan blant annet brukes til å finne ut hvor en avstandsavhengig tidsverdi bør implementeres. Videre vil en avstandsavhengig tidsverdifordeling muligens gi en mer realistisk beskrivelse av den gitte situasjonen og hvordan de reisende vil verdsette forbedringer i transportsystemet. Dette kan i sin tur føre til endringer i den beregnede nytten fra prosjekter, hvordan prosjekter verdsettes og følgelig hvordan ulike prosjekter vurderes mot hverandre.

Preface

This master thesis concludes the five-year master's degree program in Civil and Environmental Engineering at the Norwegian University of Science and Technology. The thesis is written by Olav Vestøl under the supervision of Trude Tørset at the Department of Civil and Environmental Engineering. James Odeck at the National Public Roads Administration has worked as co-supervisor.

The motivation for this study is based on the valuation of travel time savings in transport systems and the use of these in projects appraisal. These projects often include huge public investments and it consequently requires a solid basis for decision. It is therefore relevant to question and investigate the procedure used today and identify possible improvements to the existing models.

The thesis has been accepted to the European Transport Conference and will be presented at the conference in Dublin in October 2019.

Several professionals have contributed with guidance and ideas throughout the process. Olav Kåre Malmin at SINTEF has provided help with the technical implementations in the Regional Transport Model (RTM). Stefan Flügel at TØI has provided information from the valuation studies and answered related questions. Marte Åsland Hansen and Terje Vidar Fordal at Cowi have given access to the data material used for the two cases and the results from previous analyses. Helga Lysgård at Nye Veier has helped with ideas on suitable projects for the analyses and accessing background information from Cowi. Finally, Øyvind Lervik Nilsen in Rambøll has helped with ideas and narrowing of scope in the early phase.

In addition to these, I am grateful for financial support from the National Public Roads Administration and the use of hard- and software as well as program licenses from the Norwegian University of Science and Technology.

Trondheim, June 2019

Olav Vestøl

Olav Vestøl

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1 Introduction

This master thesis is built up by different sections. Chapter 1 introduce the thesis and the overall motivation and procedure. Chapter 2 provides a description of the main content of each attachment. Chapter 3 provides an overview of the most important abbreviations as well as a translation of important terms from Norwegian to English.

The main part of this master thesis is the scientific paper presented in chapter 4. This paper considers an important topic in the field of transportation analysis, namely how travel time savings in the transport network should be valued and used in appraisal.

Chapter 5 to 13 are attachments that provide in-depth information about some of the most important aspects discussed in the paper, as well as describing the literature search strategy and limitations for the thesis. The attachments are designed in a way that they can be read individually. This allows the reader to go in depth in selected topics. Finally, chapter 14 concludes and summarizes the thesis.

The overall inspiration for this thesis is how travel time savings caused by improvements in the transportation network should be valued. Because people are different they will consequently value their time differently. Moreover, value of time varies not only from person to person, but between several other components, such as time of day, geography, length of trip, travel mode, purpose and more. Although some of these differences are accounted for in the models today, there are also many aspects that are given little consideration. The main motivation for this thesis is therefore to investigate one of the aspects that is not properly included in the models today and hence contribute to bringing the modeling framework further.

The specialization project in the fall semester of 2018 included studies of value of time and how the parameter may vary with different components. One of these is how value of time depends on travel length. Literature suggests that value of time should increase with trip length. However, the models used in Norway today only considers value of time in two or three trip length segments. This is therefore a relevant issue and investigated in this thesis.

2 Overview of Attachments

The following attachments are included in this thesis and are meant to give additional information about some of the most important topics presented in the paper. Below is a brief description of the attachments to make it easier for the reader to navigate through the material.

Attachment 1 – Concept of Value of Time and Generalized Costs: Presents the basic concepts of value of time and generalized costs and the use of these in transportation models.

Attachment 2 - Benefit-Cost Analysis: Presents the Benefit-Cost Analysis in general and introduce the method used for these analyses in Norway. Moreover, the implementation of the BCA in the Norwegian Regional Transport model is presented as well as some uncertainties related to the topic.

Attachment 3 - Stated Choice Methods: Introduce stated choice methods as a procedure to collect information from a large sample of people.

Attachment 4 - Value of time in the Regional Transport Model: Describes how value of time is used in the model used for transportation analysis in Norway. The attachment includes detailed information about where value of time occurs in the model and how the values can affect the estimation results.

Attachment 5 - Sensitivity Analysis in RTM: Presents the sensitivity analysis performed in the paper. The attachment includes detailed information about what parameters that have been changed and the procedure to implement the changes in the model.

Attachment 6 – Valuation Studies and Results: Presents a selection of valuation studies from Europe. The attachment gives an overview of the results and how value of time differs between the studies for different areas in Europe.

Attachment 7 - Trip Length Dependent Model for Value of Time: Presents the suggested new model for distance-dependent values of time in the RTM model. This includes background for the model, such as similar models collected from other countries, and the reason for implementing such a model.

Attachment 8 – literature search strategy: Presents the overall strategy used in the literature search.

Attachment 9 – Limitations: Describes the limitations for this paper and what simplifications that has been done in the process.

3 Terminology

Several abbreviations are used in the field of transportation analysis. The most important ones used in this thesis are given in Table 3-1.

Table 3-1: Abbreviations

Abbreviation	**Explanation**
BCA	Benefit-Cost Analysis
BC-Ratio	Benefit-Cost Ratio
CD	Car driver
CP	Car passenger
GC	Generalized Costs
LoS	Level of Service
NPV	Net Present Value
PT	Public transport
Rp	Revealed preference
SC	Stated choice
SP	Stated preference
VoT	Value of Time

A translation of travel purposes and modes used in the Norwegian transport models are presented in Table 3-2 and Table 3-3.

Table 3-2: Travel purposes, English-Norwegian translation

Reisehensikt	**Travel purpose**
Arbeidsreiser	Trips to/from work
Tjenestereiser	Service trips
Firtidsreiser	Leisure trips
Hente/Levere-reiser	Deliver/pick-up trips
Private reiser	Private trips
Lange reiser	Long trips
Godstransport	Freight
Skoleturer	Education
Flyplass	Airport

Table 3-3: Travel modes, English-Norwegian translation

Transportmiddel	**Travel mode**
Bilfører	Car driver, CD
Bilpassasjer	Car passenger, CP
Kollektivtransport	Public Transport, PT
Sykkel	Bike
Til fots	Walk
Hurtigbåt	Speed boat
Ferje	Ferry
Tog	Train
Fly	Plane

4 Scientific Paper

The scientific paper is presented in the following.

The impact of distance-based value of time on transport models and benefit-cost analyses: A Norwegian case study

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Keywords
Sensitivity analysis
Distance-dependent Value of Time
Consumer surplus
Benefit-Cost Analyses (BCA)
Road projects

0. Abstract

Empirical evidence from value of time studies have shown that the value of time is higher for longer trips as compared to shorter trips i.e., value of time varies by distance traveled. A common practice when implementing value of time in transport models and Benefit-Cost Analyses (BCA) is that one sets a limit for shorter and longer trips and then use different, but distance-independent values of time, for the different trip length intervals.

In this paper, we first analyze the effect of changes in the input parameters for value of time through a sensitivity analysis. Second, the impact of using distance-based value of time; as opposed to the current practices, on the outturns of regional transport models and BCAs is analyzed. We use two different road projects from Norway as case studies. Our framework for the implementation of a distance-based value of time model proceeds as follows: (i) We derive the distance-based value of time model from the previous value of time studies for Norway and Europe, (ii) we re-run the transport model using the derived distance-based value of time and finally, (iii) identify the effects of using a distance-dependent model on the consumer surplus for the two cases.

The sensitivity analysis reveals that changes to the input parameters for value of time has varying effect on the final estimations results, however, changes done in the demand model and traveler benefit module tends to change the calculated benefit. The suggested model also has varying effects on the results, depending on e.g. type of project and composition of trips in the network.

1.0 Introduction

Transport infrastructure plays an important role for the well-functioning of economies. Whether it is roads, rail, air, sea or any other mode of transport, it is important and necessary in our globalized world that people and goods are transported efficiently and in a sustainable manner. Infrastructure projects are often complex and demands huge investments. Number of proposed projects are usually higher than what available funds can cover, and projects must therefore be ranked against each other. Moreover, since most infrastructure projects in Europe are funded by governments, there are a set of social objectives that must be satisfied (Bristow and Nellthorp, 2000).

One of these objectives is economic efficiency, meaning the projects implemented should be the ones that generate the most benefit for the society. Since the 60s and 70s, Benefit-Cost Analysis, BCA, have been used for project appraisal (Grant-Muller *et al.*, 2010). The BCA is a framework where benefits and costs for a given project are estimated and summed up to give an overview over the total impacts. Here, both monetized and non-monetized impacts will be included, but the number of impacts considered and the comprehensiveness of the studies will vary significantly among countries (Bristow and Nellthorp, 2000). The BCA is probably the best method available and the most common framework used for project evaluation in the EU (Bristow and Nellthorp, 2000). The method is used both when evaluating the merits of individual projects but also when evaluating the merits of different alternatives of the same project (Eliasson and Lundberg, 2011) (Mackie, Worsley and Eliasson, 2014).

The monetized part of the Benefit-Cost Analysis considers benefits and costs that can be valued in a monetary unit. First, the benefit contribution includes improvements in the three cost components; time, distance and direct costs. Second, costs include direct monetary costs such as construction and maintenance, accidents etc. Some of these components are easier to estimate than others and some will probably also vary a lot among individuals and between countries. Consequently, there are uncertainties related to the benefit calculations (Börjesson, Eliasson and Lundberg, 2014), such as uncertainty in traffic forecasting and the valuation of travel time savings.

Experiences from UK-benefit calculations revealed that time savings accounted for 80% of the monetized benefits for some major road schemes (Mackie, Jara-Díaz and Fowkes, 2001). Based on this, the most important component when estimating the benefit from different infrastructure improvements is the time savings and consequently the valuation of these. In the models used for transport appraisal in Norway, the input to the calculated benefit from travel time savings is built up as follows; First, costs components of traveling between the zones in the network are estimated. Second, changes in the travel patterns are calculated by the demand model. Thereafter, travel time savings are calculated from the net assignment and finally, the valuation of the time savings are estimated in the traveler benefit module. Value of time is included in all these steps and the effects on the final estimation results will be further investigated in this paper.

To be able to convert the travel time savings to a monetary unit and hence be able to compare the travel time improvements to the costs, the concept of value of time is introduced. By adding up the time savings for all the travelers in the network and multiplying this with the value of time it is possible to calculate the total monetary benefit from the project.

Value of time is therefore implemented in the models used to calculate benefits from infrastructure projects. The values are based on surveys, dominated by stated preference surveys, and try to show the average values of the population to provide the best estimation results possible (Jones and Bradley, 2006). Based on the surveys, values are divided into categories, such as travel purpose and travel mode. Some models also divide trips by trip length, but only in a very limited number of levels, such as over/under

70km. This means that a trip of 65km and a trip of 75km can have very different value, although they are very similar in distance travelled.

This does not seem natural and different literature suggests that values of time should be differentiated based on trip length. Some relationships between travel length and value of time have been estimated, but the results and methods used for appraisal is not documented (Quinet *et al.*, 2013) (Axhausen *et al.*, 2014) (Axhausen *et al.*, 2008). With such distance-dependent models it will be possible to assign values of time that corresponds to the actual trip length, and this will result in benefit estimations that better replicate the real situation.

The Norwegian method divide trips into levels over/under 70 kilometers. This means that one value is assigned to all trips shorter than 70km and one value to all trips longer than 70km. This simplification might lead to the wrong values being assigned to trips especially around the limit of 70 kilometers. Therefore, there is a need for new method where the assigned value of time depends on the length of the trip.

This leads to the following research questions; 1. How sensitive is the different calculation steps in the Norwegian regional transport model to changes in the input values for value of time? 2. How will a distance dependent model for value of time affect the estimation results from Norwegian road schemes?

Unfortunately, previous literature has not examined these two issues in the context of Norway. The aim of this paper is therefore to investigate the concept of distance dependent values of time in more detail. This will be done as follows; First, a sensitivity analysis concerning the use of values of time in the transport models is performed. The goal of this analysis is to find out in what part of the analysis the model is the most vulnerable to changes in the input parameters. The Norwegian regional transport model is used for the analysis. Second, a distance-dependent model for values of time is implemented in the model and tested on two Norwegian road projects. The results are analyzed and the effects of using a distance-dependent model identified.

The analyses are performed with the following limitations. First, the paper will cover the analysis of trips performed as car driver. This means that public transport, as well as travelers going by bike or foot will not be included. Moreover, the analysis is performed independent of capacity, meaning it is assumed that there are no capacity problems where the two projects are located. While the sensitivity analysis is performed with the same model as used for the official BCA for the project, the implementation of the new model has some further assumptions. First, the network assignment is done with respect to time only, meaning distance and direct costs components are neglected. Furthermore, only work and leisure trips from the demand model (TraMod_by, Rekdal *et al.*, 2013) are considered for the distance-dependent model.

Finally, the paper is built up as follows. Section two describes the theoretical background and state of the art literature review. Section three describes the method used in this paper and the results are presented in section four. Finally, the paper is discussed and concluded in section five.

2. Literature review

Public investments projects have a set of social objectives that must be achieved (Bristow and Nellthorp, 2000). One of these goals is economic efficiency, meaning public funds should be spent in a way that results in the most benefit possible. To make sure this is satisfied, a defined framework is necessary. This framework, known as the benefit cost analysis, BCA (*Appendix 2 – Benefit-Cost Analysis*), is used in several different disciplines, including road and infrastructure projects. The BCA makes it possible to consider all impacts of a scheme and compare them in a monetary unit (Mackie, Worsley and Eliasson, 2014).

Benefit-cost analyses have been used for project evaluation for decades and is an important tool for transport investment evaluation in many countries (Eliasson and Lundberg, 2011) (Börjesson, Eliasson and Lundberg, 2014). The method is widely known, and different countries have their own practice when it comes to carrying out the analysis. Consequently, what is included in the BCA differs for the different countries. However, valuating travel time savings is one of the most important components to estimate the benefit contribution of the BCA. For major road schemes in the UK, it was found that travel time savings accounted for 80% of the monetized benefits (Mackie, Jara-Díaz and Fowkes, 2001) and valuation of these savings is therefore of huge interest in the appraisal process.

As BCA is built up by both a benefit and cost component, it is important to keep track of both components and how they are affected by the project. Both costs and benefits can be divided in monetary and non-monetary impacts, meaning whether it is possible to measure the impacts in a monetary unit. As benefits from infrastructure projects are dominated by travel time savings, there is need for a conversion unit, value of time, VoT. This unit, together with the concept of generalized costs, is used in the transport modelling procedure and is hence an important parameter to investigate in detail.

However, value of time is not a constant factor that is the same for all user groups and locations. The factor is rather a component that is estimated based on comprehensive valuation studies. Consequently, the numbers are also related with uncertainties that affects the results and may hence cause errors in the results.

2.1. Valuation studies

One of the most important parameter of transport planning is the value of time, meaning how travel time savings are valued in a monetary unit (Mackie, Worsley and Eliasson, 2014). These values are estimated through valuation studies carried out by countries and organizations. Although there are several factors affecting the total estimated benefit from infrastructure projects, travel time is, as described above, the most important factor in these calculations.

Valuation studies are carried out for multiple locations around the world. For this paper, a selection of European studies has been chosen. Table 4-1, page 15, summarizes the selected studies and their main results for the following countries; Norway, Sweden, Denmark, Germany, Switzerland, the Netherland, France and the UK. The different studies are performed differently and gives varying results both when it comes to the resulting values and variations among the different attributes.

Since it is both time consuming and expensive to collect information from all travelers about how they value their time in different situations, a representative selection of the population is used to estimate the values. Two survey types dominate in this work, revealed preference, RP, and stated preference, SP, surveys. Revealed preference surveys are based on actual choice situations done by the travelers and reported to officials (Olio and Oña, 2018). Due to the relatively extensive work needed related to RP-surveys, Stated Preference surveys, SP-surveys (Jones and Bradley, 2016), are the most common method used to collect travel data for time valuation studies. SP-surveys are based on hypothetical choice decisions where respondents provide their answers to questions based on a reference trip which they report in the beginning of the survey.

Stated preference surveys have been used for transportation research for more than 20 years (Jones and Bradley, 2006). These surveys are built up by different choice games where the respondents are asked questions based on chosen attributes and levels on these. These questions will reveal how much the respondents are willing to pay in order to save time or change travel mode (Louviere, Hensher and Swait, 2000).

When recruiting respondents to these surveys it is important to have a representative selection from the public to make sure the answers reflect national values that can be used for appraisal. Figure 4-1 shows the trip length distribution for the Norwegian valuation study and the two cases presented in this paper. Values estimated from the valuation study are used in appraisal for the two projects described. If these values are to be representative, the values should be based out of the same trip length distribution as the proposed project. As this is not the case here, and that e.g. the percentage of trips in the interval 0-10km is much higher for two projects compared to the valuation study, the result can be that values based on the wrong assumptions are used in the BCA. The solution to this might be to use location specific values of time, however this might cause problems stating time is higher valued in certain areas or for certain projects. Therefore, the same values are used in appraisal today, independent of location.

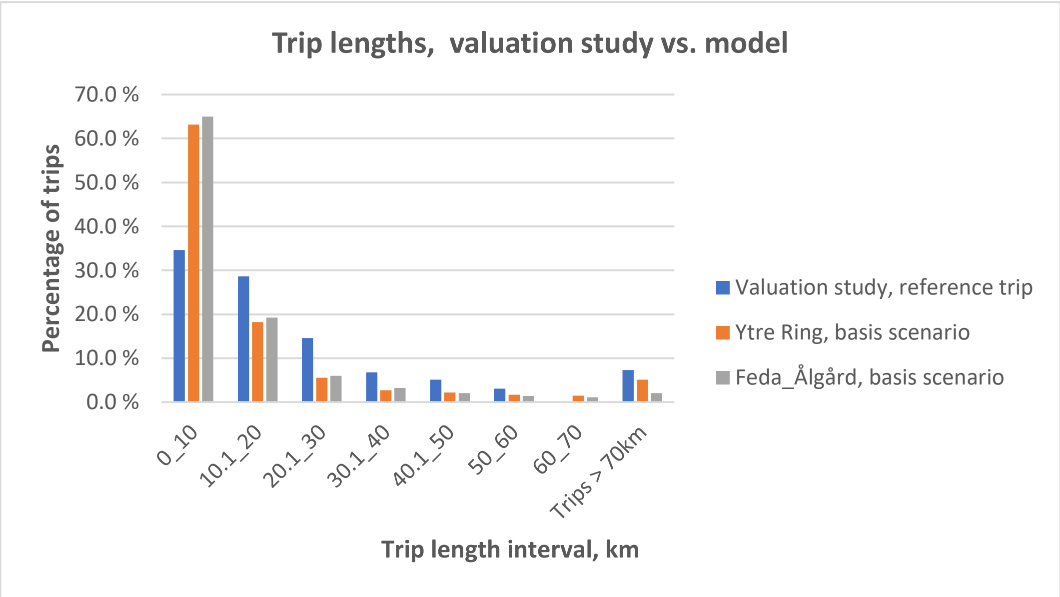

Figure 4-1: Trip length distribution from the Norwegian valuation study and the projects Ytre Ring and Feda-Ålgård

Another observation is that the observations used to estimate the value for trips shorter than 70km is mainly from trips shorter than 30km. Moreover, the number of respondents used to estimate VoT for trips above 70km is based on few respondents. The basis for estimation of these values can therefore be questioned.

The surveys presented in Table 4-1 all group the trips into different groups based on trip purpose and travel mode. Trips performed by the different modes and with the different purposes might value time differently. Furthermore, individual preferences cause the valuation of time to vary among individuals. Since value of time varying completely by each individual is hard to achieve, the aggregation of travelers in groups based on mode and purpose is used. As Table 4-1 shows, the purposes and travel modes included in valuation studies, varies significantly among the surveys.

Literature suggests that value of time increase with trip length (Wardman, 1997) and the national Swedish value of time study shows that values are significantly higher for longer trips compared to shorter trips (Algers, Dillén and Widlert, 1994). In addition, (Wardman, 2004) states that time savings on longer journeys will be higher valued due to more boredom, fatigue and discomfort compared to shorter trips.

Results from the surveys are used to estimate the value of travel time savings for appraisal purposes. If values should be differentiated by trip length, this should also be implemented in the transportation models to better reflect the actual situation. This is the main motivation for this study.

The valuation studies presented in Table 4-1 shows the results from valuation studies for the selected European studies. There is one major difference in the studies, how value of time and trip length are related. First, fixed values of time indicate that value of time is given as a fixed value, either the same value for all trip lengths or divided into a very limited number of different trip length segments. Second, continuous values of time indicate that values of time are given as a function of trip length. Most countries use the fixed VoT distribution, however some countries have implemented a continuous relationship. (*Attachment #6 - Valuation studies and results*).

The values presented by the valuation studies describe how travelers perceive their time during travel and hence how they would value improvements in the transport situation. These values are not used directly in the transportation models however, they are important because they work as the basis for estimating values to the model.

2.1.1 Traditional models

The traditional models use a fixed value for their VoT estimations. From the selection above, this is the case for Norway, (Farideh *et al.*, 2010) (Halse, Flügel and Killi, 2010), Sweden (Algers, Dillén and Widlert, 1994) (Börjesson and Eliasson, 2014), the UK (Stefan *et al.*, 2015), Denmark (Fosgerau, Hjorth and Lyk-Jensen, 2007), Switzerland (Axhausen *et al.*, 2006), the Netherlands (Kouwenhoven *et al.*, 2014) and Germany (Axhausen *et al.*, 2014). Although these models are built up differently and present different results regarding value of time, most of them divide the value of time into trip length segments. This means that the applied value of time is constant within the same trip length segment but may vary between different intervals. All these surveys, except for the Danish study, have values increasing with trip length. However, the values and length of the intervals vary significantly among the studies.

Table 4-1: Selection of European valuation studies

#	Country, year	Mode, short	Mode, long	Purpose, short	Purpose, long	short/long (km)
1	Norway, 2010	Car driver (CD), public transport (PT), ferry, speed boat	CD, train, bus, plane, speed boat	work, other private, all private, business, all trips	work, other private, all private, business, all trips	100
2	Norway, 2010, additional study	CD, PT, ferry, speed boat	CD, train, bus, plane, speed boat	work, other private, all private, business, all trips	work, other private, all private, business, all trips	50
3	Sweden, 1994	CD, reg. train, long distance bus, Reg. bus	CD, Air, IC Train, X2000, Reg. train, LD Bus, Reg. Bus	work, other	all trips	50
4	Sweden, 2014	CD, Bus, Train	CD, Bus, train	work, other	all trips	100
5	UK, 2015	CD, Bus, other PT, Rail	CD, Bus, Other PT, Rail	commute, other non-work, emplyees' business	commute, other non-work, emplyees' business	5,20,100
6	Denmark, 2007	CD, Bus, Metro, S-train, Train	CD, Bus, Metro, S-train, Train	Commuter, Education, Leisure, Maintenance, All	Commuter, Education, Leisure, Maintenance, All	25
7	Switzerland, 2006	CD, PT	CD, PT	Commute, Shopping, busniess, Leisure, Total	Commute, Shopping, busniess, Leisure, Total	n/a
8	The Netherlands, 2014	CD, train, bus/tram/metro, all surface modes, air, recr. navigation	n/a	Commute, business, other, all		n/a
9	Germany, 2015	CD, PT, plane, all	CD, PT, plane, all	Work, education shopping, leisure, commercial, non-commercial, all	Work, education, shopping, leisure, commercial, non-commercial, all	50 + cont.
10	France, 2013	CD, car-coach, rail, air, all	CD, car-coach, rail, air, all	professional, personal-holiday, personal-other	professional, personal-holiday, personal-other	cont.

2.1.2 New models

In addition to the fixed VoT described above, some countries have established relationships between value of time and trips length, meaning VoT is now given as a function of distance. This is done in Germany (Axhausen *et al.*, 2014) and France (Quinet *et al.*, 2013).

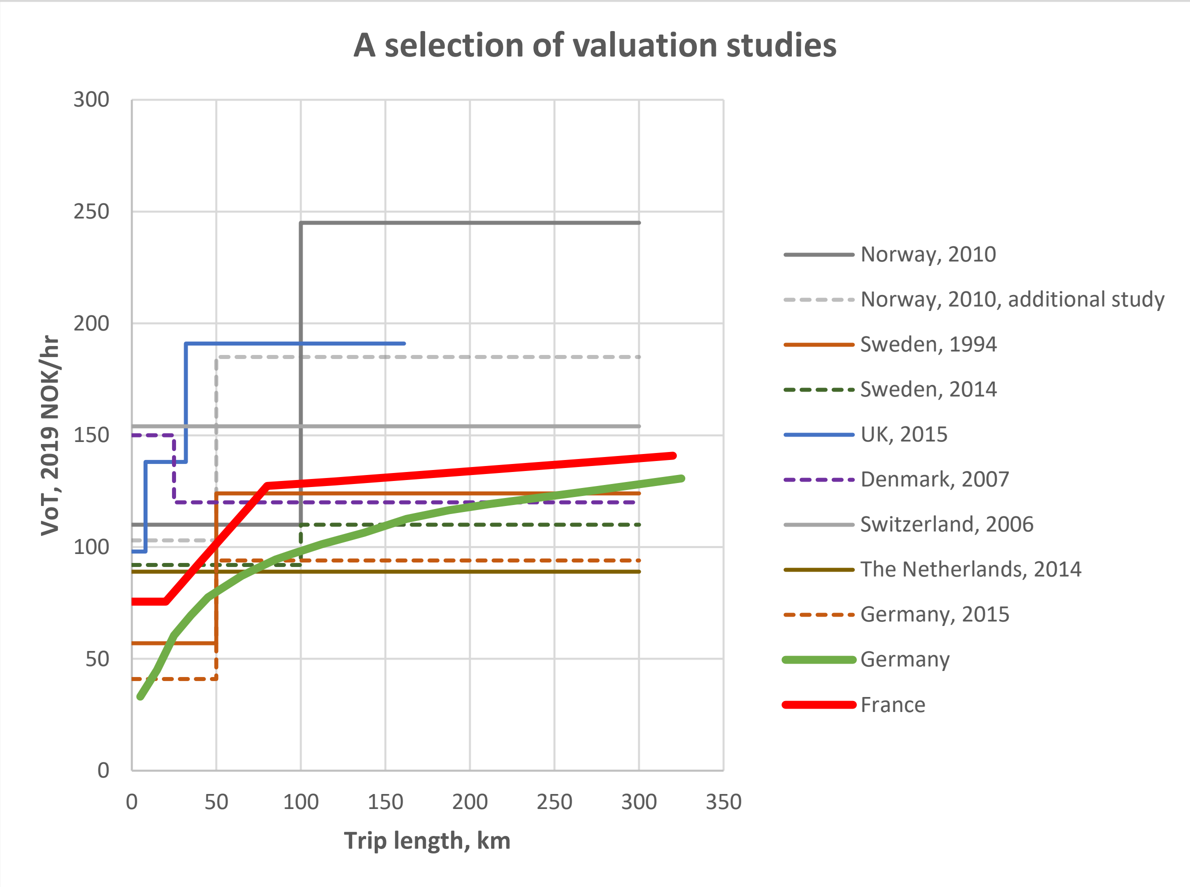

Figure 4-2: Value of time, traditional and new models, (2019 NOK)

Figure 4-2 shows how the German and French study vary with trip length. In addition, the other studies presented in Table 4-1 are given in the figure to show the differences. Figure 4-2 shows that values used in the different countries, are quite similar for short trips. Also, the German and French values show similar development in time value. The Norwegian values for long trips are higher than any other international values used in appraisal and based on few respondents, as discussed in Figure 4-2. Our suggestion for a continuous time value is inspired by these international practices.

2.2 The Norwegian value of time study

The Norwegian valuation studies are carried out by the Institute of Transport Economics and presented as reports for the different subjects. One of these subjects is the Norwegian value of time study (Farideh *et al.*, 2010), where Norwegian values for travel time savings are estimated based on Stated Preference surveys.

As presented in Table 4-1 above, the Norwegian models estimate values for two trip length segments, under and over 100km. In addition, another study have been carried out where the split between short and long trips is 50km (Halse, Flügel and Killi, 2010), meaning a greater portion of the trips in the network will be characterized as long trips. Moreover, a new valuation study is currently carried out, from which new values will be presented in the near future. This study will also provide values divided into more trip length segments, meaning it will be possible to obtain at least some kind of a distance-based relationship.

2.3 The Regional Transport Model – RTM

In Norway, the regional transport model, RTM, (Tørset, Malmin and Bang, 2013) is the main tool used to estimate benefit from infrastructure projects. The tool is implemented in the software Citilabs Cube (*Citilabs*®, 2016) and estimates the transport situation for a reference scenario and a project scenario, before comparing these two in the benefit calculations.

For each scenario, the calculations are performed as follows. First, the LoS-data step calculates travel cost between all zones in the network for all modes available. It is assumed that travelers make rational choices and choose the alternative that maximizes their utility in every situation (Dodgson, 1981). In the first step, generalized costs are calculated for all zone-relations and the route with the lowest total cost is skimmed. The skimming procedure creates matrices with all relevant information for the given route. Second, the demand model calculates travel demand between all zones, including number of trips generated in and attracted to all zones. The information from LoS-calculations in step 1 is used in utility functions to estimate the attractiveness of all zones and hence how many trips that will be attracted and produced in the different zones for all modes. Third, results from the demand model only tells how many trips that are attracted and produced in the different zones, and in the third step these trips are assigned to the network. Again, it is assumed that travelers will choose the route that gives the total lowest costs possible.

After these three steps have been performed for both the reference and project scenario, the last step, the traveler benefit module, compares the scenarios and calculate change in travel time, distance and direct costs for all zone-relations in the network. Changes in these three costs components are thereafter summed up for all travelers in the network and multiplied by the value of these savings. This gives the total change in consumer surplus for the project.

Appraisal models in Norway today use fixed values of time in the estimation. As theory shows that the values should be differentiated into trip length intervals, it is relevant to investigate how such models will change the estimation results for Norwegian road projects.

3. Methodology

The method used in this paper is divided into two separate parts, each answering one of the research questions. First, the methodology for performing the sensitivity analysis is described. Second, the new model for distance-dependent values of time is introduced.

3.1 Sensitivity analysis

The sensitivity analysis is performed to answer the first of the two research questions; How sensitive is the different calculation steps in the Norwegian regional transport model to changes in the input values for value of time. To answer this, the input parameters for value of time is changed in all of the four steps of the transport model. (A*ttachment 5 – Sensitivity analysis in RTM*)

The analysis has been performed as follows. First, basic scenarios have been simulated in the software, giving the situation without the new projects implemented. For these analyses, year 2022 has been selected as the opening year of the project and hence when the benefits start to accumulate. Thereafter, each of the four steps in the transportation model have been investigated individually. For each step, the value of time parameter has been adjusted to investigate how the estimation results change. A total of ten scenarios have been analyzed for every step, with VoT adjusted up and down by up to 50% in ten-percent intervals.

When changing the value of time parameter, the change is implemented for the entire model, meaning all private car trips are assigned the new value, independent of whether they are using the new road or not. To make sure the changes in benefit are caused by the project implemented and not the change in value of time for the entire model, one unique reference scenario has been created for all the adjustments of value of time. This means that for all of the scenarios with adjusted VoT parameter, an exclusive basis with the same adjustments in VoT is created and used as the scenario for comparison.

As the measuring parameter, change in consumer surplus is used. This represents the change in benefit for the travelers for the new situation compared to the existing situation. If this is a negative number, the proposed project leads to the average traveler being worse off compared to before the implementation. On the other side, if the number is positive, travelers are better off than before.

The regional transport model is built up by four steps, as described in section 2.3. (*Attachment #4 – Value of time in RTM*). Adjustments of the VoT-parameter has been implemented in all these steps, as described in the following.

Although value of time is included in the calculations performed in all four steps in the regional transport model, they are implemented differently and grouped into different categories in the different steps. For the LoS-calculations in step1, the same value is used for all travel purposes. For the demand model in step 2, trips by private car is divided into work, service, private, leisure and pick-up/deliver trips. Step 3 use work, service, leisure and long trips. Lastly, step 4 divide trips by work, service, leisure long trips and airport. Table 4-2 shows the values used in the transport model today.

In the sensitivity analysis, these values are changed either directly or indirectly. In step 1 and 3 changes are done in the Genkost-file, located in the RTM-framework. This file provides input to the model with implicit values of time. For step 1, only one value is changed, LOS_TID, in order to adjust the parameter for value of time. For step 3, the values for NF_TID is changed for all travel purposes. The implicit values indicate that the values are not directly available in the model but can be found from the input information.

For step 2, the demand model, the situation is different. As the demand model is running outside of RTM, changes have been done to the parameter files used by the demand model. Parameter files for all the travel purposes have been changed according to the percentages described above. Moreover, this means that the values given in Table 4-2 below is not changed directly but change as a result of changes in the parameter files. Finally, step 4 use the values of time directly, meaning the values are given as direct input values to the program. Followingly, the values are increased and decreased by changing the number given in Table 4-2 directly.

Table 4-2: Value of time in RTM

(* Values for women/men < 50 years old, **Value for service trips not included ***Leisure trips in step 3 include private trips, pick-up/deliver and leisure from step 2, ****Values for long trips in step 4 are for work, service and leisure respectively.)

Step	Travel purpose, CD	Value (NOK/hr)
1	All trips	81
2	Work	76/58*
	Service	**
	Private	90
	Pick-up/deliver	109
	leisure	81
3	Work	72
	Service	240
	Leisure	96***
	Long trips	540
4	Work	99
	Service	444
	Leisure	84
	Long CD	215/444/167****
	Airport	204

3.2 The new model – distance-dependent VoT

Based on the existing models and the information collected, a new model with trip length dependent values of time has been developed. The suggested model is not an attempt to show the correct relationship between value of time and trip length, since this requires extensive work in estimating the values. However, the goal is to shows one possible relationship and answer the second research question; How will a distance dependent model for value of time affect the estimation results from Norwegian road schemes? The results will be useful in future work of estimating a fully distance-dependent model for value of time.

Several simplifications have been made for this implementation. Initial tests showed that the most sensitive steps regarding changes in the input parameters for value of time, was step 2, the demand model, and step 4, the traveler benefit module. Furthermore, previous research shows that a trip length dependent model in the network assignment step affects the calculated project benefit (Kim and Yook, 2018).

With a distance-dependent model in step 2, the demand model, being difficult to implement, as well as limitations considering time and scope of this master thesis, step 3 and 4 was chosen for the implementation of the distance-based model.

Other simplifications have also been done. First, only private car trips as driver are considered. Second, network assignment is performed considering time only. This means that time is the only considered parameter when assigning trips to the network as opposite to the traditional model where network assignment is done considering time, distance and direct costs. Third, a distance-dependent model is only implemented for the two travel purposes work and leisure trips estimated by the demand model (TraMod_by). This is done because more than 80% of the trips in the network belong to these two categories for both cases, as given in Table 4-3. Moreover, work and leisure trips estimated by TraMod_by are in the short trip segment (up to 70km). Table 4-4 shows that most of the trips for the two cases belong to this trip length interval.

Table 4-3: Trip distribution, Ytre Ring and Feda-Ålgård

<table>
<tr><th>Travel purpose</th><th>Ytre Ring</th><th>Ytre Ring</th><th>Feda-Ålgård</th><th>Feda-Ålgård</th></tr>
<tr><td>Work</td><td>20.2 %</td><td rowspan="3">TraMod,
90,2%</td><td>21.6 %</td><td rowspan="3">TraMod,
93,4%</td></tr>
<tr><td>Service</td><td>7.6 %</td><td>7.8 %</td></tr>
<tr><td>Leisure</td><td>62.3 %</td><td>64.0 %</td></tr>
<tr><td>Education</td><td>1.0 %</td><td rowspan="4">Other,
8,8%</td><td>1.1 %</td><td rowspan="4">Other,
6,6%</td></tr>
<tr><td>Airport</td><td>1.7 %</td><td>0.9 %</td></tr>
<tr><td>Freight</td><td>4.2 %</td><td>2.7 %</td></tr>
<tr><td>Long trips</td><td>3.0 %</td><td>2.0 %</td></tr>
</table>

Table 4-4: Trip length distribution, Ytre Ring and Feda-Ålgård

Trip length segment	Ytre Ring	Feda-Ålgård
Total_0_10	63.2 %	65.0 %
Total_10_20	18.2 %	19.2 %
Total_20_30	5.6 %	6.0 %
Total_30_40	2.7 %	3.2 %
Total_40_50	2.2 %	2.1 %
Total_50_60	1.7 %	1.4 %
Total_60_70	1.4 %	1.1 %
Total_70+	5.1 %	2.0 %

From Table 4-4, short trips dominate the trip distribution and will hence be an important contributor to the benefit. However, as longer trips have higher value of time, the contribution to the benefit from the different trip length segments may vary between the two projects.

The implementation is performed in four scenarios, as explained in Table 4-5. Scenario 1 represents the basis situation with fixed values for both steps. Scenario 2, 3 and 4 shows the situation where the distance-dependent model is implemented in one or both steps. This way, it is possible to investigate the effects of implementing the model in the different steps.

Table 4-5: Scenario definitions

Scenario	Step 3	Step 4
1	Fixed VoT	Fixed VoT
2	DD VoT	Fixed VoT
3	Fixed VoT	DD VoT
4	DD VoT	DD VoT

Figure 4-3 and Figure 4-4 shows the relationships between value of time and trip length that is implemented in the model. For both steps, the basis for the relationships is the values used in the model today, as given in Table 4-2. For the network assignment step, the values are 72 NOK/hr for work and 96 NOK/hr for leisure. The values are increased in a stepped function from these values up to 70km in 10km increments. This stepped function will hence show an increasing value with trip length. After 70km the same value is assigned to all trips, as given in Figure 4-4. For step 4, traveler benefit module, values are increased according to Figure 4-3, from 99 NOK/hr for work and 84 NOK/hr for leisure up to the values for long trip for the same purposes, 215 NOK/hr and 167 NOK/hr (*Attachment #7 – Trip length dependent model for VoT*).

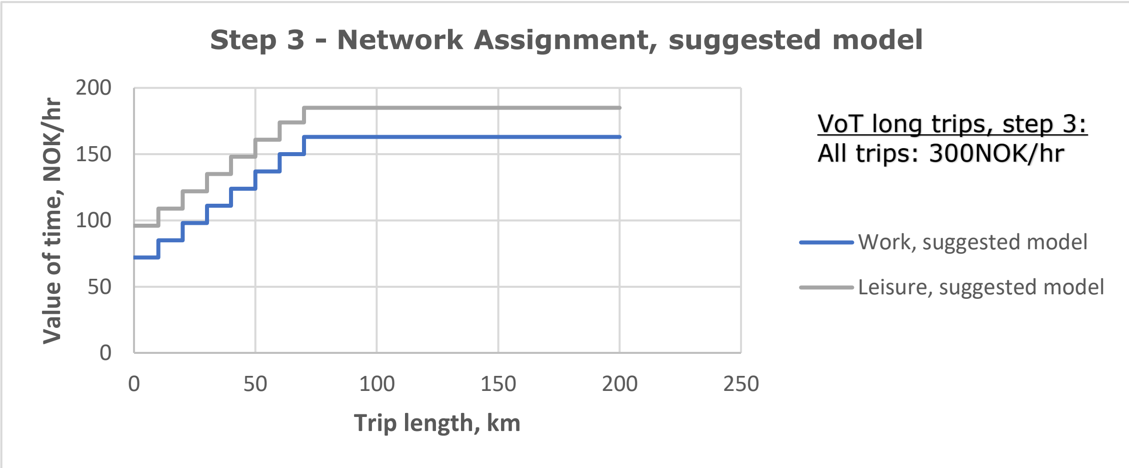

Figure 4-4: Distance-dependent VoT, Network assignment

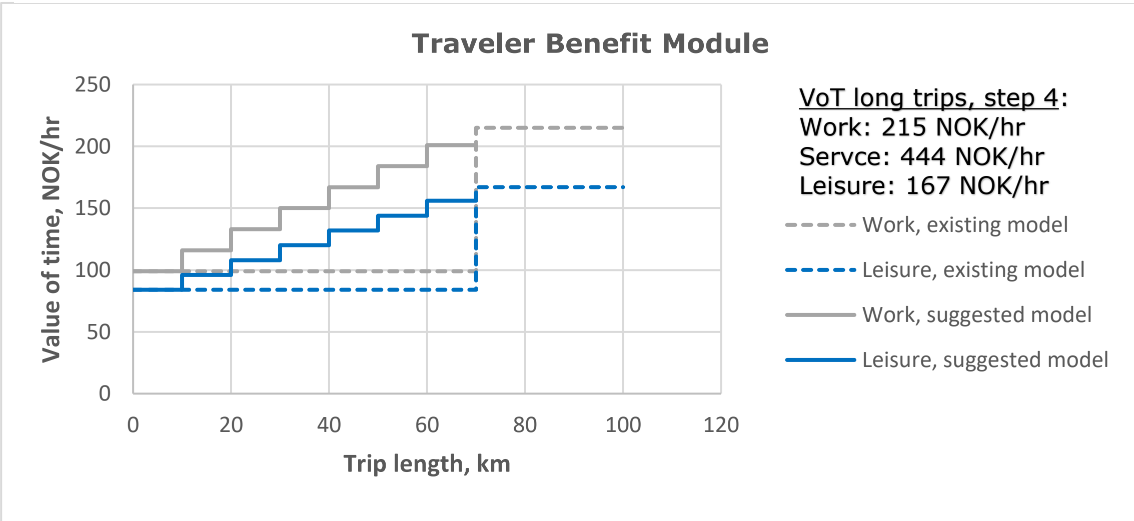

Figure 4-3: Distance-dependent VoT, Traveler benefit module

3.3 Case introduction

The models suggested above are implemented in two Norwegian projects, E18/E39 Ytre Ring and E39 Feda-Ålgård located in southern Norway. Both projects are owned by Nye Veier and part of their portfolio of road projects. The goal of Nye Veier is to build roads that are socio-economic profitable, meaning the benefits related to the projects is greater than the costs.

With Nye Veier having several project alternatives and alternatives within the same project, it is important to choose the best available project at all times, to maximize benefit for the public. When doing this, it is important to have a solid analysis framework to make sure all projects are evaluated on the same basis. Part of this framework is the valuation of travel time savings, and hence it is relevant and important to do analyses that questions the methods used today and identify their strengths and weaknesses.

For both project there have previously been performed transportation analyses (Cowi, 2018a) (Cowi, 2018b). These analyses are sued as the basis for the calculations performed in this paper. Cowi has provided all input files necessary to perform the analyses, including network with all scenarios defined.

3.3.1 E18/E39 Ytre Ring

The project covers a new ring road around the city center of Kristiansand in the Southern Norway. The road is planned from the intersection Vige on the eastern side of the city, to Grautheller west of the city, including an intersection with the road Rv. 9 north. This project will result in less traffic going through the city centre and hence have several positive effects for the local environment. Although the project will cause the distance from Vige to Grautheller to be 0,8km longer than today's situation, travel time will be reduced by 2,7 minutes due to the increased speed limit (Cowi, 2018a). The project will have both long-distance trips travelling east-west, but also significantly portions of shorter local trips.

Figure 4-5: E18/E39 Ytre Ring, project definition

3.3.2 E39 Feda-Ålgård

E39 Sørvest is the overall project covering the three stretches given in Figure 4-6 below. Feda-Ålgård is the westernmost of the three projects and will include an upgrade of the existing two-lane road with varying speed limits, to a four-lane road with speed limit of 100 km. This will significantly reduce travel time and increase safety for travelers between the two major cities Kristiansand and Stavanger. For the stretch Feda-Ålgård travel time will be reduced by 41,7 minutes and distance by 25,3km (Cowi, 2018b).

Feda-Ålgård will have a higher portion of long distance trips on the new road compared to Ytre Ring due to its location between two major cities.

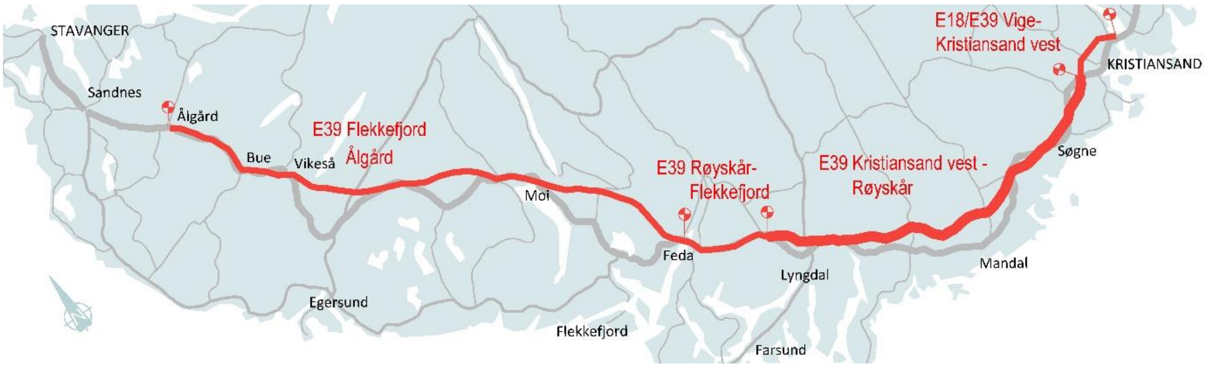

Figure 4-6: E39 Feda-Ålgård, project definition

4. Results

This chapter presents the results from the sensitivity analyses and the implementation of the new model described in the methodology chapter.
The results are presented focusing on total calculated benefit for the scenarios. This number indicates whether the estimated projects benefit will increase or decrease when the input parameters for VoT is changed.

4.1 Results - Sensitivity analysis

Graphical presentations of the results from the sensitivity analyses for Ytre Ring and Feda-Ålgård are given below. From the figure, it is clear that there are variations when it comes to how sensitive the estimated change in consumer surplus is to changes in the input parameters. Figure 4-8 and Figure 4-7 shows the change in consumer surplus for the scenarios.

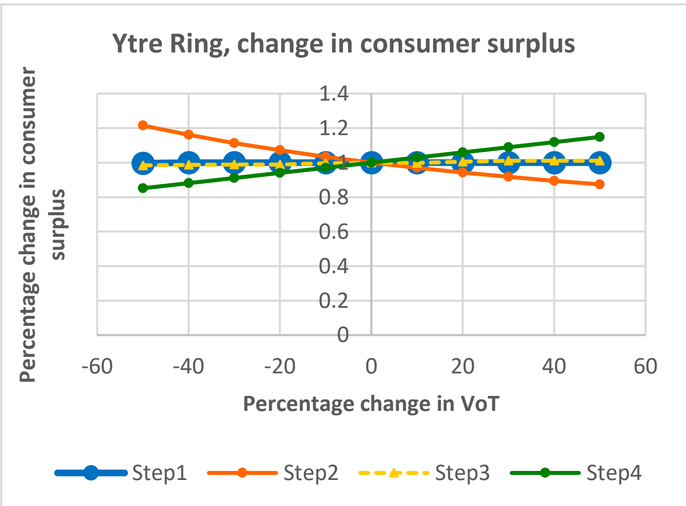

Figure 4-7: Sensitivity analysis, Ytre Ring

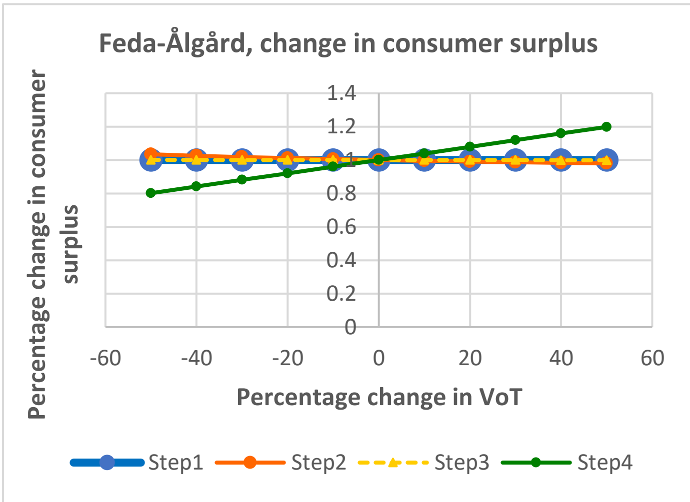

Figure 4-8: Sensitivity analysis, Feda-Ålgård

The figures show that the LoS-calculations in step 1 and network assignment in step3 are relatively unchanged for the different inputs for VoT. Step 1 calculates LoS-data along the route with the lowest generalized costs. If the alternative routes are relatively more expensive compared to the existing one or no alternatives exists, the same route will be skimmed in the first step for all values of VoT. This will again cause the input to the demand model to be identical for the different levels of VoT, and the estimated change in consumer surplus will remain the same.

Generalized costs are also used in step 3 to assign trips to the network. The same situation as described for step 1 will be the case. If trips do not have a real alternative to the route they use today, the same route will be preferred although the VoT-parameter change. The results are small changes in the consumer surplus, because travelers experience the same situation as before.

The demand calculations in step 2 are more affected by the changes in the input parameters. As this step calculates travel demand between all zones in the network, changes in the input parameters for VoT will affect the attractiveness of the different zones and hence cause number of trips produced and attracted in the zones to change.

For Ytre Ring there is a significant reduction in calculated consumer surplus when the VoT parameter is reduced. Analysis of trip productions and attractions in the close proximity of the project reveals that there is a reduction in number of trips generated and attracted to the zones when the VoT parameter increase. This again cause the new road to have less travelers and hence fewer people that benefit from the project, Finally, this cause the calculated benefit to decrease. (*Attachment #5 – Sensitivity analysis in RTM)*

For Feda-Ålgård, the changes in calculated benefit is smaller compared to Ytre Ring. The same analysis as performed for Ytre Ring reveals that there in this case also is a decrease in travel demand between the zones when the VoT parameter increase. However, the changes are not as large as for Ytre Ring, and the effects on the calculated benefit is therefore also relatively much smaller than for Ytre Ring.

For the last step, traveler benefit module, changes in the input values for VoT directly affects the calculated consumer surplus. VoT in step 4 is multiplied by time savings in the given scenario compared to the reference scenario. When this value is increased or decreased, the calculated consumer surplus will be directly affected, and follow a linear pattern.

4.4 Results - Distance dependent model

Based on the assumptions described above, a distanced dependent relationship for VoT has been implemented in step 3 and 4 in the transport model.

Table 4-6 and Table 4-7 show the estimated benefit for Ytre Ring and Feda-Ålgård for the four scenarios described in Table 4-5. For Ytre Ring, scenario 2 shows a relatively unchanged situation when it comes to calculated benefit from TraMod_by trips. Benefit other here represent benefit calculated for the trips not included in TraMod_by (education, airport and long trips) with fixed VoT as used in the models today. The share of TraMod_by benefit ranges from 67% up to 72% in scenario 3 and 4. As TraMod_by trips accounted for more than 90% of the trips in the network (Table 4-3), it is clear that longer trips with a higher VoT contribute relatively more to the calculated benefit per trip compared to the shorter ones.

Table 4-6: Results, Distance-dependent model, Ytre Ring

Scenario	Benefit TraMod_by	%-change in TraMod_by	Benefit other	Total benefit	% TraMod_by
1	5266576	0.00 %	2649484	7916059	66.53 %
2	5268875	0.04 %	2649484	7918358	66.54 %
3	6662257	26.50 %	2649484	9311740	71.55 %
4	6666112	26.57 %	2649484	9315595	71.56 %

Feda-Ålgård has a similar distribution of TraMod_by trips compared to Ytre Ring (Table 4-3). Despite this, the benefit contribution from TraMod_by trips for Feda-Ålgård is much lower. Only 28% of the benefit in the basis scenario for Feda-Ålgård is from TraMod_by trips, while the percentage increase to 37% when the distance dependent model is implemented. This reveals that the trip distribution is of importance when it comes to the benefit calculated for the different scenarios.

Table 4-7: Results distance-dependent model, Feda-Ålgård

Scenario	Benefit TraMod_by	%-change in TraMod_by	Benefit other	Total benefit	% TraMod_by
1	12654971	0.00 %	33082948	45737919	27.67 %
2	12649492	-0.04 %	33082948	45732439	27.66 %
3	19783313	56.33 %	33082948	52866260	37.42 %
4	19773945	56.25 %	33082948	52856892	37.41 %

5. Concluding remarks

The goal of this paper was to answer the following two research questions: 1. How sensitive is the different calculation steps in the Norwegian regional transport model to changes in the input values for value of time? and 2. How will a distance dependent model for values of time affect the estimation results from Norwegian road schemes?

This has been done through two different parts. First, a sensitivity analysis considering changes in the VoT parameters in the different calculation steps in RTM has been performed. The goal of this work har been to identify how the calculated benefit is affected by changes in the value of time parameter in the different calculation steps in RTM. Second, a new distance-based model for value of time has been implementing in selected steps of the model. This model aims to better reflect how travelers value their time for different trip lengths.

The results from the sensitivity analysis shows that the calculated benefit varies, both among projects and the different calculation steps in RTM. For the first step, the route with the lowest GC must be changed if there should be any changes in calculated benefit. If not, the same route will be skimmed and there will be no change in the results. In many situations, there are few or no alternative routes and a change in the preferred route in step 1 would require huge changes in some of the cost components. As this is often not the case, there are rarely big changes in this first step. The same situation happens for the third step, where trips are assigned to the network. If the changed Value

of Time should result in any change in benefit, a new route must be perceived as the best for the travelers. This again requires change in the GC calculations for the zone relation. As this often requires big changes in the composition of the cost components, the effects from changed input values for VoT in the network assignment step are often limited.
This is supported by our calculations, which shows that the results from step 1 and 3 are nearly unchanged for the changes in input parameters.

Results from the sensitivity analysis shows that the demand model and traveler benefit module are more affected by changes in the input parameters compared to the two described above. First, as the demand model estimates travel demand between the different zones, changes in the input parameters for value of time may cause the attractiveness of different zones to change. This will cause changes in traffic flow on the links and hence change the calculated benefit for the projects. For the projects here investigated, Ytre Ring experience more changes in travel demand compared to Feda-Ålgård and consequently bigger changes in calculated benefit from the project. Second, the traveler benefit module multiplies the changes in cost components with factors describing the value of that component. When the value of these savings increases, the calculated benefit will also change in the same direction. Both projects here investigated experience this relationship and have an increasing benefit with value of time.

These results show that the transport model is sensitive to changes in the demand model in step 2 and the traveler benefit module in step 4. The two other steps have nearly no change in calculated benefit for the two cases Ytre Ring and Feda-Ålgård.

The sensitivity of the model to changes in the input parameters have been investigated. The results presented in this paper states that the model is sensitive to changes in the traveler benefit module, where the results vary in a linear manner depending on size of the input variations. For the demand model, the answer is that the sensitivity depends on the type of project and composition of trips in the network. For the two other steps, the model is not sensitive to changes in the input parameters for VoT for the two projects here investigated.

The second research question consider the effects of a distance based VoT in the network. As the distance-based relationship is not implemented in the first two steps, we have no background to say how the results would have varied. However, based in the results from the sensitivity analysis, it is expected that the results from step 2 would have been affected by the new model, but that step 1 would have been relatively unchanged.

The distance-dependent model implemented in the network assignment in step3 cause almost no change in the estimated results and leave the estimated benefit virtually unchanged. As described in the sensitivity analysis, route choices in step 3 often requires large changes in one of the cost components to change. Since the results from step 3 are close to unchanged, this means that the route choices have not changed significantly. However, the implementation of the distance-dependent model in step 4 greatly impacts the results. The calculated benefit from TraMod_by-trips increases by 26% and 56% for Ytre Ring and Feda-Ålgård respectively. This shows that implementing a distance-dependent relationship for value of time in the transport model affect the results. However, the calculation step where the model is implemented highly affects the results.

From the sensitivity analysis and the distance-dependent model implemented above, it is clear that value of time is an important parameter when investigating calculated benefit. Using the wrong values of time can cause the estimated benefit from projects to be either over- or underestimated in the model. With BCA being important for decision processes, an error in the benefit estimations can cause projects to be implemented on the wrong basis. This can result in the rank between projects to be wrong, causing projects that are not the most profitable to be implemented. The social objective related to economic efficiency, meaning the project that generates the most profit to society should be implemented is hence not satisfied.

Several simplifications have been done in the calculations (*Attachment #9 – Limitations*). For the first part, the sensitivity analysis, the study is limited to trips performed by private car. This means that other travel modes are given the same values as in the traditional model. Moreover, traffic assignment is performed independent of capacity, meaning it is assumed there are no problems related to capacity in the networks. Third, only benefit caused by private transport users are considered and correction factors in RTM are neglected.

For the second part, the distance-dependent model, more simplifications in addition to those described for the sensitivity analysis, are done. Here, only work and leisure trips estimated by the demand model (TraMod_by) are assigned a distance-dependent model. This means that other trips, such as long trips, freight, etc. are given the traditional values independent of travel length. Furthermore, network assignment is performed considering time only. This means that the only cost component describing GC in the network assignment between zones is travel time.

The results from the sensitivity analysis and the implementation of the distance-dependent model shows that the calculated benefit from the projects is affected in different ways for the changes in input values for value of time. Moreover, with the changes being significant for some of the steps here investigated, the possible effects on other projects is considerable. Therefore, the idea of distance-dependent values of time should be brought further.

As value of time is known to increase with trip length, the principle idea is to include distance-dependent values of time in all calculation steps in RTM. This would possible results in one uniform model and provide all steps with an increasing value of time with trip length. However, one crucial requirement in this regard would be to make sure the values assigned to the different trip length intervals are based on a representative number of respondents to lower uncertainty in the estimated values. Today, as shown in Figure 4-1, the number of respondents in the upper trip length intervals, used to estimate values for longer trips are very scarce and values hence related to uncertainty. With these values being high compared to shorter trips, and contributing significantly to the calculated benefit, it will be important to minimize the uncertainty related to these values.

However, based on the results from the sensitivity analyses, the demand model in step 2 and the traveler benefit module in step 4 affects the estimation results the most. For the two projects investigated in this paper, the effects on the calculated benefit from changes in step 2 and step 4 vary but can possibly change the project benefit significantly.

Based on these findings, the recommendation for future development of the model is to implement a distance-dependent model for value of time in the demand model and the traveler benefit module. As described above, one critical assumption for this is to make sure the values used for the different trip length segments are estimated from a representative selection of respondents.

Since travel time and travel length are highly correlated in the transport network, it is possible to include models where value of time depends on travel time rather than travel length. This has not been looked at in this paper but is relevant for future work when considering how value of time varies among travelers in the network for different trip lengths.

Finally, the implementation of new models or the improvement of existing ones is an attempt to bring the modeling procedure closer to the situation perceived by travelers in the network. This will lead to information that better reflects how travelers experience the network and the background for the decisions they make. Followingly, this will lead to more realistic models and hence improve decision basis for infrastructure projects.

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5 Attachment #1 – Concept of Value of Time and Generalized Costs

The concepts of value of time and generalized costs are important for transportation analyses and plays an important role for the results from these estimations. Therefore, it is relevant to discuss these concepts in more detail to get a better understanding of their relevance and relation to transport analyses.

5.1 Value of Time - Introduction

In transportation systems there are multiple factors affecting how people behave and what decisions they make. When modelers try to replicate the real world and understand travel behavior there are several factors that must be determined. One of these is the concept of Value of Time, which is one of the most important concepts in transport economics (Mouter and Chorus, 2016). This concept makes it possible to compare the different costs and benefits of travel in one monetary unit and is hence one fundamental idea in the evaluation of infrastructure projects.

As explained in Small (2012) there are multiple reasons why value of time is important and why it is useful in numerous situations, including evaluation of investments and policies, investigation of behavioral questions and for transport modeling purposes. While the study of behavioral aspects might belong more to other fields than transportation research, both investment and policy studies and modeling are of great interest for traffic and transportation engineers. With this, it is clear that the concept of value of time is of high importance and important to study in more detail to get a good understanding of the concept.

Moreover, when deciding between different projects in the transportation sector, there are often more project proposals than could be funded. Since infrastructure projects in Norway usually are funded with public money, it is important that money is spent in a way that profits the general public the most. Therefore, it is important to have a common framework to analyze all impacts of projects. In Norway this is done through the Benefit-Cost Analysis (Statens Vegvesen, 2018) (*Attachment #2*). When this method is used, it is possible to rank the projects and implement the ones that generates most benefit first. When this is done, the projects chosen will provide as much benefit as possible to the society.

There are different notions that are used when it comes to the value of travel time and time savings. Value of time, VoT, describes the overall value of time and can include valuation of time in other situations than time savings in transport networks. Value of travel time, VTT, describes the value of time related to travel. Value of travel time savings, VTTS, describes the value of time saved in the transport network due to improvements in the system. Although there are different notions available, they can all be used to represent value of time saved in the transport network, and the notion of VoT will be used in this attachment.

5.2 Value of Time – the concept

A basic principle for the use of value of time is the understanding that travelers try to maximize their utility in every situation (Dodgson, 1981). This means that travelers try to maximize the positive consequences and try minimizing the negative impacts of traveling. However, as travel is often seen as an undesirable way of spending time, it is assumed that travelers would rather spent their time doing something different (Metz, 2008). Minimize the negative impacts of travel will therefore be the prevailing way of maximizing utility in the transport system.

When modeling travel behavior, it is assumed that willingness to pay to reduce time can be interpreted as value of time. This principle assumes that a change in price and travel time can be compared and that the trade-off between travel time and money can be investigated.

Different methods are used to estimate value of time, with data collected from surveys being one of the main sources (*Attachment #3*). In these surveys, individual choices for trade-offs between money and time are investigated. These choices are later analyzed in order to estimate the value of time parameters. Although value of time is a very important parameter in transportation modeling, the value is hard to estimate with certainty and much effort is put down to improve these estimates.

With value of time being difficult to estimate and different methods being used in the estimation process, there are differences in the values applied in transportation models in the different stages of the model. Moreover, there are disagreements regarding what values that should be used in the different stages. If different input variables change the results from the model, this might cause different projects to be more or less beneficial or cause the rank between projects to change. Therefore, it is of high importance to investigate this in more detail and see how the results vary with changes in the input variables. This will therefore be discussed in attachment #5.

5.3 Generalized Costs - Introduction

In addition to the concept of value of time described above, the concept of generalized costs, GC, is important when talking about valuation of time in transportation models.

Value of time, as described above, is the parameter used to describe how people are willing to trade money to save travel time in the network, typically due to a new and faster road and reduced travel times. However, the traveler’s choice may depend on several other factors in addition to travel time and the concept of generalized costs is therefore introduced.

The idea of generalized cost is that that the total cost of travel from an origin to a destination is given as contributions from several factors, such as travel time, distance, on board time, queues, waiting time, delays, comfort etc. and that all these factors may affect the choices that are made during travel.

Generalized costs is the concept that makes it possible to compare the different cost components and measure the attractiveness of different alternatives in the transport network (Wardman and Toner, 2018). Since travelers value the different cost components differently, this is a method to increase the realism of the choices made in the model.

5.4 Generalized Costs – the concept

The total cost of a trip is built up by the different cost components and their weights. Table 5-1 illustrates the different cost components that might be included in the GC calculations. What parameters that are included in the cost functions depends on factors such as mode, time of day, location etc. For car, the function will be built up by travel time, distance costs and direct costs such as tolls, parking fees. Other modes will have other factors, such as reliability, transfer, access/egress and waiting time for public transport.

Table 5-1: Generalized Cost components

What	Description
On board time	Driving a car, riding a bus etc.
Waiting time	Time spent waiting for a bus, train etc.
Access/egress time	Time getting to and from the mode of transport, e.g. train station
Transfer	Changing from one mode to another or between the same mode
Queue	Driving in heavily congested conditions
Comfort	How comfortable is the mode, e.g. able to sit on public transport
Reliability	How reliable the mode is, e.g. whether the mode actually departs
Punctuality	How punctual the mode is, e.g. whether it departs/arrives on time
Variability	How probable it is to arrive on time, highly linked to reliability and punctuality
Direct costs	Parking fees and tolls (typically to be paid only by drivers)

All these components affect how people decide between alternatives. However, to be able to use this information in the decision process it is necessary to have a relationship between the components to find the total value of different alternatives. This is given as generalized costs and represents the total cost of a choice.

As GC is built up by the different components in Table 5-1 and their weights, the total cost of a trip can be reduced or increased by changing either the weights of the different parameters (e.g. travel time, waiting time etc.) or by changing the value of the parameter itself (e.g. the value of on-board time, waiting time etc.). The weights of the parameters are changed by changes in the network, such as road improvements, or improvements that increase reliability, comfort etc. The value of the parameter itself is given by surveys and are based on how the public value their time in different situation. These values can also be changed but requires that there are changes in how people value their time in the different situations.

5.5 Uncertainty and criticism

Both Value of Time and Generalized Costs plays important roles in the transportation analysis process. However, both methods have uncertainties related to them and this must be considered.

For Value of Time, uncertainty is related to the estimation of VoT from surveys. This is discussed more in attachment 3.

For Generalized costs, uncertainties are related to what parameters that are included in the equations and what weight they have relative to each other. This strongly affects the results from the estimations and must therefore be analyzed carefully.

Some also argues that the limitations of the generalized cost concept has been forgotten and overlooked and that the concept is used only because it is a familiar concept that has been used for a long time (Wardman and Toner, 2018).

Finally, it is difficult to measure all factors that affects the calculation of value of time and generalized costs. However, a model is needed for e.g. project decisions and the one presented is probably the best available and therefore used. That being said, the model should be continuously developed, and new techniques should be included if this can improve the estimation results.

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6 Attachment #2 - Benefit-Cost Analysis, BCA

6.1 BCA in general

Benefit-Cost Analyses (BCA) are widely used for analysis of different projects and in decision making. The goal is to use a strategy that considers both the benefits and costs of different projects and thereafter being able to rank the projects against each other. Because available funds are often limited, the project that generates the most benefit relative to its investment cost should be implemented first. This is especially important in public projects where a set of social objectives usually must be achieved (Bristow and Nellthorp, 2000). Among others, economic efficiency is one of these objectives and therefore necessary to investigate in more detail. In addition to rank different projects against each other, projects usually also have several different alternatives, and hence these alternatives must also be evaluated to maximize profit. BCA is developed as a helpful tool in the process of implementing the projects that generates the most benefit first.

Different criteria are used in the BCA analysis to define what projects that are the most profitable. The basis for the strategy is the Pareto Criteria, saying that one person cannot be made better off without making another person worse off (*Pareto's Efficiency - The Economic Times*, 2018) This tells us that a project should be implemented if no one is worse off and at least one person is better off after the project is implemented. In reality, this is very hard to achieve. Unfortunately, most projects will have negative consequences for some people, and if that is the case, no project can be implemented according to the Pareto Criteria.

As a result of this, another criterion is being used. Kaldor-Hicks criterion states that a project should be implemented if winners can compensate losers. This means that if the total benefits of a project is greater than the total costs, the project should be implemented (Law and Smullen, 2008). Moreover, if this is the case the project will provide a net benefit for the society, the total welfare will increase, the average person is better off, and the project should therefore be implemented.

For the BCA analysis, the latter criterion is used, meaning the project causing the most overall benefit should be implemented. However, as the criterion states, this does not guarantee that no one will be worse off, but that the average person affected by the project will be better off after the project is implemented.

However, using BCA as a strategy have been debated, questioned and criticized for basing the decisions on uncertain assumptions about the future and the problem related to subjective valuation of different benefits compared to each other (Börjesson, Eliasson and Lundberg, 2014). Despite these critics, BCA are used in a wide range of projects and is important in many project decisions, probably due to the lack of more suitable methods. Uncertainties in the BCA will be discussed in the end of this attachment.

6.2 BCA - Calculations

BCA analyses are based on cost and benefit estimations that have been performed using different types of estimation techniques and computational software. Costs and benefits are further analyzed using different profitability analyses. The two following are here described:

- Net Present Value, NPV
- Benefit-Cost ratio per budget NOK

Profitability criterion are used to analyze whether benefits from a project is greater than the costs, and hence whether the project should be implemented or not.

Moreover, based in the different criteria, it is possible to find the most profitable projects and implement the projects with the highest return first. By doing this, the total benefit available will be maximized.

6.2.1 Net present value

This first method simply takes the present value of benefits minus the present value of costs. If this net present value, NPV, is positive, this means the project is profitable and should be implemented from an economic point of view. In other words, the projects generate more benefits than it costs and therefore the society will be better off if the project is implemented. Both benefits and costs must be discounted and compared in the same year, to account for the fact that benefits and costs often occur at different times.

The following formula is used, as defined by (Statens Vegvesen, 2018).

$$NPV = \sum_{t}^{n} \frac{N_t - C_t}{(1+r)^t}$$

Where the following parameters are used, given in Table 6-1.

Table 6-1: Cost-benefit ratio parameters

Parameter	**Description**
NPV	Total net present value
N_t	Total benefit for the analysis period
C_t	Total cost over the analysis period
T	Analysis period
R	Discount factor

Based in the formula above, it is possible to find the project that generates the most benefit and hence should be implemented. NPV gives the absolute value of benefit or costs, depending on whether the project is profitable or not.

6.2.2 Benefit-Cost ratio per budget krone

The second decision criterion is Benefit-Cost ratio per budget NOK. This method takes the net present value of the project (NPV) over the cost of the project funded by the government. With this method, a project will be profitable if the value is greater 0. If a project has a Benefit-Cost ratio per budget NOK = 0,5 this means for every NOK spent in the project there will be a return of 1,5 NOK, a profit of 50% and hence the project should be implemented.

$$B - C\ ratio\ per\ budget\ NOK = \frac{\sum_t^n \frac{N_t - K_t}{(1+r)^t}}{C_{bud}}$$

Where the following parameters, given in Table 6-2.

Table 6-2: Cost-benefit per budget krone parameters

Parameter	Description
B-C ratio per budget NOK	Net profit per budget NOK
N_t	Total net benefit over the analysis period
C_t	Total cost over the analysis period
C_bud	Project costs over government budget
T	Analysis period
R	Discount factor

The BCA ratio per budget krone gives a percentage return for every krone invested by public money. The two ratios NPV and BC-ratio per budget krone is hence not comparable directly and must be calculated separately.

6.2.3 Use of profitability criterion

What profitability criterion that should be used depends on the funds available. If funds are unlimited, all projects that generates a positive NPV should be implemented. This is because all these projects will cause the average traveler to be better off and hence should be implemented. However, this is rarely the case, since funds are limited in most situations. When funds are limited, the project with the highest BC-ratio per budget NOK should be chosen. This is because governments want to invest in the projects that return the most profit per invested NOK from their funds.

6.3 BCA in the Norwegian Regional transport model

In Norway, the BCA method is used in public infrastructure projects as decided by the National Public Roads Administration (Statens Vegvesen, 2018). The method considers both monetized and non-monetized benefits and costs related to proposed projects.

The framework is described in “Håndbok V712 Konsekvensanalyser”, by Statens Vegvesen (Kjerkreit, 2017). This handbook describes how an impact assessment is supposed to be performed for projects in Norway and what aspects that are included in these analyses.

The impact assessment used in Norway is divided into two parts, one considering the impacts that are assigned a monetary value and one considering impacts that are non-monetized.

6.3.1 Monetized impacts

Monetized impacts include all positive and negative impacts that are a consequence of the given project and are given a monetary value. In Norway, this means that the impact is measures in NOK and easily can be compared to e.g. investment costs and maintenance costs. In the Norwegian model, the following impacts are considered for the monetized impacts:

- Benefit for transport system users. This includes both time and vehicle costs, positive health effects from more walk/bike trips and costs of walk/bike trips that don't feel safe during the trip.
- Benefits for operators, including income and costs for public transport companies.
- Budget costs for the government, such as investment and maintenance costs and tax income.
- Impacts on society, such as accident costs and environmental costs.

6.3.2 Non-monetized impacts

In addition to the monetary costs and benefits in the framework, it is important to consider the non-monetized impacts. However, this work is related to great challenges when it comes to the evaluation of different aspects. Individuals will have a different perception of what is the most important when it comes to the non-monetized impacts. Included in this category is outdoors/urban and rural life, landscape, diversity, heritage and natural resources. These are wide categories and all of them includes several different aspects. It is up to the consultants to identify the different aspects for the given projects and estimate the importance of each of them.

6.3.3 Implementation in RTM

The regional transport model used for transport analysis in Norway has a separate module that calculates the benefit from proposed projects. This module, known as the Traveler Benefit Module is the fourth step in the modeling procedure, as described in attachment 4. The input to this step is the results from step 3, network assignment, that assigned all trips to the network and hence have results with travel costs and volumes for all zone-relations.

In the benefit module, two scenarios are compared to one another. First, the basic scenario represents the situation without changes in the input parameters. This means how the situation will be if the project is not implemented. Second, the project scenario is the situation with the proposed project implemented and hence changes in traffic distribution, travel costs and volumes. In the TNM module, these two scenarios are compared, and every zone-relation is investigated. Based on the input information provided, the total benefit is calculated from the following two contributions.

- First, travelers that are already in the system will experience either an increase or decrease in travel between their origin and destination zone. This change in cost can be caused by either change in travel time, distance or direct costs. These travelers will consequently have an increased or decreased benefit depending on whether costs increase or decrease. The example in Figure 6-1 illustrates a decrease in price and consequently an increase in demand. This means that existing consumers will experience lowered GC and increased benefit, given with area B in the figure.
- The second part is built up by new travelers that are either attracted to the zone-relation due to lowered GC compared to their existing trip or travelers that choose not to travel between the zones due to increased GC and hence choose another destination. In Figure 6-1 this is illustrated by new travelers coming to the zone-relation as a consequence of the lowered GC. Area C shows the increase in benefit caused by these travelers.

Consumer surplus before implementation of the new project is given as area A in the figure. The new consumer surplus is given as area A + B + C. This benefit is thereafter summed up for all zone-relations in the network. If the total consumer surplus is greater after the implemented scenario compared to before, the project is profitable and should be implemented.

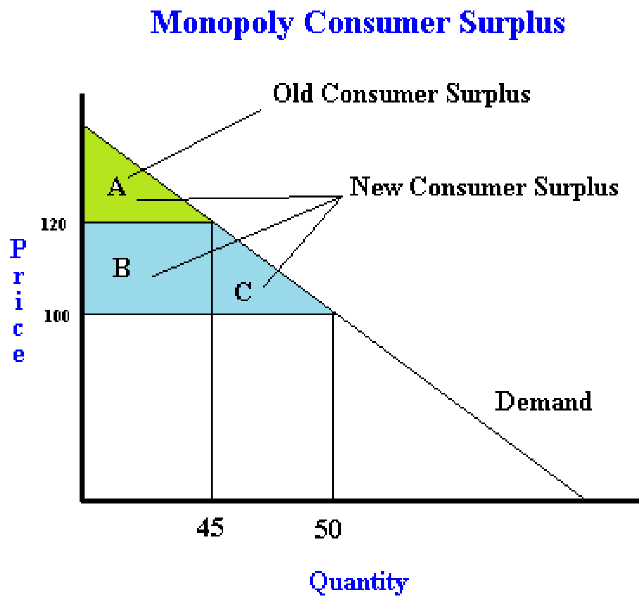

Figure 6-1: Change in consumer surplus (Monopoly consumer surplus, 2019)

6.4 Uncertainties in the BCA framework

Benefit cost analyses are used for project evaluation in a wide range of different projects around the world. These analyses influence and affects projects of great import, such as infrastructure projects. However, critics have been addressed regarding the foundations for the BCA, and that the analysis is built up on uncertain assumptions. (Kornhauser, 2000) (Börjesson, Eliasson and Lundberg, 2014). Despite this, the analysis is today the most common method to perform project appraisal, probably much due to the lack of other and more suitable methods.

Some of the uncertainties in the BCA framework.

- Transport demand in the basic and the project alternative is uncertain and based on the calculation from transport models. For Norway, these numbers are based on the Regional Transport Model, and as described in attachment 4, these estimations are based on a predicted future transport scenario and hence uncertain.
- Value of time in the Traveler Benefit module affects the result in a significant way (*Attachment 5*). Consumer surplus is directly affected by the input VoT to the traveler benefit module.
- Assumptions regarding analysis period and discount factors are uncertain. In Norway today, 40 years is used as the analysis period. However, infrastructure facilities will often provide benefit for a longer time than this and benefits may therefore be underestimated in the models. Also, the discount factor affects how future benefits and costs are valued today. The factor used for infrastructure projects in Norway today is 4%.
- Subjective valuation of benefits and costs in the model introduce uncertainties. Since not all effects from projects are measurable in a monetary unit, these must

be converted to such units. However, people value these impacts differently and to value them in a monetary unit can hence be difficult and depend on who is doing the job.

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7 Attachment #3 – Stated Choice Methods

This attachment is mostly based on information collected from *Stated Choice Methods – Analysis and Application, Chapter 2: Introduction to stated preference models and methods* (Louviere, Hensher and Swait, 2000) and covers some of the most important aspects of the Stated Choice theory.

7.1 Introduction

Transport analyses are important in several situations and serves as input for several different purposes, including Benefit-Cost analyses (*Attachment 2*). When performing such analyses, the goal is to replicate the real world as good as possible and make models that can predict travel demand and behavior in the future. This requires input information about several different aspects, ranging from transport network, household information, zonal data, travel costs and volumes to mention some. In addition to this, how the travelers value improvements in the network, e.g. how travelers value travel time savings, is an important part of these analyses.

All travelers are different and will consequently value their time differently. It is therefore important to get information about how different travelers value their time and other transport related components when they travel in the network. Moreover, the cost components will be perceived differently in different situations and on different trips, making it more complicated to estimate values that can be used for modeling purposes. Since there are huge variations in value of time among individuals and type of trip, it is important to have enough respondents to be able to estimate the values as correct as possible and make them valid for the entire population. However, getting information about all travelers in the network is nearly impossible and would have required enormous resources. Therefore, different estimation techniques are used in this process, where some will be described in the following.

7.2 Individual choices

All individuals will have their own perception of what is the right choice in a given situation. Because people are different, people's opinion of what is the best choice will differ depending on several factors, such as age, gender, geography etc. When using a selection of the population to estimate results that are used as the basis for the entire population, it is therefore important that the selection covers all groups in the population and that the answers reflects the average person. This means that rather than just a few respondents, a big sample of respondents will be necessary to obtain a realistic and reliable estimation of the choices of the public in a given situation. Furthermore, this makes such work time and money consuming.

Several factors affect what people will do and what choices they will make when facing a situation where a choice is needed. This includes other people's opinion, advertising, household and family constraints, habit, experience and many others. A decision will be based on all these factors and therefore it is not easy to determine what factors are the most important.

From this, estimating people's response in different situations is complicated and must be performed with precision and accuracy. To be able to do this, different methods are established, such as Stated Choice Methods, that will be described in the following.

7.3 Stated Choice Methods - Structure

Stated choice methods are based on what respondents would have done in a given situation. The method is built up by hypothetical choice situations where the respondents must make a choice based on the information provided. Based on these answers, it is possible to estimate the choice of the public and hence obtain information that can be used for various purposes.

The stated choice method is used in Stated Preference, SP-surveys. These surveys are built up by hypothetical games where the respondents are given different scenarios where they must make choices based on a set of input parameters. To increase the realism in the surveys, a reference alternative is often included. By doing this, the respondents are asked to add data about a trip they have recently performed, and this will be used as a reference for the questions in the survey. Variables, such as travel costs, are varied around the input information from the reference trip. How the respondents answer on these questions and how they trade off money for time savings are used in the process of estimation the value of travel time and different travel time components for use in appraisal.

With a survey such as the stated preference, it is possible to have a controlled environment with a pre-defined relationship among attributes. This means it is possible to ask questions in a way that reveals useful information about travelers and their choices. Although stated preference surveys are dealing with hypothetical situations, meaning what people would have done in a given situation, they are often the most appropriate way to get the information sought for.

There are several reasons why SP-surveys can be the best way to collect the necessary information. First, SP surveys can be preferred when observational data is expensive and/or time consuming to collect. Surveys collecting information about performed choices, so called revealed preference, are reliable because they collect information about actual choices, but they might be complicate, time consuming and expensive to collect. Therefore, SP surveys might be a better alternative. Second, SP-surveys are suitable when information about future choices are limited or non-existing. This can be the case if new products are to be introduced and there are no similar products today that can be used to estimate the demand for the products. In this case, a hypothetical questionnaire, SP, must be used.

Third, if new variables are introduced that explain new possible choices, stated preference surveys can be used to estimate the probability of choosing the new alternatives. Moreover, if the model assumptions are not satisfied by the observational data, SP-surveys can be the solution. This can be the case if the model is built up by a set of new assumptions that are not present in the observed data today.

Following, SP-surveys can be useful if the product is of a type that is not being traded in the real economic market. One example here is environmental goods such as the value of a road or consequences of different emissions. Also, if explanatory variables are either highly collinear or have little variability in the marketplace it can be argued that stated preference surveys are more suitable than surveys where revealed preference is used.

7.4 Types of Stated Preference surveys

Although stated preference is one group of surveys, based on hypothetical questions about a given topic, there are different possible ways to design the surveys. Here, some of the main one will be discussed.

First, choosing one alternative from a set of possible ones will give the most preferred alternative among the respondents. However, this method will not give any information about how the non-chosen alternatives are perceived by the respondent. Therefore, additional questions will be necessary to investigate how the other alternatives are ranked compared to each other.

Second, to deal with the problem stated above, a complete ranking among different alternatives is possible. In this case, all alternatives in the choice set will be ranked from most to least preferred. By doing this, there will be much more information about all alternatives, not only what alternatives that is the most preferred. However, this method will not give any information about the difference in preference between alternatives, that is how much more preferred alternative 1 is compared to alternative 2.

Third, a method to state whether the respondent like the alternative or not can be used. This method can be used to divide between alternatives that are preferred and alternatives that are not. As the case is for the first method described here, this method provides no information about what alternatives are the "most liked" and what is the "least liked" one.

Finally, to deal with the problem of not knowing how much more preferred one alternative is compared to another, it is possible to ask the respondents to rank alternatives on a scale from e.g. 1 to 10. By this method, an alternative with a score of 10 will be twice as likely for the consumer to use compared to an alternative with a score of 5.

As discussed here, there are several different ways to ask questions to get the sought information that can be used to perform the estimations.

7.5 Stated Preference Survey – the method

This appendix focuses on stated preference surveys for the use in transport related situations and the general method for this is described in the following.

Basis for the stated preference survey is the concept of random utility maximization. This concepts states that every individual will try to maximize their utility in a given situation by choosing the appropriate alternatives. For the stated choice concept, there must be a valid set of alternatives to choose between and thereafter the respondents will do their choices based on the idea that they will maximize their utility. Since transport often is seen as a necessity, meaning travel is something all must do, it is about minimizing the negative impacts from travel. In many cases, this means minimizing the total travel cost by minimizing the travel costs components, such as travel time, travel distance and direct costs (tolls/parking fees etc).

Moreover, it is assumed that all travelers will follow the rule of utility maximization and try to maximize their utility in every situation. This means that when answering the stated preference survey, the respondents will answer as to minimize the negative impacts of travel. Consequently, the answers from the survey can be processed and give information about how people trade money for time, meaning how much money they are willing to pay for improvements in the transport system.

The practical implementation of the survey is often done as an online survey where travelers are recruited by different strategies such as advertising online and by mail. To make sure the data is representative for the population, it is important to make sure people from different population groups are recruited. This includes people from different parts of the country, from different household sizes and income groups and different age groups and gender to mention some.

After finishing the data collection, the answers are used in the process to estimate value of time for the different travel modes and purposes. Discrete choice methods are used to estimate value of time from stated preference and revealed preference data. According to (Hensher and Greene, 2003), the Mixed logit models are the most promising of these models currently available.

7.6 Stated preference and the Norwegian valuation study

Values of time for use in transport appraisal in Norway are estimated by the Institute of Transport Economics and published as the report "Value of time, safety and environment in passenger transport – Time" (Farideh *et al.*, 2010).

The estimated values of time are a result of stated preference data that are processed to estimate value of travel time. As described above, stated preference surveys are hypothetical questionnaire's where respondents are asked questions about their preferences in different situations. Furthermore, these results are used to establish a relationship between money and travel time and hence estimate how much travelers are willing to pay to save time. Different notions can be used to describe this value, here value of time, VoT is used.

As described above, value of time will be modelled as a disadvantage due to the necessity of the trip. This means that every traveler will have their own valuation of the time spent in the transport system and consequently their own valuation of the travel time. From a modelling standpoint this cause complications, since individual preferences are hard to model in complex transport system. Therefore, values of time are divided into groups based on travel purpose and travel mode. This assumes that travelers in the same group will have more or less the same value of time and hence can be grouped together.

The stated preference surveys are therefore designed in a way that these differences can be observed and used in the estimation process.

The surveys are structured as follows:

1. Questions to collect information about the respondent, such as demographic characteristics and socio-economic background.
2. Questions to collect information about the reference trip of the respondent. This trip is used to adjust future questions to the respondent.
3. Set of questions to collect information about how the respondent trade off time against time savings in the network. The reference trip is used as the basis to make the choice situations more relatable to real world scenarios for the respondents.
4. Final questions to conclude the observations and collect more data about the respondent.

Table 7-1 gives the travel purposes estimated in the Norwegian value of time study and the Norwegian translation.

Table 7-1: Travel purposes in the Norwegian valuation study

Trip purpose	Trip purpose (Norwegian)
Trips to/from work	Reiser til/fra arbeid
Other private trips	Andre private reiser
All private trips	Alle private reiser
Service trips	Tjenestereiser
All trips	Alle reiser

The following travel modes are estimated in the study. In addition to the modes given in Table 7-2, walk and bike trips are estimated.

Table 7-2: The Norwegian Value of time study, long and short trips

Short trips (<100km)	Long trips (>100km)
Car driver	Car driver
Public transport	Train
Ferry	Bus
Speed boat	Plane
	Speed boat

As mentioned above, it is important to have respondents from all groups of the population, ages, geography etc. One important parameter is also the length of the reference trip and how the reference trips are divided into trip length segments. It is important that the reference trips cover a representative selection of the total trips, meaning both short and long trips are included. Figure 7-1 shows the length of the reference trip, collected from the Norwegian value of time dataset.

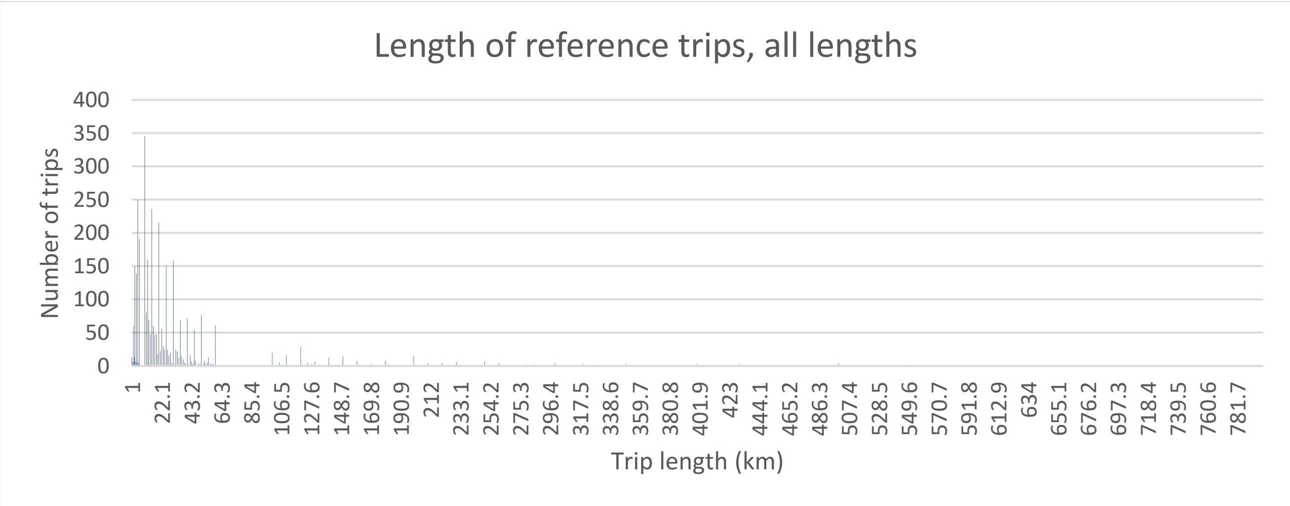

Figure 7-1: Length of referencec trips, all trips

The figure shows number of respondents with the different lengths of the reference trip. From the study, most of the reference trips are located in the shorter trip length segment. To better illustrate this, Figure 7-2, shows the distribution for trips in the interval 0-100km, with one column for all trips above 100km. This figure illustrates that trips in the shorter trip length segments dominates for the reference trips.

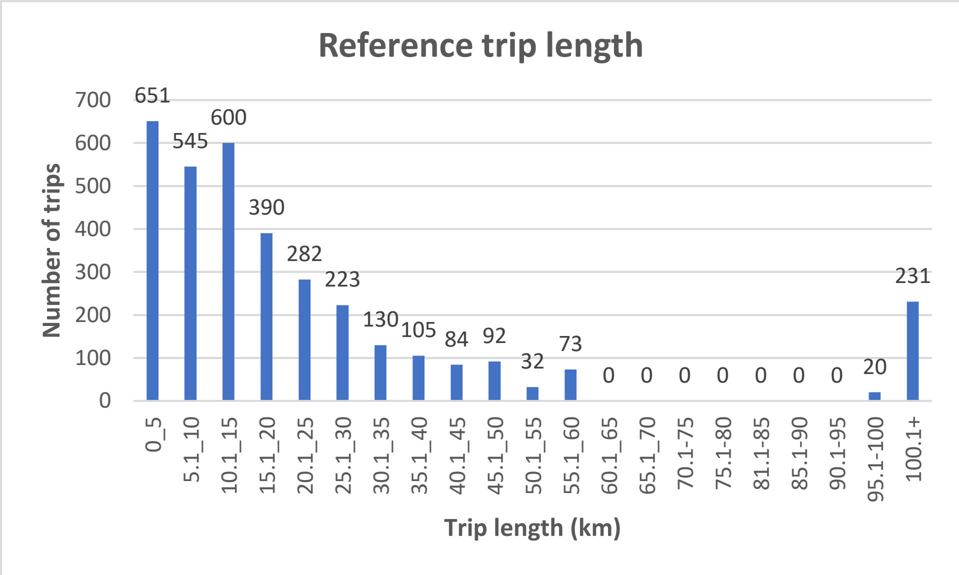

Figure 7-2: Length of reference trips, interval 0-70km

Value of time parameters estimated from the valuation studies are divided into short trips below 100km, and long trips above 100km. This means that the values for the interval 0-100km is estimated based on trips mostly in the interval 0 to 30km. Furthermore, the values for longer trips are based on a very limited number of respondents since most trips are in the very short interval. As described above, it is important that the respondents represent the entire population to make the values valid for appraisal purposes. With the huge amount of trips in the interval 0-30km it is possible that trips I the interval 50-100km is underrepresented in the surveys and this can consequently cause errors in the estimates. The same situation will be the case for longer trips, since these values are based on very few respondents. Since VoT for these trips usually are much higher compared to shorter trips, they can possibly causer huge errors in the estimates.

7.7 Stated Choice Methods – Uncertainty

Since stated choice surveys are based on a hypothetical situation, there will always be uncertainty related to the results. The reliability of the results will depend on whether the respondents answer what they actually would have done in the situation. It is not unrealistic that people will answer more "correct" in the survey than what they actually do in the situation.

Other possible factors that can affect the survey results is the handling of responses after the survey is finished. The methods used in the estimation of variables from the survey data will affect what the results look like and hence what values that will be used for appraisal.

As discussed in the previous section, it is also uncertainty related to the representativity of travelers taking part in the survey. If one trip length segment is overrepresented in the survey dataset, this can cause the segment to be overrepresented when estimating the value of time for the entire segment, and hence cause errors in the estimates.

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8 Attachment #4 – Value of time in RTM

8.1 Introduction to transportation models

There are different models available for transportation analysis in Norway today. These models all have their strengths and weaknesses and are suitable for different purposes.

To model travel behavior and the effects of different infrastructure projects, the Regional Transport Model, RTM is the main tool and is the one used in this paper. However, there are other important models that are used for various modeling purposes:

- STRATMOD is a strategical model to predict and analyze the effects of new transport measures in city areas in Norway. (Norheim, Tormod and Haug, 2016) Due to the increased focus on more environmental friendly transport modes, there is a need to model these changes and the effects of the different measures (Tørset *et al.*, 2012). STRATMOD is therefore developed to accommodate these needs.
- Trenklin is a model used mainly to investigate the effects of rail projects. (Flügel and Hulleberg, 2016)
- NTM is the model for long trips in Norway (trips with a length of more than 70 km) (Tørset, Malmin and Bang, 2013).
- Godsmodellen is used to model freight trips in and to/from Norway (Tørset, Malmin and Bang, 2013)

The NTM-model and Godsmodellen are used together with RTM in Cube to model the total transport demand in Norway. Both the demand for long trips and the demand for freight transport is estimated with the respective models and implemented in Cube as fixed matrices, meaning they are not estimated by the demand model used for RTM. The RTM and demand model will be discussed more in the following.

Citilabs Cube (*Citilabs®*, 2016) is the software where RTM is implemented together with NTM and Godsmodellen. The Regional Transport Models is a simplified representation of the real world and tries to model the connection between transport supply and demand (Tørset, Malmin and Bang, 2013). Models like this is useful in several different situations that requires estimates for what the transport situation will look like in the future. Therefore, it is important that the models reflect the most important aspects and produce results that can be used as a basis for decision making in different projects.

In the model, travel time is modeled as a disutility. This means that travelers will try to reduce the time spent in the transport system, because travel is a necessity rather than something you do for its own sake. Moreover, this means that travelers will choose the mode and route that minimize the travel costs, given the other attributes of travel.

8.2 Terminology used in RTM

Some important terminology is useful to have clearly defined before studying the Regional Transport Model in detail:

- Zone: The total area of interest is divided into different zones. These zones can be of various size and have different population. The idea is that households, employments and other trip attracting and generating facilities are aggregated to larger units to be handled by the model.
- Nodes and links: The transport network consists of nodes and links. Nodes are dots that are connected with links. Nodes are placed where something important happens (such as intersections etc.) and links symbolize the network connecting all the nodes.
- Network: The sum of all links, nodes and zones.
- Origin: A zone where trips start
- Destination: A zone where trips end
- Zone-pairs: Two zones that are connected through the network. If there are trips going between the two zones, one zone will be an origin and the other a destination.
- Internal trips: Trips that start and end in the same zone. This means the same zone is the origin and the destination of the trip.
- Internal distance: length of internal trips.
- Zone centroid: One point in the zone where all trips start and end. This means that although trips may start from different locations inside the zone, all trips are for practical reasons said to start at this specific point.
- Zone connector: The zone centroid is connected to the network through a zone connector. This connector may vary in length depending on the area. All trips that go to/from this zone will go through this connector to access the network.

8.3 Four step model in RTM vs. the Four step travel demand model

The four-step travel demand model (*Four-Step Travel Demand Model*, 2019) used in Transportation forecasting is defined as follows:

1. Trip generation. How many trips are produced and attracted in the different zones?
2. Trip distribution. Where do trips start and end, e.g. link origins and destinations together to trips.
3. Mode choice. What mode of transport is used for the different trips?
4. Network assignment. What route is selected between the zones?

This four-step framework is used in the process of estimating travel demand and what routes that are used by the travelers. The procedure is the basis for the transport planning tools used today, however the calculation order and layout differs from the calculation order in RTM.

The model used in Norway, the Regional Transport Model, also use a four-step procedure, defined in the following. From here on, when referring to the four calculation steps, the steps in RTM, described in next section, are considered.

8.4 Value of Time in RTM

Value of time in RTM occurs at several different locations (Malmin, 2013). As described above, the calculation in RTM is divided into four steps, where the steps have different input data and consider different aspects of the modeling process.

Simplified, the process can be described as follows:

1. Network program generates LoS-data from input data provided to the program.
2. Demand model (TraMod_by) runs and calculates origin-destination matrices based on the LoS-data from step 1.
3. Network program assigns the trips based on the origin-destination matrices from step 2. This gives traffic flows on the different links in the network.
4. The traveler benefit module calculates the change in consumer surplus by comparing the cost components (time, distance and direct costs) between the reference and project scenario for all zone relations in the network.

The process is described in the following and the four steps investigated.

For the different stages, values of time used in the model is presented. These values are the values used in the RTM model for the projects E18/E39 Ytre Ring and E39 Feda-Ålgård. The values may therefore vary from the ones given in the technical documentation of RTM (Malmin, 2013).

8.4.1 Step 1: LoS-data

The regional transport model assumes that travelers will choose the best route available to them at all times. Several factors affect traveler's perception of what is the best alternative and what people think is the best route may vary among individuals.

However, to be able to model these choices, the LoS-calculations are done using one or more of the parameters listed below. For car trips, all three variables are used, for other trip purposes the specifications are described below.

- Travel time
- Travel distance
- Direct costs related to travel, such as tolls and parking fees

For all zone-relations in the model, there is a related travel time, distance and direct cost. The first step in the model consider all zone-relations and estimate generalized costs for all possible routes. The formula below describes how generalized costs are estimated, using the three cost components; travel time, travel distance and direct costs.

$$GC = \sum_i p_i \times V_i$$

With parameters as in Table 8-1.

Table 8-1: Step 1, GC variables

Variable	Description
p	Parameter (weighting of time, distance or direct costs)
V	Size of variable (minutes, kilometers or NOK)
i	Component (travel time, distance and direct costs)

In step 1 in the regional transport model, the following parameters are used, given in Table 8-2.

Table 8-2: Step 1, GC parameters

Parameter	Value
p_{time}	81 krone/hour
$p_{distance}$	1,61 krone/km
p_{cost}	0,8 krone/krone

This information is given for four different types of trips: car, public transport, walk and cycle. Calculation of generalized costs differ for these different modes.

Car trips include all of the three parameters in the generalized cost calculation. The equation therefore looks like the following:

$$GC_{car} = p_{time} \times travel\ time + p_{distance} \times travel\ distance + p_{cost} \times travel\ cost$$

Although travel time and distance are often highly correlated, both are included to be able to account for e.g. ferry trips. For ferry trips, travel time will increase but travel distance (by car) is constant during the trip.

For public transport trips, travel distance is not included in the generalized cost calculations. This is because public transport passengers do not have a distance costs, because this is included in the ticket fare. Therefore, it is assumed that two trips with the same attributes regarding travel time and direct costs, not are perceived differently even if the distance travelled is unequal. Generalized costs for public transport passengers is therefore:

$$GC_{PT} = p_{time} \times travel\ time + p_{cost} \times travel\ cost$$

For walk and cycle trips, only distance is included in the generalized cost equation. This is because it is assumed that walkers and cyclists do not have any direct costs related to their travel.

$$GK_{walk,cycle} = p_{distance} \times travel\ distance$$

Based on these generalized costs calculated from the equations above, the route with the lowest GC for all zone-relations for all of the four modes is skimmed. This skimming procedure investigates the given route in detail and produce matrices with all relevant information about the route. There will be separate matrices for the different data, such as one matrix with on-board time for public transport between all zones, and one matrix with travel time by car for all zone-pairs in the network.

8.4.2 Step 2: Demand model

As described in step 1, general costs are calculated for all zone-relations and the one with lowest GC is skimmed. In this second step, the demand model is used to estimate travel demand between the different zones. In this process, the total cost of the different routes is an important input factor and affect the demand between different zones.

The demand model (Rekdal *et al.*, 2013) used for estimating travel between zones for the different modes is called Tramod_by, which is an integrated part of RTM. Tramod_by is a transport demand model that calculates trip matrices based in the input information.

People value their time differently depending on what kind of journey they are on, and hence travel demand must be calculated for different purposes. Tramod_by calculates trips for the following purposes, given in Table 8-3. In addition, a model for school trips is included in TraMod_by, estimating school trips in the network.

Table 8-3: Trip purposes in TraMod_by

Trip purpose
To/from work
Service
Leisure
Private trips
Pick up/drop off

Moreover, travel demand is estimated for the different modes given in Table 8-4 below.

Table 8-4: Travel modes in TraMod_by

Travel mode
Car driver
Car passenger
Public transport
Cycle
Walk

The demand model estimates travel demand based on input information provided to the program. This information includes among others, population, households and other trip generating facilities in the network and LoS-data from step 1. Attractiveness of the different zones are calculated from the input information, e.g. how many trips that will be attracted and produced in every zone. Utility functions are used to estimate number of trips between all zones in the network. Parameters for each variable in the utility function are estimated implicitly and may differ from values used in other steps of the model.

Implicit values of time are used in the demand model, meaning the values are not given directly but can be estimated from the input information. Table 8-5 shows the values used for some of the travel purposes, in NOK/hour, (table 4.7, Rekdal m.fl. and table 2, Rekdal m.fl.)

Table 8-5: Values of time, private trips

(Values from table 4.7, Rekdal m.fl and table 2, Rekdal m.fl. *values for women/men < 50 years old, **Values for women/men)

	Work	Private	Leisure	Pick-up/drop off
Car driver	76/58*	90	81	109
Car passenger	141/107**	74	79	96
Public transport	56/49**	29	39	96

The result from stage 2 are trip matrices divided between different travel modes and travel purposes, describing the travel demand to and from all zones in the network. All trips start at an origin, the starting zone, and end at a destination zone. These matrices are hence called origin-destination matrices, showing number of trips starting and ending in all the different zones in the network.

These matrices are further assigned to the network in the network assignment step.

8.4.3 Stage 3: Network assignment

The resulting origin-destination matrices from step 2 are used in this third step to assign trips to the network. Although origin-destination matrices are calculated in step 2 describing how many trips are going between all the zones, the demand model does not consider the route choice between the zones, meaning what links are going to be affected. However, this is done in this step.

One important concept when it comes to trip assignment is whether the trips are assigned capacity dependent or independent. If the trip assignment is performed independent of capacity on the link, this means link flows will have no impact on travel time on the link. Moreover, this means that if the link is the one with the lowest generalized costs before trip assignment, this link will also have the lowest generalized costs after trip assignment and the GC will be unchanged.

On the other hand, if the trip assignment is dependent of capacity, this means link volumes will affect travel time and hence generalized costs on the links. If this is the case, the trip assignment must be performed in intervals, meaning a portion of the total flow is assigned to the network and travel times for the different routes are recalculated. With increased flows on some links, travel time might change and hence the best route available might differ from the previous iteration. Followingly, the next portion of the total flow will be assigned to the new link with the lowest GC. After finishing all iterations, the total flow will be spread across different routes.

For trips performed by public transport, walk or cycle, trip assignment is performed independent of capacity. Furthermore, for these three travel modes, generalized costs are calculated in the same way as done in step 1.

When it comes to car trips, the trip assignment depends on whether the modeling is performed on a daily level or divided into rush and non-rush periods. If the modeling is done on a daily level, trip assignment is performed independent of capacity. On the other hand, if the modeling is divided into rush hours and non-rush hours, trip assignment in rush-hours takes into account that congestion may increase travel time on the links and hence use a capacity dependent assignment of trips.

Table 8-7 show the values of time used in assigning the trips to the network for private car trips, in NOK/hour. Here, the travel purposes; private, leisure and pick-up/drop-off from the demand model is merged to leisure trips.

Table 8-6: Values of time used in network assignment for private car

Purpose	To/from work	Service	Leisure	NTM, long trips	Gods
Car driver	72	240	96	300	540

8.4.4 Stage 4: Benefit calculations

In this step, change in consumer surplus is calculated for all drivers, and summed up to a total increase or decrease in welfare. The calculation is divided into two separate procedures, one for private user trips and one for public transport trips. The private user benefit calculation considers private trips and the change in benefit based on change in the different cost components for the travelers. This is explained in more detail below. The second, public transport benefit calculates the change in income for the public transport companies. This part is not considered in the paper and hence not covered in this attachment.

8.4.4.1 Private user benefit calculation

The basis for user benefit calculations is the change in consumer surplus for the users of the transport system. Figure 8-1 (Monopoly consumer surplus, 2019) shows a graphical representation of the change in consumer surplus when the price is changed. Initially, with generalized costs equal G0=120 there are X0=45 consumers that choose to buy the product (or travel with the given mode or on the route). This results in a consumer surplus given by area A in the figure. Moreover, when the price is lowered to G1=100, there are X1=50 number of consumers that find the alternative the best. The lowered price and the increased number of consumers will lead to increased consumer surplus based on the two following contributions (Bertelsen *et al.*, 2015):

- Consumers already in the system increase their benefit due to the reduced generalized costs, e.g. they have to pay less. This is illustrated by area B in the figure.
- New consumers that are attracted to the system because of the lowered price. This is illustrated by area C in the figure below.

Total change in consumer surplus is therefore area B + C. Moreover, these calculations are done for all zone-relations in the system and the total change in consumer surplus for all travelers is then the sum of all these contributions.

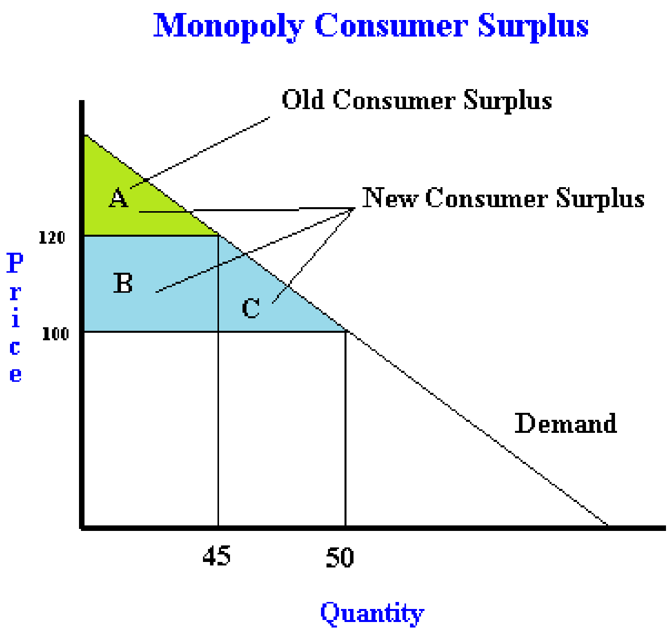

Figure 8-1: Change in consumer surplus (Monopoly consumer surplus, 2019)

The values described in Table 8-7 are used in the benefit calculations. More values are used and given in the input information to the model, but Table 8-7 shows a selection to show the magnitude of the values. The values are collected from the transport models used for the projects E18/E39 Ytre Ring and E39 Feda-Ålgård.

Table 8-7: Values of time in benefit calculations

(NOK/hr, *values for work/service/leisure)

	To/from work	Service	Leisure	Long trips
Car driver	99	444	84	215/444/167*
Car passenger	99	444	84	215/4447167*
Public transport (bus)	69	444	63	93/444/96*

The following formula is used to calculate the total change in consumer surplus between all zones in the model:

$$B_{mo} = -\frac{1}{2}\sum_{ij}\left(GC^{0}_{(mo.ij)} + GC^{1}_{mo,ij}\right)\left(x^{0}_{ij} - x^{1}_{ij}\right) + \sum_{ij} GC^{0}_{(mo,ij)}x^{0}_{ij} - \sum_{ij} GC^{1}_{(mo,ij)} - x^{1}_{ij}$$

With the following attributes, given in Table 8-8.

Table 8-8: Change in consumer surplus equation parameters

Parameter	Description
GC	Generalized costs between zone i and j
X	Transport volume between zone i and j
0-alternative	Basis scenario
1-alternative	Project scenario

In the scenario given in Figure 8-1 above, the consumer surplus increases and hence the travelers are in total better off. In addition to this, it is important to include that this increase in consumer surplus requires some use of public resources. This is a cost for the society and must therefore be subtracted from the increased surplus to find the total change in benefit.

The correction factor for the use of society's resources is accounted for private cars and freight transport.

The following formula is used to calculate the correction for use of public resources:

$$C_{Tarb} = \sum_{kjtt}\left(p_{off,kjtt} - p_{mo,kjtt}\right) * \sum_{i,j}\left(Tarb^{1}_{i,j} - Tarb^{0}_{i.j}\right))$$

With the following attributes, as in Table 8-9.

Table 8-9: Correction factor calculation, variables

P	Cost of driving
Off	Actual cost
Mo	Costs in model
Kjtt	Type of vehicle
T_arb	Transport work between zone i and j, for alternative 0 (reference) and alternative 1 (project scenario)

Total benefit is then given as follows:

$$B_{tot} = B_{mo} - C_{Tarb}$$

The results from the user benefit module is the total benefit minus the correction factor, giving the total consumer surplus for all users of the transport system.

The correction factor is here included to describe how societies' costs are accounted for. However, the correction factor is not included in the calculations in the paper.

8.5 Notes on errors in the estimates

As several simplifications are done in the transport analysis, errors in the estimated must be identified and discussed.

It is assumed that the estimation results are representative for the entire population in the country or area that is investigated. This assumption requires that all parts of the population is represented in the model and that the relative size of the different respondent groups reflect the population in the area. There are several possible sources of errors in the estimation results:

- The value of time used in the different steps are uncertain. Some values are implicit values given by the model while others are explicit values collected from valuation studies. Furthermore, trips are aggregated to different travel purpose groups in the different steps and this can cause some errors in what travel purposes that are assigned to the different groups.
- If the selection of respondents to valuation and travel studies for the area does not reflect the entire population, this can cause some population groups to be over or underestimated in the model. Consequently, this can cause the estimation results to be incorrect for the given project.

8.6 Bibliography

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9 Attachment #5 – Sensitivity Analysis in RTM

9.1 Introduction

A sensitivity analysis of the RTM calculations has been performed. The goal of this work is first to analyze where in the regional transport model values of time are used and thereafter investigate where the model is the most sensitive to changes in these parameters. The method used for this sensitivity analysis is described in detail in this document.

This attachment is structures as follows:

- Section 1: Description of changes done to the model in the sensitivity analysis.
- Section 2: Presentation of results from Ytre Ring.
- Section 3: Presentation of results from Feda-Ålgård.
- Section 4: Analysis and comparison of results.
- Section 5: Present general traffic distribution data and modal split for the networks.

9.2 Section 1 – Sensitivity analysis structure

The Regional Transport Model is divided into four steps where different calculations are performed in the different steps. As described in attachment 4, the four steps are:

1. Network program generates LoS-data from input data provided to the program.
2. Demand model (TraMod_by) runs and calculates origin-destination matrices based on the LoS-data from step 1.
3. Network program assigns the trips based on the origin-destination matrices from step 2. This gives traffic flows on the different links and routes.
4. The traveler benefit module calculates the change in consumer surplus by comparing the cost components (time, distance and direct costs) for the reference and project scenario for all zone relations in the network.

The different steps have values of time that are calculated based on different assumptions and with different methods. This makes it challenging to compare the different values and identify how they affect the results.

To identify what steps in the calculations that affect the estimation results the most, a sensitivity analysis of the RTM calculations has been performed. These analyses use the calculated benefit for the project as the main measuring parameter to investigate the effects of changed input VoT. In addition to this, total transport work, number of car trips and average trip length are used to identify the effects.

Consumer surplus is calculated by comparing the current scenario with a basis/reference scenario and calculate the change in travel costs for all zone relations. Total consumer surplus gives the total change in cost components for all travelers in the network. As described in attachment 1, maximizing benefit in the transport system is about minimizing the cost of travel, hence minimizing the different cost components. If the change in consumer surplus is positive, meaning travel costs are reduced between two zones in the network, the travelers between these zones are better off and the result is increased benefit. If the opposite is the case, meaning travel costs are increased, travelers are worse off and total benefit reduced.

Here, the four different steps are analyzed in separate operations and the results summarized in graphs and tables. The procedure for varying the value of time parameter in the different calculation steps is described in the following.

When performing the analyses, a project scenario is compared to a reference scenario and the change in benefit is due to the implementation of the proposed project. When changing the parameter for value of time it is necessary to compare the project scenario with adjusted VoT-parameter to a basis with the same adjustments in the VoT-parameter. The goal is to measure the effects of the proposed project with different value of time. Since all trips in the network will be affected by the change in VoT, an exclusive basis for each scenario is necessary. This will be the case for all steps that cause changes in transport demand or network assignment, meaning step 1, 2 and 3. Since step 4 only considers changes in the valuation of time savings, the same basis can be used for all these scenarios.

Step 1: LoS-calculations
Step 1 in the Regional Transport Model calculates LoS-data from the provided input-information. All zone-relations are skimmed along the route with the lowest generalized costs for the different modes.

Generalized costs are calculated as the total cost of travel. One general formulation of generalized cost is:

$$GC = \sum_i p_i \times V_i$$

Where the components are described in Table 9-1:

Table 9-1: Generalized cost calculations

Parameter	Description
GC	Generalized costs
P	Weight of parameter, such as weighting of travel time (minutes), distance (kilometer) or direct costs (NOK).
V	Size of variable p, e.g. number of minutes, kilometers or NOK.
i	Generalized Cost component, such as travel time, direct costs or travel distance

For all zone-relations, generalized costs are calculated for all possible route choices. The route with the lowest GC is thereafter skimmed and the results used as input to the demand model in step 2.

For car trips, the GC function consists of travel time, distance and direct costs and is calculated as follows:

$$GC = P_{time} * time + P_{dist} * distance + P_{cost} * cost$$

With components as described in Table 9-2.

Table 9-2: Generalized costs calculations components

Parameter	Description	Size of component
U	Utility	
P_time	Weight of time component	81 NOK/hour = 1,35 NOK/minute
Time	Time use for given route	
P_dist	Weight of distance component	1.61 NOK/kilometer
distance	Distance of given route	
P_cost	Weight of cost component	0,8 NOK/NOK
Cost	Direct costs for given route, such as toll etc.	

Value of time is here defined as the relationship between the time parameter and the cost parameter. These factors are given in Table 9-2 as P_time and P_cost. The following formula represents the value of time, with the unit of NOK per minute. This value is hence an implicit value of time since the value is not given directly from the model, but rather calculated from the parameters.

$$VoT = \frac{P\_time}{P\_cost} = \frac{\frac{U}{min}}{\frac{U}{NOK}} = \frac{NOK}{min}$$

With the values given in Table 9-2, the value of travel time savings for step 1 can be calculated as:

$$VoT = \frac{81\frac{NOK}{hour}}{0{,}8\frac{NOK}{NOK}} = 101{,}25\ NOK/hour$$

To check the sensitivity for changes in step 1, the implicit value of time can be changed by changing one of the parameters, either P_time or P_cost. For simplicity, the variable P_dist is neglected. An increase or decrease in the P_time or P_cost parameter will cause the size of GC from the different alternatives to change and can hence possibly change what route that is skimmed. This can thereafter result in changes in the LoS-matrices which is the input to the demand model. Finally, the estimation results can be changed due to the difference in input values to the demand model.

For step 1, changes are done to the "LOS_TID" parameter. This parameter is stored in "Applikasjoner -> Parametre -> Genkost" directory in the RTM framework. "Genkost" is a dbf-file that includes information about LOS_TID, LOS_DIST and LOS_KOST. All these variables are used in the previous described GC formula.

In step 1, LOS_TID is changed according tom Table 9-3. The basis scenario is the 0-alternative where the value for LoS_TID is 1.35. m10-m50 and p10-p50 indicates a decrease and increase in the value, respectively.

Table 9-3: Sensitivity analysis, step1, parameters

LOS_TID	m50	m40	m30	m20	m10	0	p10	p20	p30	p40	p50
	0.68	0.81	0.95	1.08	1.22	1.35	1.49	1.62	1.76	1.89	2.03

In step 1, there is no differentiation on travel purpose. This is because step 1 only considers skimming the route with the lowest generalized costs independently of travel purpose or mode.

Table 9-3 shows that the parameter representing value of time is varied in both directions from the starting point. The simulation runs have been performed introducing new Genkost-files for each of the runs, with different values for the LOS_TID parameter. This is done by changing what dbf-file that is linked in the calculations by changing the code from "Parametre\Genkost.dbf" to "Parametre\Genkost_{Scenario_code}". By doing this, the current scenario will use the correct file related to the scenario through the "Genkost_{Scenario_code}-file name. It is also possible to change the value in the file manually for every scenario run, but this allows not to run more scenarios continuous without changing the value in between.

The following codes have been changed in order to use the new "Genkost"-file:

- Inndata -> «Skriver faktorfil for kollektivsystem»
- LOS-data -> «LOS-data bil kap.uavhengig»
- LOS-data -> «LOS-data gang og sykkel»
- Nettfordeling -> Nettfordeling bil -> Nettfordeling bil døgn -> «Nettfordeling»
- Nettfordeling -> Nettfordeling bil -> Nettfordeling bil døgn -> «Beregner rutevalgsfiler for selected link osv.»
- Nettfordeling -> Nettfordeling bil -> Nettfordeling bil time -> «Nettfordeling»
- Nettfordeling -> Nettfordeling bil -> Nettfordeling bil -> «Kostnader til trafikantnyttemodul»

Step 2: Demand model
The demand model estimates travel demand between all zones in the network, for all modes. LoS-matrices from step 1, in addition to other zonal information is used to estimate the total travel demand. In this estimation process for private trips, the demand model uses specific models for the different travel purposes.

Trips for five different travel purposes are estimated in the demand model. These are (Norwegian in brackets):

- Private trips (private reiser)
- Leisure trips (fritidsreiser)
- Deliver/pick-up (hente/levere reiser)
- Work trips (til/fra arbeid, arbeidsreiser)
- Service trips (tjenestereiser)

Different models within the demand model is used to estimate the travel demand for the different purposes. However, all models are built up by utility functions representing the utility of all alternatives. To include all relevant costs, the models include several different variables and parameters, such as direct cost parameters, travel time, and several dummy variables depending on the traveler. All these variables together with their weights are used to estimate the cost of all alternatives and hence the attractiveness of the different alternatives in the choice set. This is used to estimate the total travel demand between all zones.

For these analyses, focus will be on private trips and how the value of the travel time parameters affects the results from the model. Therefore, the travel time component is changed in the different models.

The following models are used to estimate travel demand between the zones for the different modes. The different models have different variables to represent the travel time component. These variables are stored in separate parameter files, located in "Regmod_v3.12.1 -> Catalogname -> Parameterfiler". Here, there is one file for all the five different travel purposes giving information about the travel cost parameters. The model used for the different travel purposes as well as the parameter representing travel time is given in Table 9-4.

Table 9-4: Sensitivity analysis, step 2, models

(*model for business trips not re-estimated in the last version of TraMod_by)

Travel purpose	Model	VoT parameter
Private trips (Par_Privat)	PRI7006md	GC_TM
Leisure trips (Par_Fritid)	FRI7009md	GC_TM
Deliver/Pick-up (Par_HenteLev)	H&L7011md	GA_TM
Work trips (Par_Arbeid)	W11 - Basismodell	CDF_TM & CDM_TM
Business trips (Par_Tjeneste)	*	CD_TM

As for step 1, the variables representing value of time are adjusted in 10 percent intervals, up to 50% increased values and down to 50% decreased values.

Separate parameter files have been made for the different scenarios with corresponding parameter codes. This makes it possible to run multiple scenarios continuously without having the need to change the parameters manually during the simulations.

Table 9-5 and Table 9-6 shows the variables changed and the values used for the different scenarios. The 0-colums gives the values used in the model today. Also, work trips do have two parameters representing value of time, one for women and one for men, respectively.

Table 9-5: Sensitivity analysis, step2 parameters, part1

Purpose	Parameter	s2m50	s2m40	s2m30	S2m20	s2m10	0
par_fritid	GC_TM	-0.01695	-0.02034	-0.02373	-0.02712	-0.03051	-0.0339
par_privat	GC_TM	-0.0314	-0.03768	-0.04396	-0.05024	-0.05652	-0.0628
par_hentelev	GA_TM	-0.03335	-0.04002	-0.04669	-0.05336	-0.06003	-0.0667
par_arb	CDM_TM	-0.0154	-0.01848	-0.02156	-0.02464	-0.02772	-0.0308
par_arb	CDF_TM	-0.02025	-0.0243	-0.02835	-0.0324	-0.03645	-0.0405
par_tjeneste	CD_TM	-0.01525	-0.0183	-0.02135	-0.0244	-0.02745	-0.0305

Table 9-6: Sensitivity analysis, step2 parameters, part2

Purpose	Parameter	0	S2p10	s2p20	s2p30	s2p40	s2p50
par_fritid	GC_TM	-0.0339	-0.03729	-0.04068	-0.04407	-0.04746	-0.05085
par_privat	GC_TM	-0.0628	-0.06908	-0.07536	-0.08164	-0.08792	-0.0942
par_hentelev	GA_TM	-0.0667	-0.07337	-0.08004	-0.08671	-0.09338	-0.10005
par_arb	CDM_TM	-0.0308	-0.03388	-0.03696	-0.04004	-0.04312	-0.0462
par_arb	CDF_TM	-0.0405	-0.04455	-0.0486	-0.05265	-0.0567	-0.06075
par_tjeneste	CD_TM	-0.0305	-0.03355	-0.0366	-0.03965	-0.0427	-0.04575

Step 3: Network assignment

The third step uses the results from the demand model and assigns the trips to the network. From the previous step it is clear how many trips going to and from all the different zones in the network and what mode they use. However, the demand model does not consider the route choice between the different zones. This is done in the network assignment step.

The network assignment is performed as to minimize the cost for the travelers. This means that the route with the lowest cost is chosen. This can either be done independent or dependent of capacity, meaning whether the traffic volumes on the link will affect travel time on that specific link or not.

Generalized costs are calculated on the same basis as explained for step 1. However, there are some important differences when it comes to the components included in the calculations. Frist, in this step, the different cost components are differentiated depending on travel purpose. This means that trips can have different components for time, distance and direct costs depending on their purpose.

Furthermore, this means that trips between the same zones may choose different routes because they value the different cost components differently, e.g. if there is a toll on one or more of the links. By doing this, two trips with the same origin and destination can have a different route choice depending on how they value the different cost components.

To test the sensitivity for changes in the third step, the parameters used to calculate generalized costs can be changed. This will affect the GC-calculations directly and can affect route choices in the network assignment. This can also cause the total benefit from the scenarios to change.

For simplicity, network assignment is performed independent of capacity. As described in attachment 4, this means that all traffic between two zones are assigned to the same route, the route with the lowest generalized costs. However, if this results in high traffic volumes on a given link this might affect the speed and consequently travel time and costs of the link. This can be accounted for by doing more iterations where portions of the total traffic volume are assigned in intervals and the new speed on the link used in further calculations. However, for the two cases in this work, it is assumed that capacity is not a problem and hence calculations performed independent of capacity.

For step 3, changes are done to the "NF_TID" parameter. This parameter is stored in "Applikasjoner -> Parametre -> Genkost" directory in the RTM framework. "Genkost" is a dbf-file that includes information about NF_TID, NF_DIST and NF_KOST. This is the same file as used in step 1, but the NF parameters are used instead of the LOS-parameters.

As for step 1, the parameter changed in this step is the one concerning time, NF_TID. The two other variables, NF_DIST and NF_KOST are neglected and assigned the same value in all scenarios.

Table 9-7 shows the variables changed for the different scenarios and the values used.

Table 9-7: Sensitivity analysis, part3, parameters

NF_TID	m50	m40	m30	m20	m10	0	p10	p20	p30	p40	p50
Arbeid	0.6	0.72	0.84	0.96	1.08	1.2	1.32	1.44	1.56	1.68	1.8
Tjeneste	2	2.4	2.8	3.2	3.6	4	4.4	4.8	5.2	5.6	6
Fritid	0.8	0.96	1.12	1.28	1.44	1.6	1.76	1.92	2.08	2.24	2.4
NTM5	2.5	3	3.5	4	4.5	5	5.5	6	6.5	7	7.5
Gods	4.5	5.4	6.3	7.2	8.1	9	9.9	10.8	11.7	12.6	13.5

Changing these parameters affects the cost of the different routes and can possibly affect what routes that are being used by the travelers. If the change in input values cause new routes to be chosen compared to the basis scenario, the calculated benefit for the scenario can be affected.

As for the previous steps, separate “Genkost”-files have been created for the different scenarios. Again, this is done to make it possible to run multiple runs continuously without having the need of changing the parameters in between.

Since the “Genkost”-file is the same as used in step 1, the following codes have been changed in order to use the new “Genkost”-file:

- Inndata -> «Skriver faktorfil for kollektivsystem»
- LOS-data -> «LOS-data bil kap.uavhengig»
- LOS-data -> «LOS-data gang og sykkel»
- Nettfordeling -> Nettfordeling bil -> Nettfordeling bil døgn -> «Nettfordeling»
- Nettfordeling -> Nettfordeling bil -> Nettfordeling bil døgn -> «Beregner rutevalgsfiler for selected link osv.»
- Nettfordeling -> Nettfordeling bil -> Nettfordeling bil time -> «Nettfordeling»
- Nettfordeling -> Nettfordeling bil -> Nettfordeling bil -> «Kostnader til trafikantnyttemodul»

Step 4: Traveler Benefit module
The last step in RTM is the traveler benefit module. Simplified, this step takes the difference in travel costs before and after an implemented scenario and multiplies the change in costs by the value of these savings. By doing this for all zone-relations and travelers in the network, the total change in benefit can be found.

To check the sensitivity for changes in these values of travel time savings the values can be changed directly in the traveler benefit module in the software. This module is a separate module, independent of the three previous steps, but uses the results from step 3 as input.

The module consists of two sub-sections, user benefit module and public transport benefit module. This paper focus on the private user benefit module only and changes are consequently implemented in this module.

The file “Parametre_TNM” provides information about values of time for the different trip purposes and travel modes. This dbf-table is the input for valuation of the different trips in the benefit module and therefore changed for the different scenarios. The three columns “Arbeid” (Work), “Tjeneste” (Service) and “Fritid” (Leisure) are multiplied by a factor to adjust the value of time for the trip purposes “Bilfører” (CD), “M-lange bilfører” (CD, M-Long) and “Lange bilfører” (CD, Long).

Separate Parameter-files have been created for the different scenarios and used in the traveler benefit calculations by changing the following codes from “Parameterfiler\Parametre_TNM” to “Parameterfiler\Parametre_{Scenario_code}. By doing this, the traveler benefit module uses scenario specific files and hence allows for different VoT in the scenarios.

- Trafikantnyttemodul -> Beregning -> «Skriver header på printfil»
- Trafikantnyttemodul -> Beregning -> «Skriver reisemiddelinfo til printfil»
- Trafikantnyttemodul -> Beregning -> «Printfil med begrenset beregning»
- Trafikantnyttemodul -> Beregning -> «Beregning av trafikantnytte»
- Trafikantnyttemodul -> Beregning -> «Setter tur-og LoS-matriser»
- Trafikantnyttemodul -> Resultatuttak -> «Skriver datafil og sluttfører printfil»
- Trafikantnyttemodul -> Resultatuttak -> «Skriver datafil og sluttfører printfil, begrenset beregning»

In the traveler benefit module, the values of time are given directly to the model and multiplied by the size of time savings. Since value of time for private car users occur in three different variables in the fourth step (“CD”, “CD, M-Long” and “CD, Long”) Table 9-8 and Table 9-9 show the values used in all of these three steps in the different scenarios.

Table 9-8: Sensitivity analysis, step4 parameters, part1

	step2m50	**step2m40**	**step2m30**	**step2m20**	**step2m10**	**0**
Car driver						
Work	49.5	59.4	69.3	79.2	89.1	99.0
Service	222.0	266.4	310.8	355.2	399.6	444.0
Leisure	42.0	50.4	58.8	67.2	75.6	84.0
Car driver, M-Long						
Work	107.5	129.0	150.5	172.0	193.5	215.0
Service	222.0	266.4	310.8	355.2	399.6	444.0
Leisure	83.5	100.2	116.9	133.6	150.3	167.0
Car driver, Long						
Work	107.5	129.0	150.5	172.0	193.5	215.0
Service	222.0	266.4	310.8	355.2	399.6	444.0
Leisure	83.5	100.2	116.9	133.6	150.3	167.0

The method described in section 1 is used for both the two cases, E18/E39 Ytre Ring and E39 Feda-Ålgård. The results will be analyzed in the following.

As described, the measuring parameters are defined as follows:

- Total calculated consumer surplus for the two projects, and how this varies with changes to the input parameter for value of time.
- Total transport work for the area.
- Total number of car trips in the model.
- Average travel length for car trips in the area.

Table 9-9: Sensitivity analysis, step4 parameters, part2

	0	Step2p10	step2p20	step2p30	step2p40	step2p50
Car driver						
Work	99.0	108.9	118.8	128.7	138.6	148.5
Service	444.0	488.4	532.8	577.2	621.6	666.0
Leisure	84.0	92.4	100.8	109.2	117.6	126.0
Car driver, M-Long						
Work	215.0	236.5	258.0	279.5	301.0	322.5
Service	444.0	488.4	532.8	577.2	621.6	666.0
Leisure	167.0	183.7	200.4	217.1	233.8	250.5
Car driver, Long						
Work	215.0	236.5	258.0	279.5	301.0	322.5
Service	444.0	488.4	532.8	577.2	621.6	666.0
Leisure	167.0	183.7	200.4	217.1	233.8	250.5

9.3 Section 2 – Ytre Ring, sensitivity analysis results

The three measuring parameters are here described and analyzed for the case of Ytre Ring. First, total change in consumer surplus is given in Table 9-10. This table gives a detailed description of total change in consumer surplus when input for value of time is changed.

Moreover, Figure 9-1 illustrates the results graphically. The x-axis shows percentage change in the parameters representing value of time, as described previously, while the Y-axis shows the related percentage change in consumer surplus.

From Table 9-10 and Figure 9-1, the second calculation step, the demand model, and step 4, the traveler benefit module, are the two most affected steps. The two other steps, LoS-calculations and network assignment experience small changes in consumer surplus.

Table 9-10: Ytre Ring, change in consumer surplus

Change in VoT (%)	Step1	Step2	Step3	Step4
-50	99.67 %	121.49 %	98.38 %	85.13 %
-40	99.98 %	116.13 %	98.72 %	88.10 %
-30	99.99 %	111.38 %	98.82 %	91.08 %
-20	99.99 %	107.16 %	98.77 %	94.05 %
-10	100.00 %	103.38 %	99.68 %	97.03 %
0	100.00 %	100.00 %	100.00 %	100.00 %
10	100.00 %	96.96 %	99.86 %	102.97 %
20	99.97 %	94.21 %	100.62 %	105.95 %
30	99.96 %	91.72 %	101.04 %	108.92 %
40	99.94 %	89.46 %	101.00 %	111.90 %
50	99.94 %	87.40 %	101.09 %	114.87 %

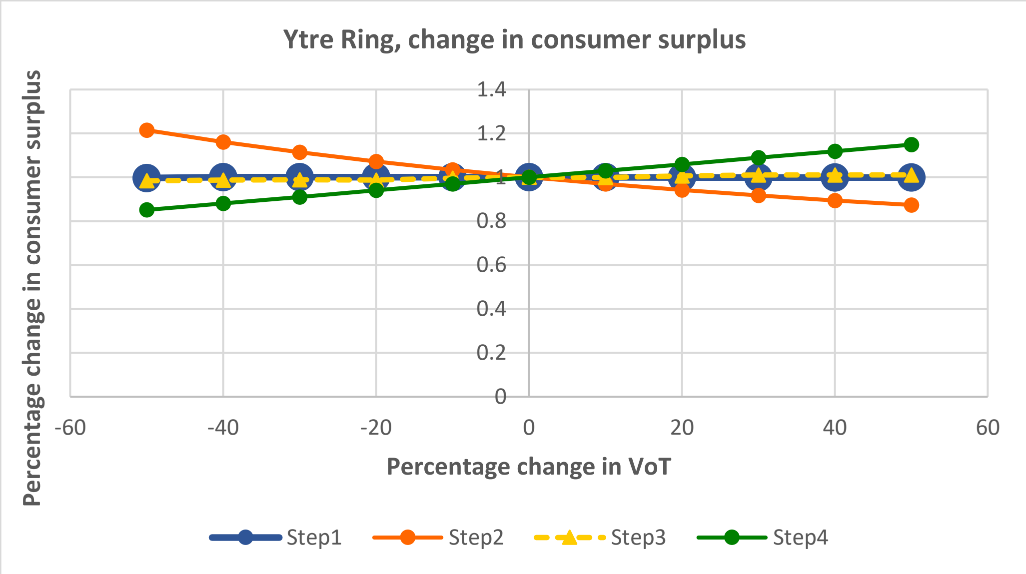

Figure 9-1: Ytre Ring, Change in consumer surplus

When it comes to changes in total number of trips, average travel length and modal distribution, the picture is similar. For these three, there will only be differences in the first three steps. Since the fourth step only considers changes in the valuation of time savings and hence only deals with the traveler benefit module, all of the parameters described here will remain the same for the fourth step.

For Figure 9-2, Figure 9-3 and Figure 9-4 the demand model cause changes in the parameters. This module estimates the origin and destinations of trips, meaning where trips go to and from. When the input parameters for these calculations are changed, this can cause changes in the matrices describing where trips go, the origin and destinations of trips.

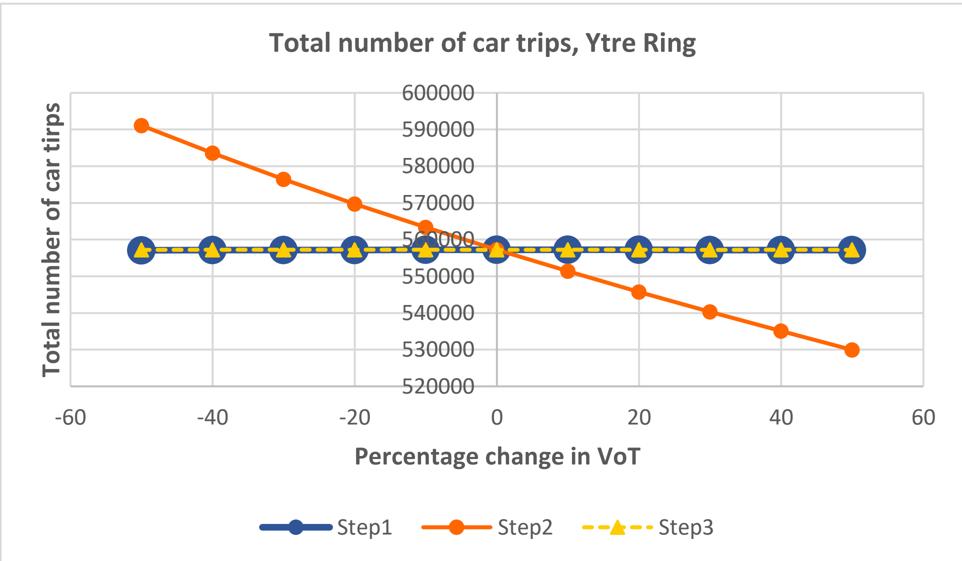

Figure 9-2: Ytre Ring, total number of trips

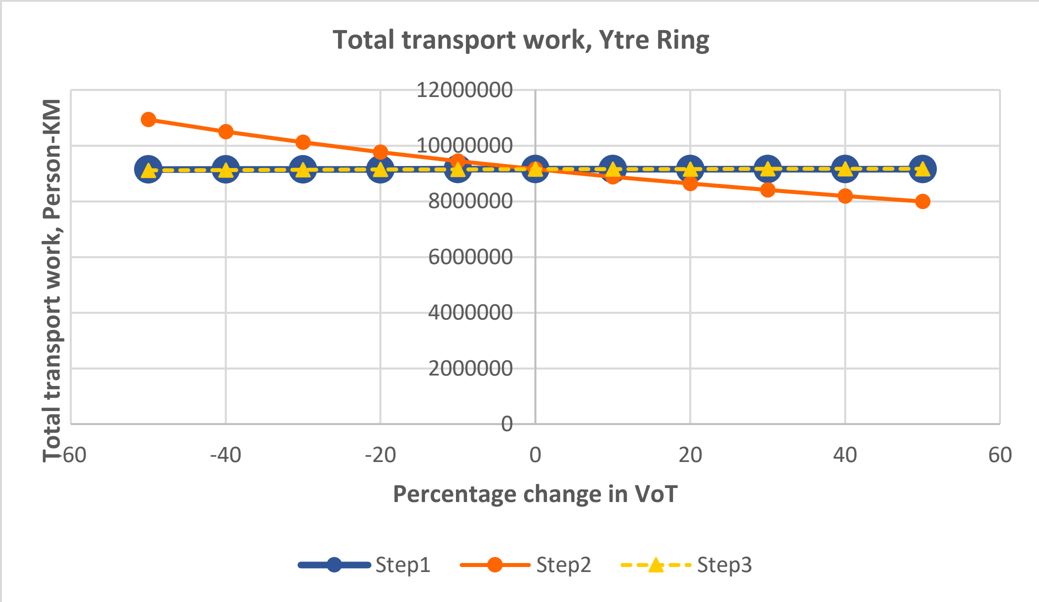

Figure 9-3: Ytre Ring, total transport work

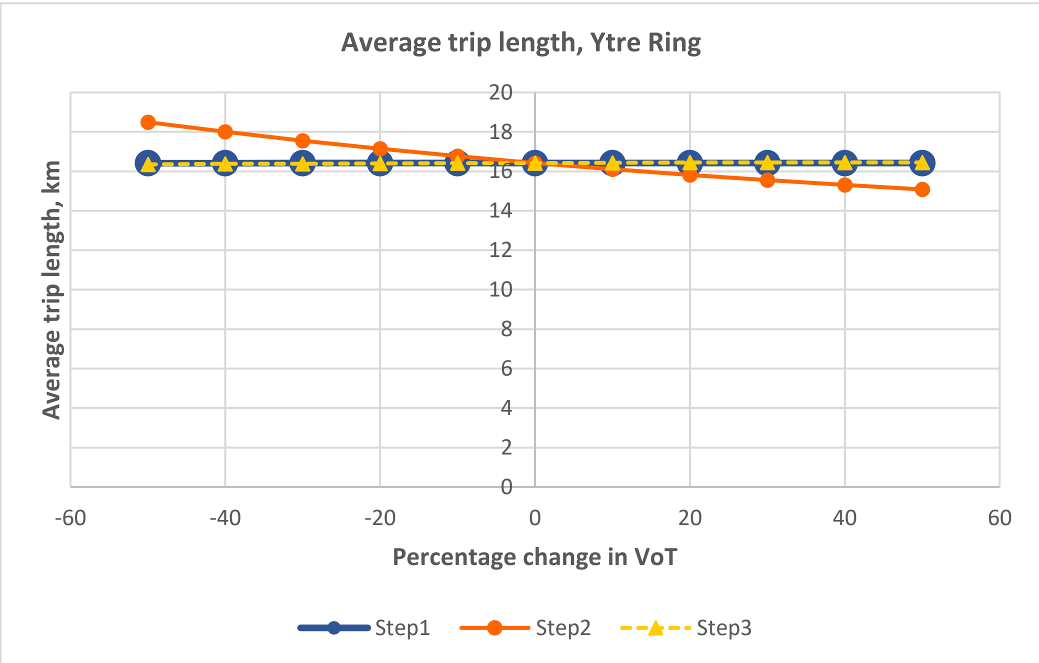

Figure 9-4: Ytre Ring, average trip length

From the figures above, the measuring parameters number of car trips, average travel length and transport work follow the same pattern as consumer surplus. This is as expected since consumer surplus is highly dependent on number of trips and the length of these trips. This will be more discussed in section 4.

Section 3 – Feda-Ålgård, sensitivity analysis results
The same analysis is performed for the second case, Feda-Ålgård. Table 9-11 gives the detailed description of how consumer surplus depends on the value of time used in the different steps in the calculations. Figure 9-5 illustrates the relationships graphically.

As for Ytre Ring, the sensitivity of the results varies with the steps. LoS-calculations in step 1 and network assignment in step 3 is relatively unchanged with the different input values for value of time. Step2, the demand model, is a lot less sensitive to changes in the input values in this case compared to Ytre Ring. For the traveler benefit calculations in step 4, the effects are similar to the ones described for Ytre Ring. Since these changes consider the direct valuation of time savings, the consumer surplus will increase linearly with increased value of time, as given in Figure 9-5.

Table 9-11: Feda-Ålgård, change in consumer surplus

Change in VoT (%)	Step1	Step2	Step3	Step4
-50	100.06 %	103.47 %	100.12 %	80.15 %
-40	100.04 %	102.62 %	100.12 %	84.12 %
-30	100.02 %	101.86 %	100.07 %	88.08 %
-20	100.01 %	101.17 %	100.03 %	92.05 %
-10	100.02 %	100.55 %	100.02 %	96.02 %
0	100.00 %	100.00 %	100.00 %	100.00 %
10	100.00 %	99.50 %	99.97 %	103.95 %
20	100.00 %	98.39 %	99.97 %	107.92 %
30	99.99 %	98.66 %	99.96 %	111.88 %
40	99.98 %	98.31 %	99.92 %	115.85 %
50	99.97 %	98.00 %	99.90 %	119.81 %

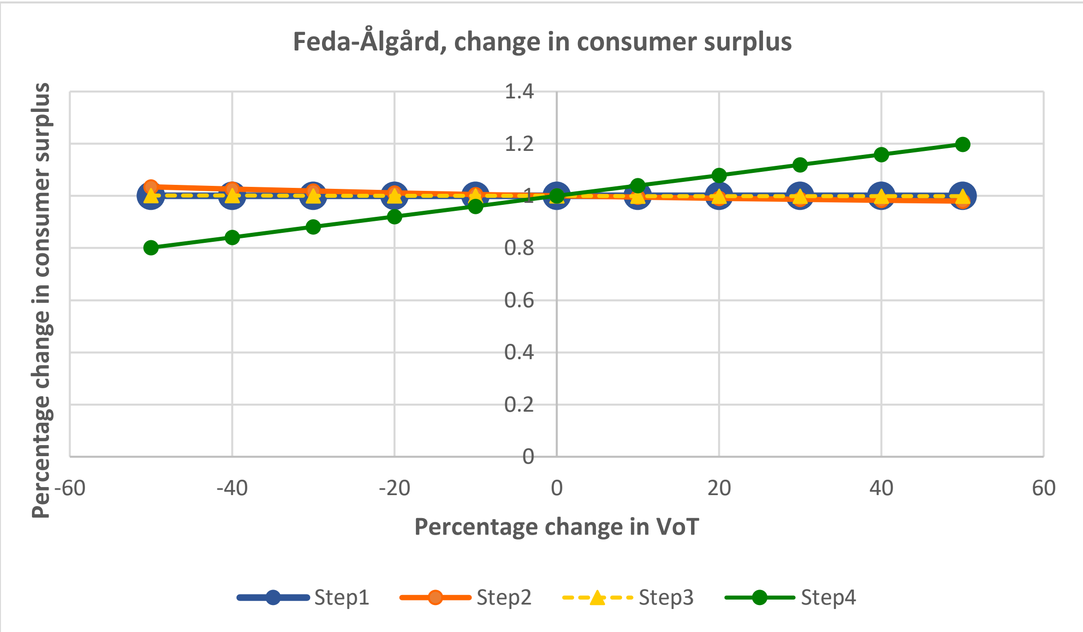

Figure 9-5: Feda-Ålgård, change in consumer surplus

Changes in total number of trips, total transport work and average trip length is analyzed in the following and given in figure Figure 9-6, Figure 9-7 and Figure 9-8.

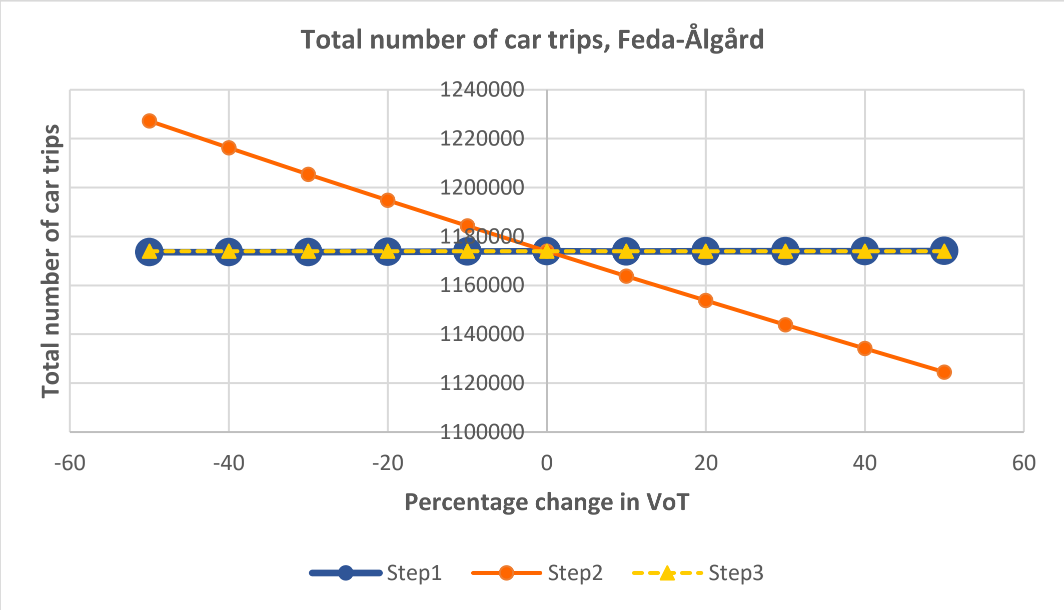

Figure 9-6: Total number of trips, Feda-Ålgård

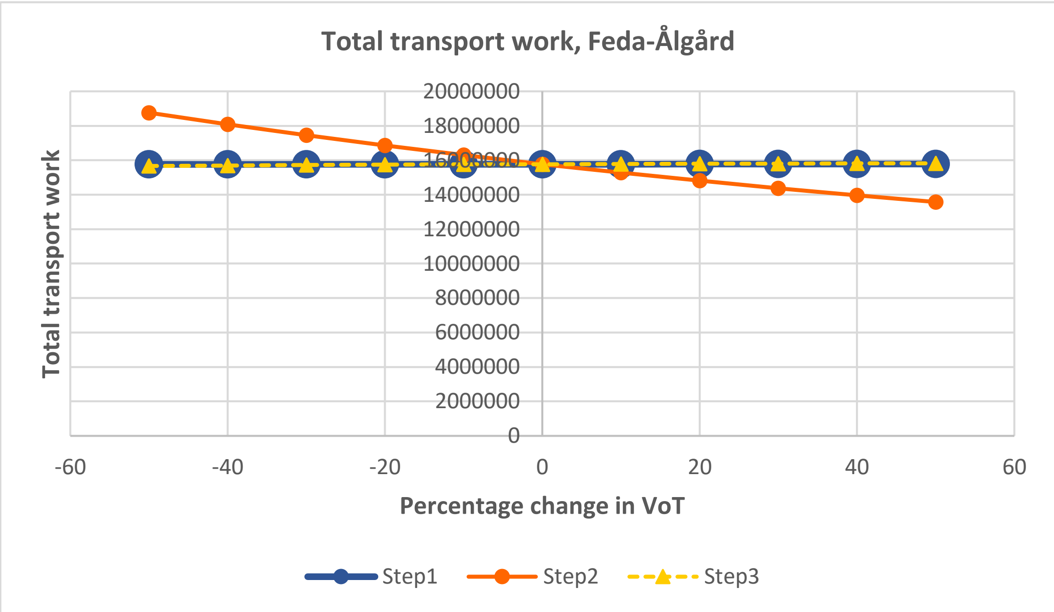

Figure 9-7: Total transport work, Feda-Ålgård

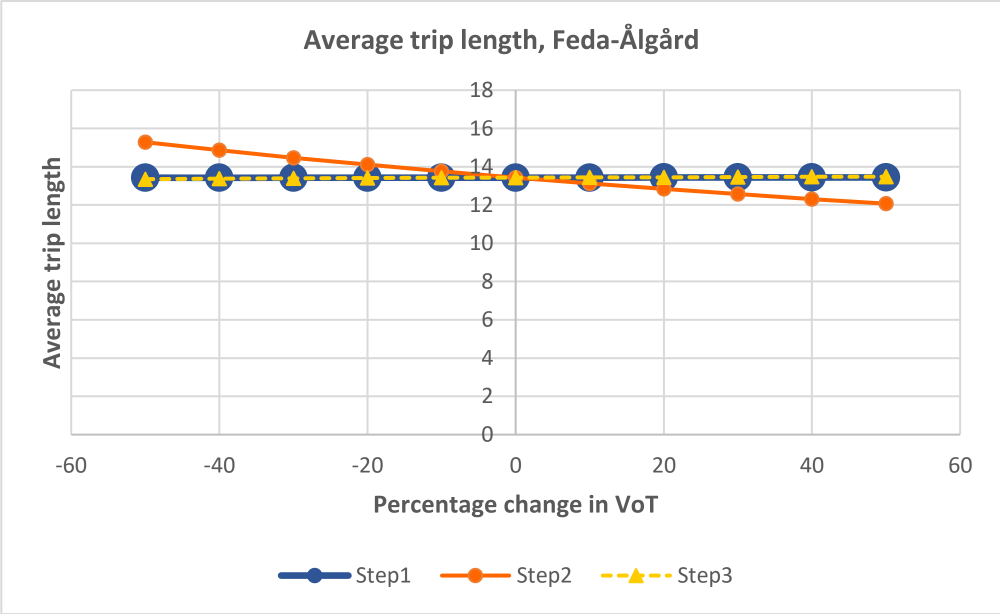

Figure 9-8: Average trip length, Feda-Ålgård

As presented for Ytre Ring above, the results giving total number of trips, total transport work and average travel length highly correlate with the total consumer surplus. These observations will be discussed in the following.

9.5 Section 4 - Analysis and comparison of results

Based on the data from section 2 and 3, several aspects regarding how consumer surplus vary with the valuation of time can be discussed.

As step 2 and 4 are the ones with the largest variations regarding calculated benefit, these two steps will have the main focus in this discussion.

Step1 - Comparison

Step1 considers the calculation of LoS-matrices for all zone-relations in the network. As previous explained, this includes skimming the network along the route with lowest generalized costs for all zone-relations. Furthermore, this means that if there are few alternatives to the chosen route in the scenario, the changes in LoS-matrices calculated from step 1 will be small. This will again cause the input to the demand model to have small changes for the different scenarios in step 1. Consequently, the estimation results from the model will be relatively similar for all scenarios.

Table 9-12 shows how consumer surplus vary for the two cases when the input parameters for value of time in step 1 is changed. The variations are small for both cases and indicates that changes in value of time in this step cause few changes to the input matrices to the demand model.

Table 9-12: Step1 – Consumer surplus variation

%-change in VoT	Ytre Ring	Feda Ålgård
-50	99.67 %	100.06 %
-40	99.98 %	100.04 %
-30	99.99 %	100.02 %
-20	99.99 %	100.01 %
-10	100.00 %	100.02 %
0	100.00 %	100.00 %
10	100.00 %	100.00 %
20	99.97 %	100.00 %
30	99.96 %	99.99 %
40	99.94 %	99.98 %
50	99.94 %	99.97 %

The changes in consumer surplus are less than 0.5% for both cases. This indicates that the changes are not related to any big changes in the transport situation but rather small changes in route choice. These small changes occur as zone-relations may have a different route that is now perceived with the lowest GC and followingly skimmed in step 1. As the changes are relatively small, the changes in the skimming procedure are probably taking place at locations with several route choices in close proximity to one another, meaning small changes in the input parameters cause small changes in the skimming procedure.

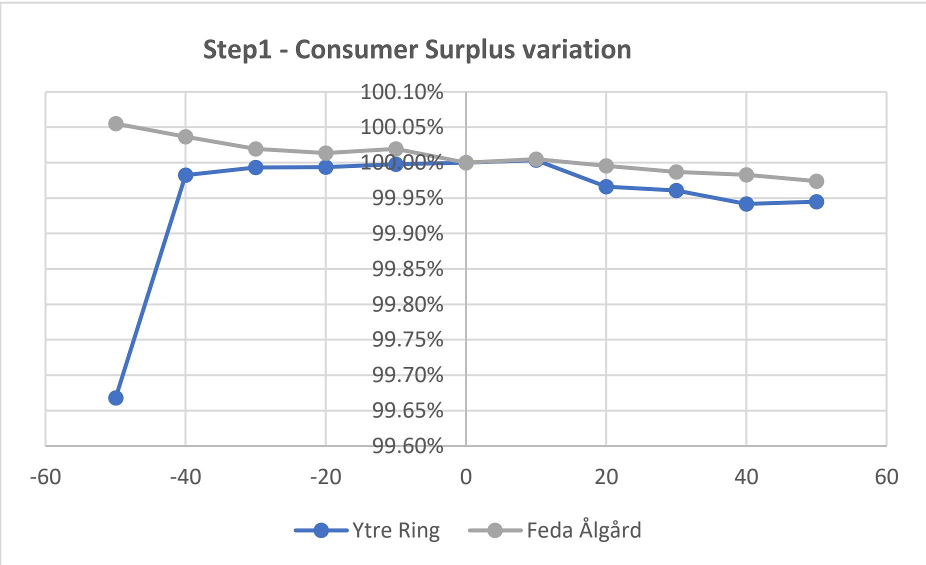

Figure 9-9: Step1 – Consumer surplus variation

The values given in Table 9-12 are the basis for Figure 9-9. As the consumer surplus for Feda-Ålgård decrease in a stable manner when VoT increase, this can be seen as the grey line. For Ytre Ring, the more unstable behavior is given with the blue line. The sudden drop in benefit for the m50-scenario is most likely caused by some kind of errors in the estimation procedure. However, the percentage change is relatively small.

To sum up for the first step, changes in consumer surplus caused by changes in the input parameters for value of time are small. When compared to the other steps in **Figure 9-1** and **Figure 9-5**, where the effects of changed input parameters are clearer, the results from step 1 is not observable.

Step2 - Comparison
Unlike step 1, the results from step 2 shows that there are more significant changes in this step due to the changes in input VoT.

Table 9-13 shows that calculated consumer surplus decrease when the value of time parameter increases as described in Table 9-5 and Table 9-6. Consumer surplus for Ytre Ring is much more affected than the other project, Feda-Ålgård.

Table 9-13: Step2 – Consumer surplus variation

%-change in VoT	Ytre Ring	Feda Ålgård
-50	121.49 %	103.47 %
-40	116.13 %	102.62 %
-30	111.38 %	101.86 %
-20	107.16 %	101.17 %
-10	103.38 %	100.55 %
0	100.00 %	100.00 %
10	96.96 %	99.50 %
20	94.21 %	99.06 %
30	91.72 %	98.66 %
40	89.46 %	98.31 %
50	87.40 %	98.00 %

Figure 9-10 is based on the table above. The figure shows the decreasing value of the consumer surplus when the value of time parameter increases.

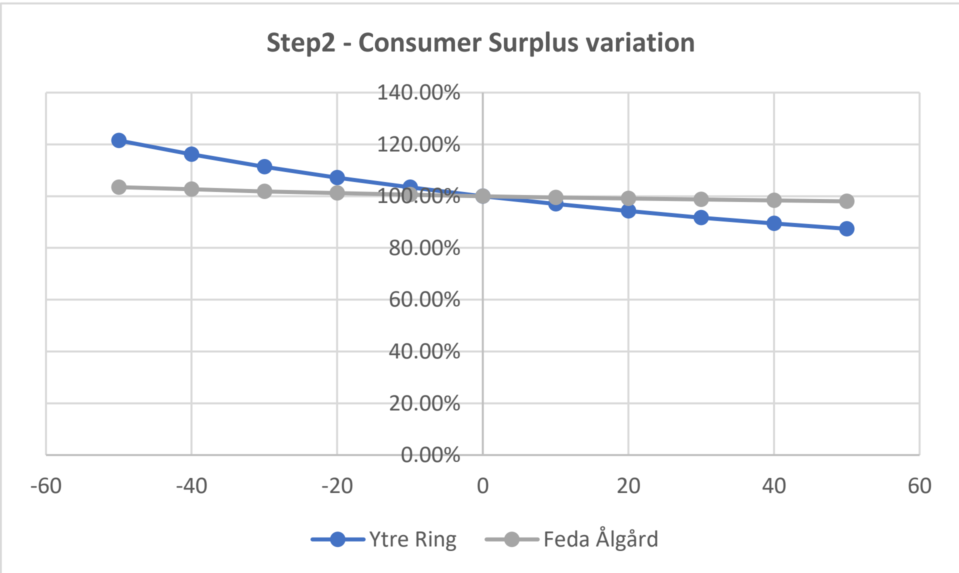

Figure 9-10: Step2 - Consumer surplus variation

The significant changes in consumer surplus for step 2 requires a detailed investigation of the situation to explain the reasons for the changes. This is given in the following.

Step 2 - Ytre Ring:
The project is illustrated in Figure 9-11. The existing road goes through the city center, while the new road passes north of the city. Table 9-14 provides information about the existing and proposed situation. Since the proposed road is a ring road, the traveled distance will increase, however, travel time will be reduced due to the increased speed limit. All information in Table 9-14 is collected from previous study (Cowi, 2018).

Table 9-14: Ytre Ring, project details

	Reference	**Ytre Ring**
Travel time (min)	8.9	6.2
Travel distance (km)	10.4	11.2
Average speed (km/h)	70	108
Change in travel time (min)	-2.7	
Change in distance (km)	0.8	

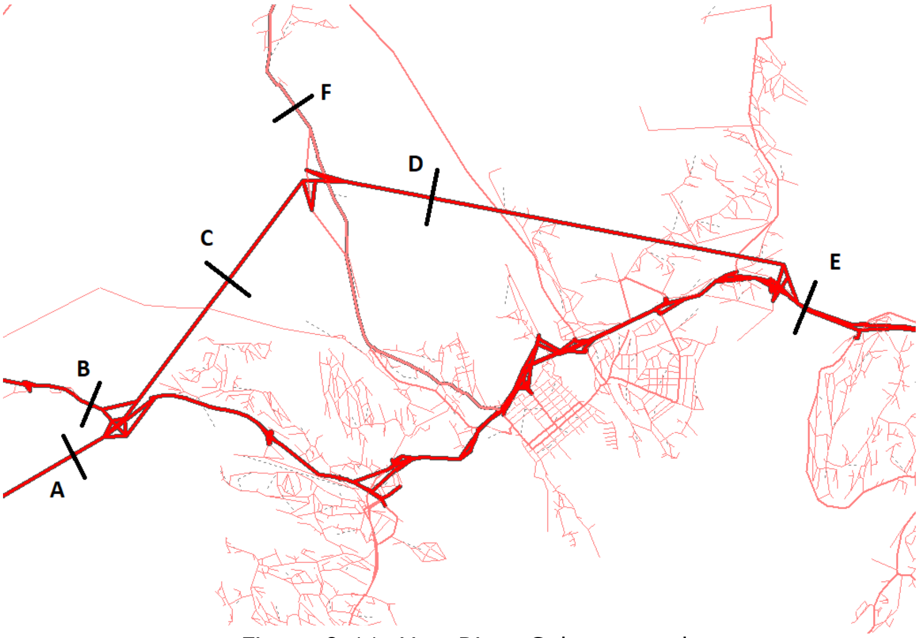

Figure 9-11: Ytre Ring, Cube network

Table 9-15 describes the traffic count locations given in Figure 9-11.

Table 9-15: Ytre Ring, traffic count locations

ID	**Location**
A	Kristiansand west, E39 new
B	Kristiansand west, E39, old
C	Ytre Ring west
D	Ytre Ring east
E	Kristiansand east, E18
F	Rv.9 north

To investigate the traffic situation when the value of time parameter varies in step 2, traffic counts have been collected for the different scenario runs. The results are described in Table 9-16.

Table 9-16: Ytre Ring, traffic counts results

	A	B	C	D	E	F
Reference step2m50	27497	9565	n/a	n/a	63569	7386
Reference step2_0	21936	7897	n/a	n/a	50659	5945
Reference step2p50	18260	6575	n/a	n/a	41710	4851
Project step2m50	31315	10692	21382	20004	66545	12997
Project_0	24807	8910	16995	16066	53202	10195
Project step2p50	20462	7472	14158	13538	43849	8206

To investigate the change in traffic from the basis scenario to the project scenario caused by the new road, the difference between traffic volumes in these two scenarios is given in Table 9-17. Here, the percentage shows the increase in traffic for the given scenario compared to its own basis.

Table 9-17: Ytre Ring, traffic count comparison

	A	B	C	F
Step2m50	3818	1127	2976	5611
	13.9 %	11.8 %	4.7 %	76.0 %
Step2_0	2871	1013	2543	4250
	13.1 %	12.8 %	5.0 %	71.5 %
Step2p50	2202	897	2139	3355
	12.1 %	13.6 %	5.1 %	69.2 %

Based on these traffic counts, traffic volumes in general decrease when the value of time parameter is increased. Moreover, the percentages show that the difference between traffic volumes in the basis scenario and the project scenario decreases when the value of time parameter is increased. These two findings are valid for all traffic count locations described above.

To explain these findings, a more detailed study of the travel behavior is described. Here, three zones are selected (Table 9-18) to explain the effects from the proposed road.

Table 9-18: Ytre Ring, zone descriptions

Zone	Location
489	North of intersection Rv.9 - Ytre Ring
506	East of intersection Ytre Ring - existing E18
684	West of intersection Ytre Ring - E39

Figure 9-12 and Figure 9-13 shows the route choice between zone 489 and 506, for the reference and project scenario respectively.

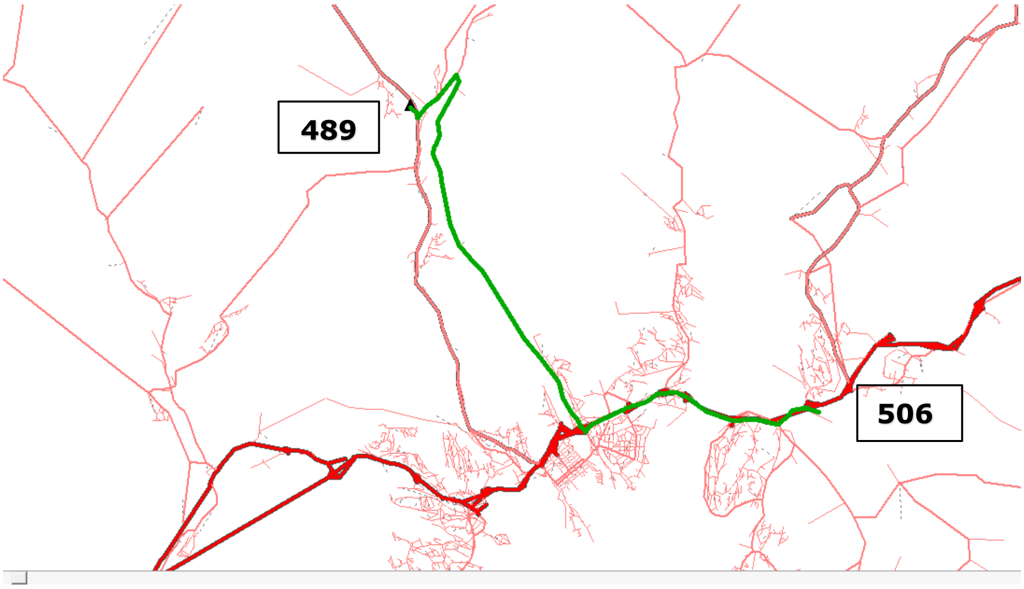

Figure 9-12: Ytre Ring, route choice zone 489-506, reference scenario

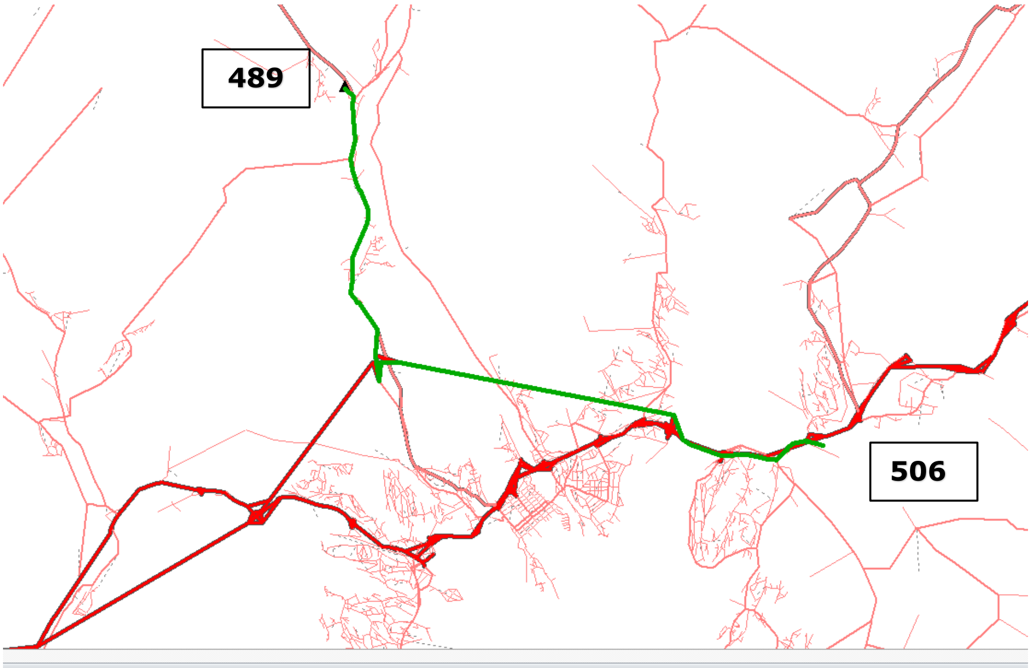

Figure 9-13: Ytre Ring, route choice zone 489-506, project scenario

Figure 9-14 and Figure 9-15 shows the route choice between zone 506 and 684, for the reference and project scenario respectively.

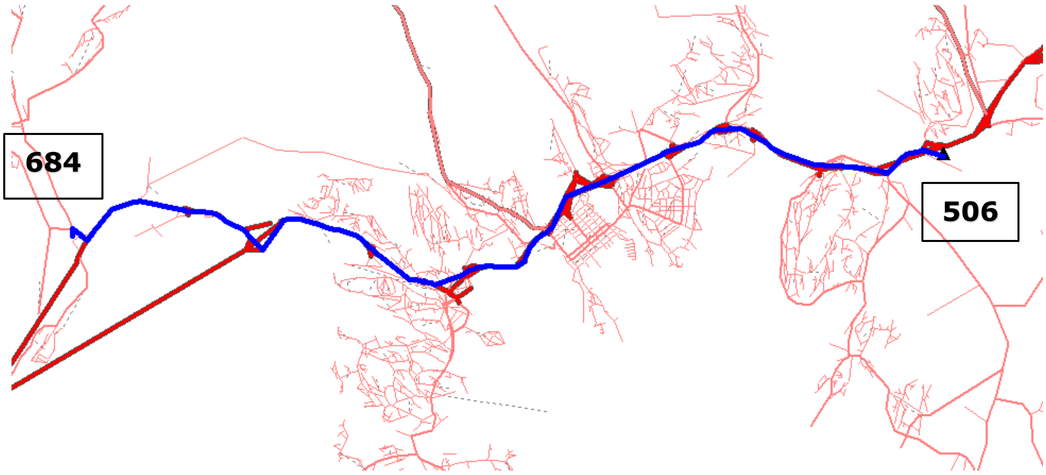

Figure 9-14: Ytre Ring, route choice zone 506-684, reference scenario

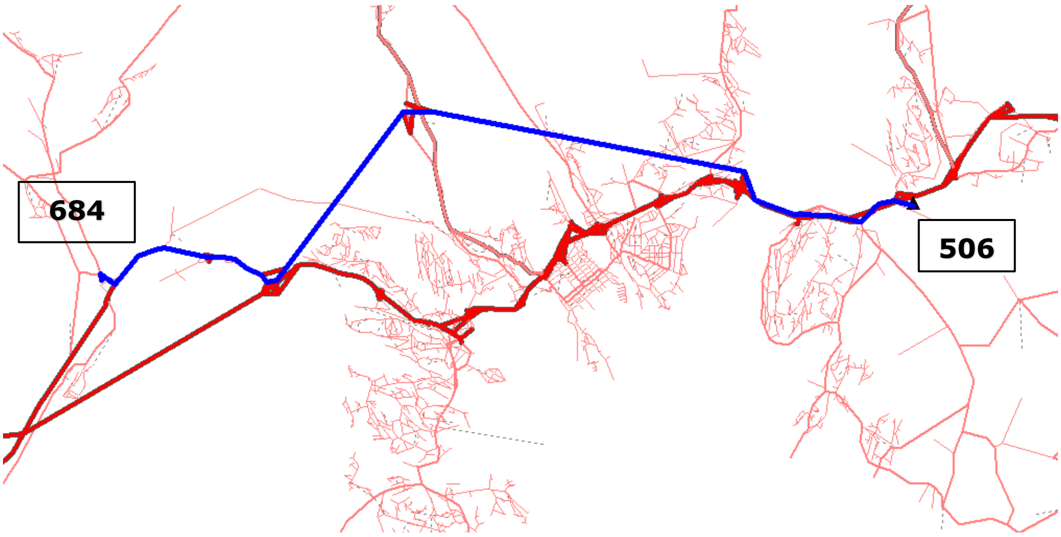

Figure 9-15: Ytre Ring, route choice zone 506-684, project scenario

Figure 9-16 and Figure 9-17 shows the route choice between zone 489 and 684, for the reference and project scenario respectively.

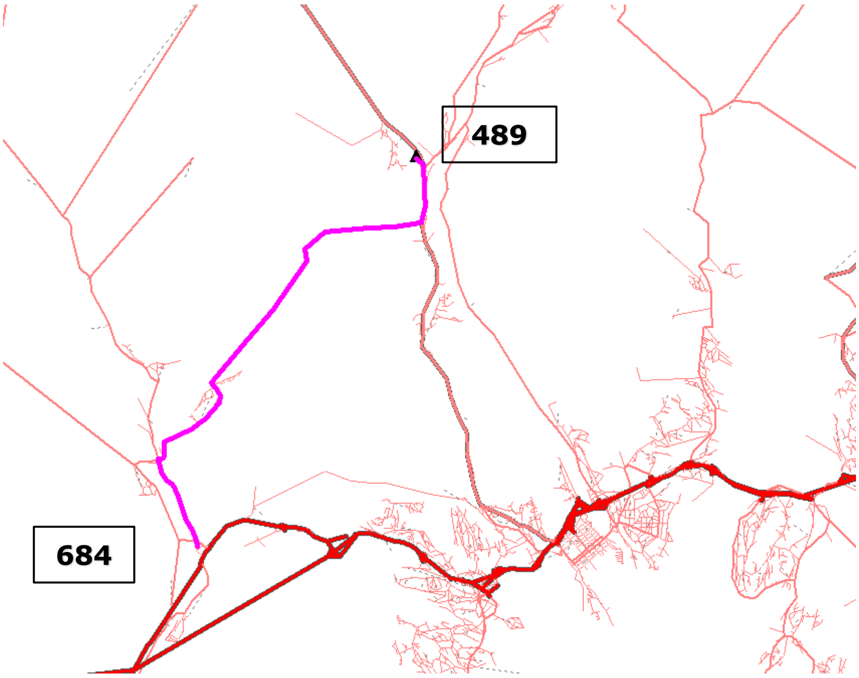

Figure 9-16: Ytre Ring, route choice zone 489-684, reference scenario

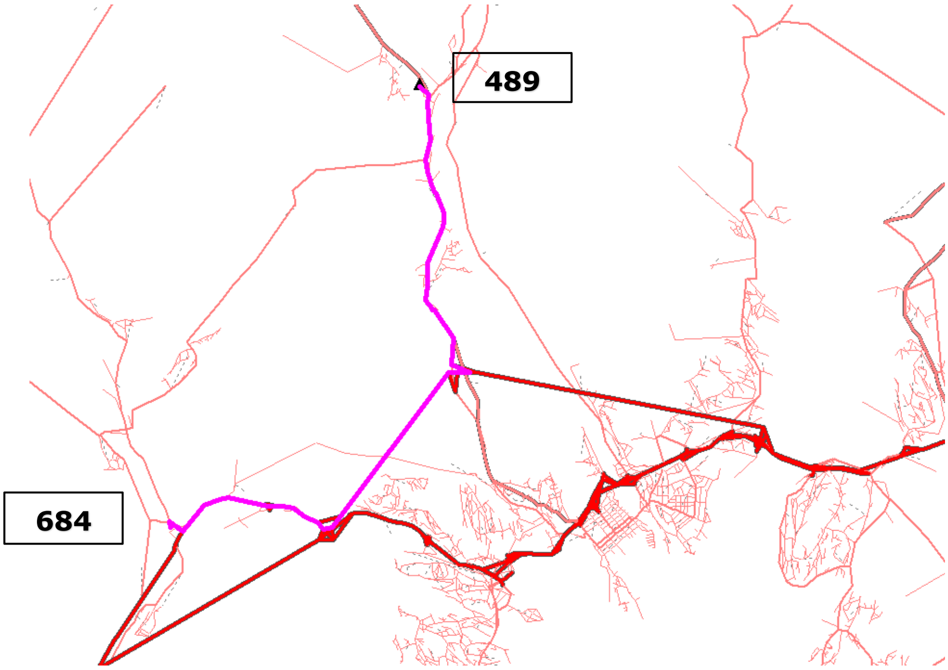

Figure 9-17: Ytre Ring, route choice zone 489-684, project scenario

All the investigated zone-relations experience a change in route choice due to the new road. Table 9-19 describes the travel demand between the three zones, for the three reference scenarios and the three project scenarios. The data is collected from "Turmatrise_CD_ÅDT_{ScenarioCode}". The two %-diff columns indicate the percentage change in travel demand for the given project scenario compared to the respective basis.

Reference_0 and project_0 indicates zero change in the VoT-parameters.

Table 9-19: Ytre Ring travel demand between zones

	506-684		**684-506**	
Reference s2m50	0.09		0.11	
Reference_0	0.08		0.09	
Reference s2p50	0.07		0.07	
Project s2m50	0.13	44 %	0.15	36 %
Project_0	0.12	50 %	0.13	44 %
Project s2p50	0.11	57 %	0.11	57 %
	489-506		**506-489**	
Reference s2m50	0.26		0.26	
Reference_0	0.22		0.22	
Reference s2p50	0.19		0.19	
Project s2m50	0.39	50 %	0.38	46 %
Project_0	0.35	59 %	0.35	59 %
Project s2p50	0.32	68 %	0.32	68 %
	489-684		**684-489**	
Reference s2m50	1.62		1.64	
Reference_0	1.35		1.37	
Reference s2p50	1.08		1.1	
Project s2m50	1.52	-6 %	1.54	-6 %
Project_0	1.31	-3 %	1.34	-2 %
Project s2p50	1.09	1 %	1.11	1 %

The following information can be collected from the table:

- All zone-relations experience a decrease in travel demand when the value of time parameter increase. This is given as the difference in demand for the scenario with 50% decrease in the VoT parameter and the 50% increase in the parameter. To illustrate, for zone-relation 506-684 in the project scenario, travel demand decreases from 0.13 to 0.11, almost 20% decrease.
- All zone-relations experience a change in travel demand from the reference scenario to the project scenario. This means that the situation after implementation of the project makes it more or less attractive to perform trips by car. For the two zone-relations 506-684 and 489-506 the new road cause travel demand by private car to increase, while the demand between the two zones 489 and 684 decreases. To illustrate, travel demand between zone 506 and 684

increase from 0.08 trips in the reference scenario to 0.12 trips in the project scenario when the VoT parameter is unchanged.

Table 9-20 describes the different travel cost components, time, distance and direct costs between the three zones. The values are collected from "LoS_bil_kapuavh_{ScenarioCode}", calculated by the network assignment module and used in the traveler benefit module. The following information can be found from the data:

- Travel time decrease for all zone relations.
- Travel distance increase for zones 506-684 and 489-684, but decreases for the last zone-relation, 489-506.
- Direct costs decrease for zones 506-684 and 489-506. For these projects, this means that travelers use a route with tolls today and switch to a route where there are no tolls.

Table 9-20: Ytre Ring, travel cost components

	TIME		**DISTANCE**		**DIRECT COSTS**	
	506-684	**684-506**	**506-684**	**684-506**	**506-684**	**684-506**
Reference	15.93	16.09	16.91	17.05	10.49	10.49
Project	12.55	13.28	17.53	18.31	0	0
	489-506	**506-489**	**489-506**	**506-489**	**489-506**	**506-489**
Reference	17.83	17.26	17.96	17.67	10.49	10.49
Project	14.2	13.8	16.96	16.46	0	0
	489-684	**684-489**	**489-684**	**684-489**	**489-684**	**684-489**
Reference	14.28	14.36	13.16	13.16	0	0
Project	12.59	12.99	14.32	14.7	0	0

<u>To sum up:</u>

Travel demand is calculated by the demand model (TraMod_by). The changes in travel demand between the different zones as described in Table 9-19, are caused by changes to the input parameters to the demand model. The model estimates travel demand between all zones in the network for the different travel modes and purposes. When the input parameters to the utility function in the demand model are changed, this can cause the estimated travel demand between zones to change.

For the zones described above, the change in input parameter for value of time cause the demand to change according to Table 9-19. Furthermore, this cause the calculated benefit from the project to change. When number of travelers using the new facility decrease, this will cause the calculated benefit to decrease.

Step 2 - Feda-Ålgård:

The project E39 Feda-Ålgård is illustrated in Figure 9-18. The figure shows that the proposed road has a straighter alignment compared to the existing road and this, together with higher travelling speeds results in lower travel times on the stretch. Details are given in Table 9-21.

Table 9-21: Feda-Ålgård, project details

	Reference	**Feda-Ålgård**
Travel time (min)	86.3	44.7
Travel distance (km)	106.7	81.4
Average speed (km/h)	74.2	109.4
Change in travel time (min)	-41.6	
Change in distance (km)	-25.3	

Figure 9-18 also shows traffic count locations for Feda-Ålgård and the description of each point is given in Table 9-22.

Figure 9-18: Feda-Ålgård, Cube-network

Table 9-22: Feda-Ålgård, traffic count locations

ID	Location
A	E39, west
B	Ørsdalsvatnet
C	Hovsvatnet
D	E39, east
E	Rv. 501

Traffic counts for the locations have been performed for three of the scenarios, in the reference and project scenario. The results are given in Table 9-23.

Table 9-23: Feda-Ålgård, traffic count results

	A	B	C	D	E
Reference step2m50	15663	n/a	n/a	11384	611
Reference step2_0	12633	n/a	n/a	9778	504
Reference step2p50	10864	n/a	n/a	8666	430
Project step2m50	18267	10348	10591	14051	863
Project step2_0	15115	9973	10030	12452	700
Project step2p50	13124	9702	9625	11323	599

The changes in traffic volumes from the reference scenario to the project scenarios are investigated in Table 9-24. The table shows percentage change in traffic volumes from the reference scenario to the project scenario for one value of the VoT parameter. In general, traffic volumes tend to decrease when the value of time parameter is increased. For location B, however, the volumes tend to be relatively stable and not affected by the changes in the VoT parameter.

Table 9-24: Feda-Ålgård, traffic count comparison

	A	B	E
Step2m50	2604	2667	252
	16.6 %	23.4 %	41.2 %
Step2_0	2482	2674	196
	19.6 %	27.3 %	38.9 %
Step2p50	2260	2657	169
	20.8 %	30.7 %	39.3 %

To explain these findings, a more detailed study of some of the zone-relations in the network has been studied in detail. Table 9-25 shows the zones investigated.

Table 9-25: Feda-Ålgård, zone description

Zone	Location
585	East of project
925	West of project
1223	Fv. 501, Rekeland

Figure 9-19 and Figure 9-20 shows the route choice between zone 585 and 1223 for the reference and project scenario respectively.

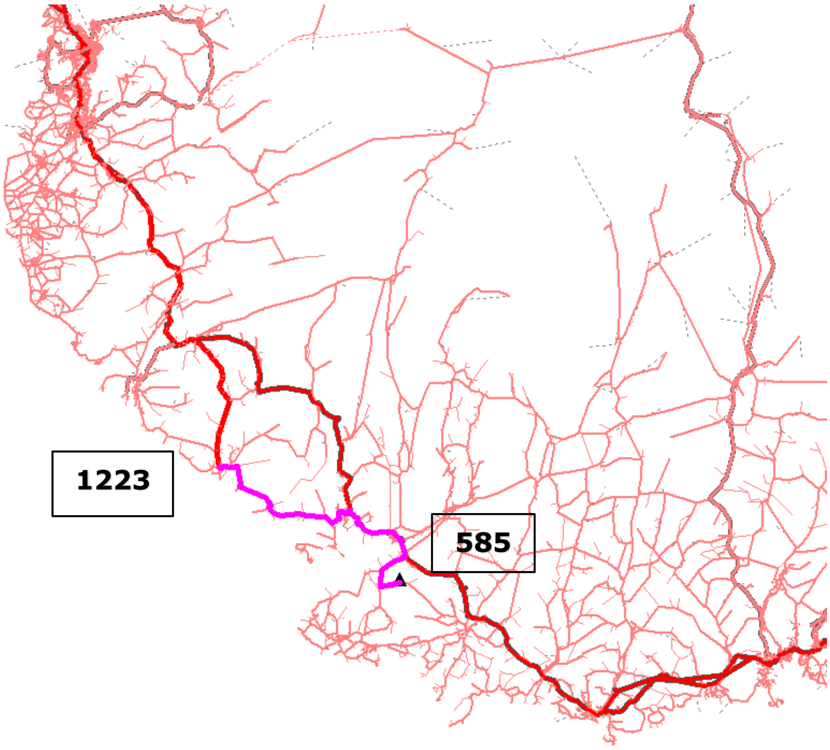

Figure 9-19: Feda-Ålgård, route choice zone 585-1223, reference scenario

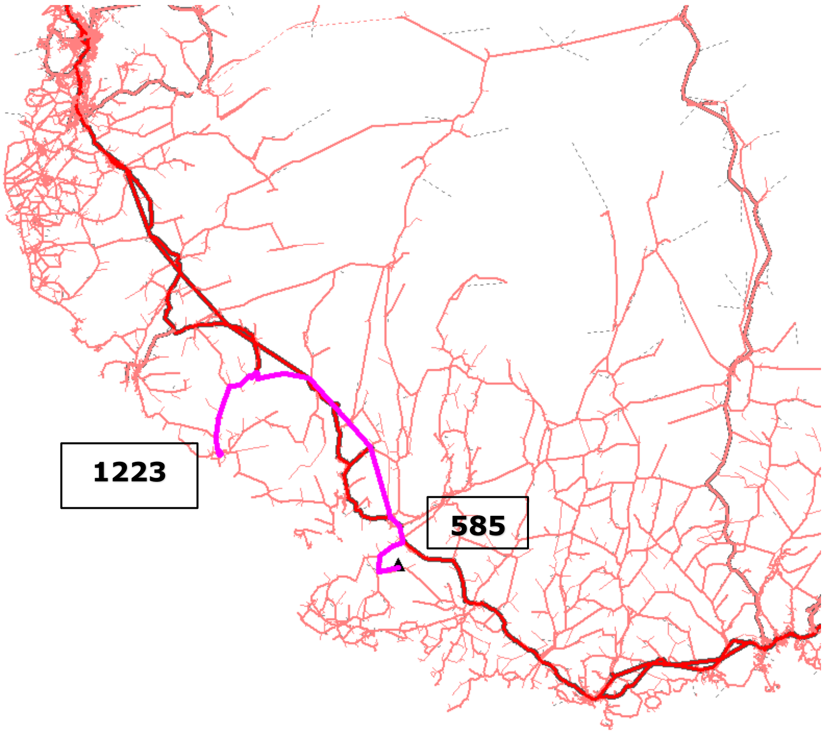

Figure 9-20: Feda-Ålgård, route choice zone 585-1223, project scenario

Figure 9-21 and Figure 9-22 shows the route choice between zone 925 and 1223 for the reference and project scenario respectively.

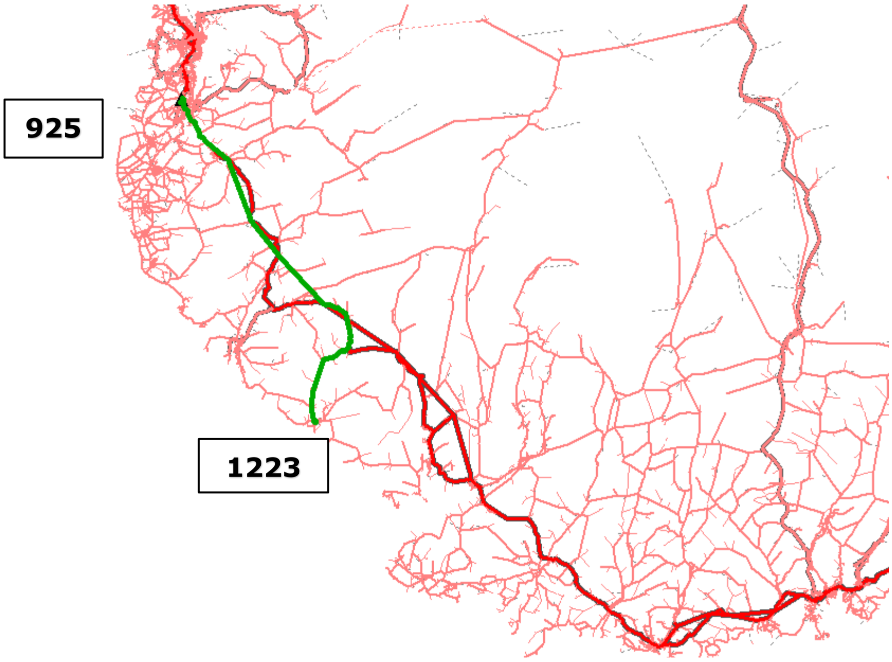

Figure 9-21: Feda-Ålgård, route choice zone 925-1223, reference scenario

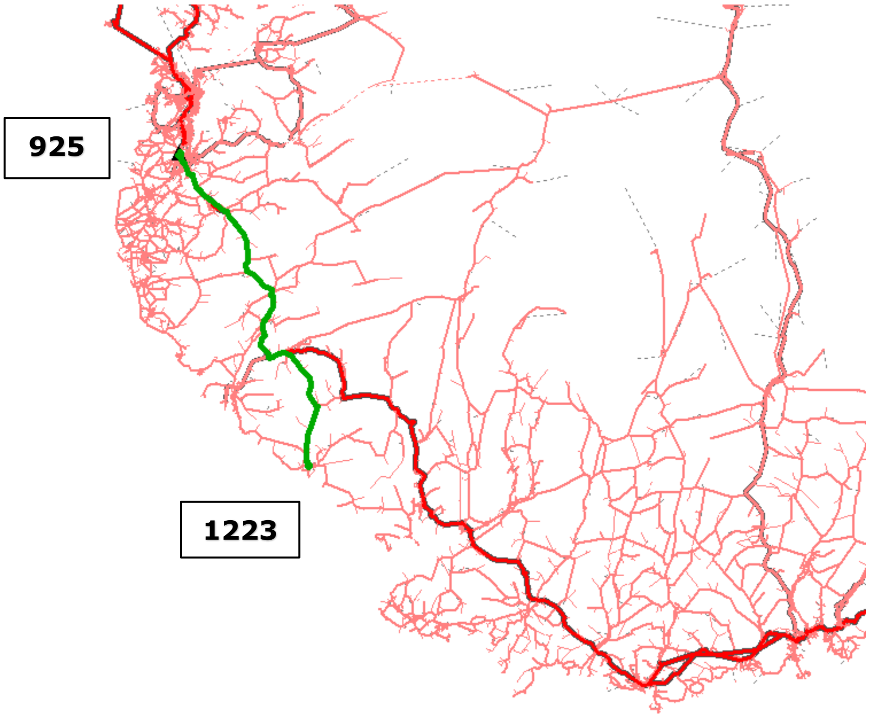

Figure 9-22: Feda-Ålgård, route choice zone 925-1223, project scenario

The travel demand between the zones presented in Table 9-19 are based on travel matrices produced by TraMod_by. Since the distance between the zones 585 and 925 is more than 70 kilometers, there are no trips estimated by the demand model for this zone-relation. Because of this, the zone-relation is not analyzed above.

Both investigated zone-relations experience a change in route choice due to the new road. Table 9-26 describes the travel demand between the zones, for the reference scenarios and the project scenarios. The data is collected from "Turmatrise_CD_ÅDT_{ScenarioCode}". The two %-diff columns indicate the percentage change in travel demand for the given project scenario compared to the respective basis.

Table 9-26: Feda-Ålgård, travel demand between zones

	781-1223		**1223-781**	
Reference s2m50	0.26		0.24	
Reference_0	0.23		0.22	
Reference s2p50	0.22		0.21	
Project s2m50	0.25	-4 %	0.23	-4 %
Project_0	0.23	0 %	0.22	0 %
Project s2p50	0.22	0 %	0.21	0 %
	585-1223		**1223-585**	
Reference s2m50	0.03		0.03	
Reference_0	0.01		0.01	
Reference s2p50	0		0	
Project s2m50	0.03	0 %	0.03	0 %
Project_0	0.01	0 %	0.01	0 %
Project s2p50	0	n/a	0	n/a

The following information can be collected from the table:

- Both zone-relations experience a decrease in travel demand when the value of time parameter is increased. This is given as the difference in travel demand from reference_step2_m50 to reference_step2_p50, and step2_m50 to step2_p50. This means that total travel demand between the given zones decrease when the value of time parameter is increased, for both the reference scenario and the project scenario.
- Travel demand between the zones before and after the new road is implemented is relatively stable. This means that the opening of the new road does not affect the number of trips between the selected zones in a significant way. For the zone-relations 781-1223 there is a small decrease in trips after the opening of the new road, while the other zone-relation experience no change in travel demand due to the new road.

Table 9-27 describes the different travel cost components, time, distance and direct costs between the three zones. The values are collected from "LoS_bil_kapuavh_{ScenarioCode}", calculated by the network assignment module and used in the traveler benefit module. The following information can be found from the data:

- Travel time decrease for all zone relations.
- Travel distance increase for both zone-relations. This is due to the use of the new and faster road, although it causes travel distance to increase.
- Direct costs are zero for both zone-relations.

Table 9-27: Feda-Ålgård, travel cost components

	TIME		**DISTANCE**		**DIRECT COSTS**	
	781-1223	**1223-781**	**781-1223**	**1223-781**	**781-1223**	**1223-781**
Reference	77.41	77.43	75.34	75.03	0	0
Project	67.53	67.78	87.8	87.81	0	0
	585-1223	**1223-585**	**585-1223**	**1223-585**	**585-1223**	**1223-585**
Reference	71.93	71.8	66.93	66.37	0	0
Project	62.05	62.15	79.39	79.15	0	0

To sum up:

Travel demand is calculated by the demand model (TraMod_by). Table 9-26 gives the changes in travel demand between the zones for different values of VoT, while Table 9-27 gives the cost components between the zones.

For the zones investigated above, the change in input values for VoT does not affect the results in the same way as was the case for Ytre Ring. Although travel time is reduced for both zone-relations, the size of the benefit will depend on the composition of the cost components in the traveler benefit module. Moreover, Table 9-13 shows that the calculated benefit from Feda-Ålgård vary significantly less for the different values of time compared to Ytre Ring. This can be explained by the small changes in travel demand between the zones and hence small changes in how many that benefit from the project.

Moreover, the consumer surplus varies in the same direction as for Ytre Ring, meaning consumer surplus decrease when the VoT parameter is increased. As for Ytre Ring, this can be explained by the decrease in travel demand between the zones when the VoT-parameter is increased. This means that with an increased VoT-parameter it is less attractive to travel by private car between the zones.

A selection of zones has been investigated to show some relationships between travel demand, value of time and the different cost components. For simplicity, only three zones have been investigated and hence it is not possible to draw any final conclusions. However, it is possible to use the observations to explain the reasons for the observed results and why the calculated benefit varies as described.

Step3 - Comparison

The results for changes implemented in the third step are given in Table 9-28 and Figure 9-23.

Table 9-28: Step3 - Consumer surplus variation

%-change in VoT	Ytre Ring	Feda Ålgård
-50	98.38 %	100.12 %
-40	98.72 %	100.12 %
-30	98.82 %	100.07 %
-20	98.77 %	100.03 %
-10	99.68 %	100.02 %
0	100.00 %	100.00 %
10	99.86 %	99.97 %
20	100.62 %	99.97 %
30	101.04 %	99.96 %
40	101.00 %	99.92 %
50	101.09 %	99.90 %

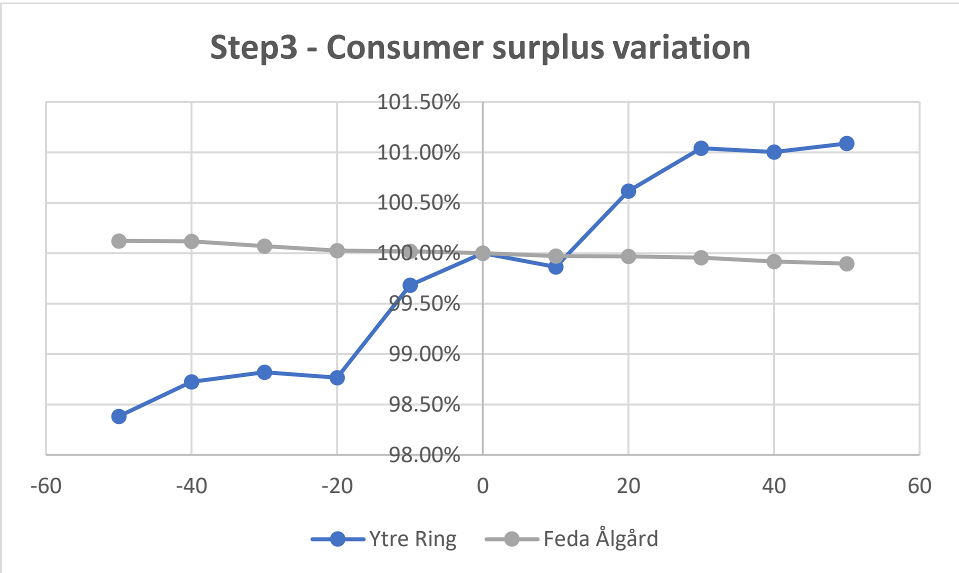

Figure 9-23: Step 3 - Consumer surplus variation

Step 3 assigns trips tom the network based on generalized cost calculations and traffic is assigned to the route with the lowest GC. If consumer surplus from the scenario should change because of changes implemented in the third step, there must be changes in network assignment. Furthermore, this means that there must be changes in what route is perceives as the cheapest by the travelers.

As Table 9-28 shows, the changes in consumer surplus in step 3 are small. This indicates that there are few changes in network assignment for the trips. This can be explained in the same way as for step 1. If there are few alternative routes for the travelers to choose between, there must be relatively big changes in the VoT to affect the output. However, the minor changes in calculated benefit is caused by small changes in route choices, typically in cities, where there are several possible routes to choose between that have nearly the same attributes when it comes to costs.

Also, worth mentioning is the fact that the calculated benefit varies in different directions for the two projects. For Ytre Ring, the increased VoT parameter cause consumer surplus to increase. For Feda-Ålgård, the opposite is the case, as an increased VoT-parameter cause consumer surplus to decrease.

The differences in consume surplus is very small and can possibly be explained by the different types of project and the traffic composition. As described in section 5, the traffic count locations for Ytre Ring do have a higher portion of TraMod_by trips compared to Feda-Ålgård. As the different travel purposes are valued differently, and longer trips given a higher value, this might explain the variations in calculated consumer surplus for the two locations as given in Table 9-28. However, as the differences in results are small for both the LoS-calculation step and the network assignment for both cases, these steps have not had a great focus in this thesis.

Step4 - Comparison
Adjusting the value of time in the traveler benefit module in step 4 cause consumer surplus to increase in a linear pattern. This is as expected because the step considers direct valuation of travel time savings. This means that when value of time increase a given amount, consumer surplus will change in the same direction.

A simple comparison of the two cases is given in Table 9-29 and Figure 9-24. The linear relationship between value of time and consumer surplus is clear.

Table 9-29: Step4 – Consumer surplus variation

%-change in VoT	Ytre Ring	Feda Ålgård
-50	85 %	80 %
-40	88 %	84 %
-30	91 %	88 %
-20	94 %	92 %
-10	97 %	96 %
0	100 %	100 %
10	103 %	104 %
20	106 %	108 %
30	109 %	112 %
40	112 %	116 %
50	115 %	120 %

Figure 9-24 shows that Feda-Ålgård is more affected by the changes in VoT compared to Ytre Ring. Type of project affects the estimation results and how changes in the input parameters affect the estimation results. Ytre Ring is a project with a ring road around a populated area. The goal of the project is to reduce travel time from east to west of the city, but also reduce traffic volumes through the city and hence improve traffic flow, especially during peak hour traffic. The ring road results in a longer travel distance for the implemented scenario compared to the existing route through the city. However, due to the increased speed limit on the new road, travel time will be reduced for travelers using the new road compared to the existing one. The fact that travel time is decreased although travel length is increased can affect the estimations results for the scenarios and how sensitive the results are to changes in the input parameters.

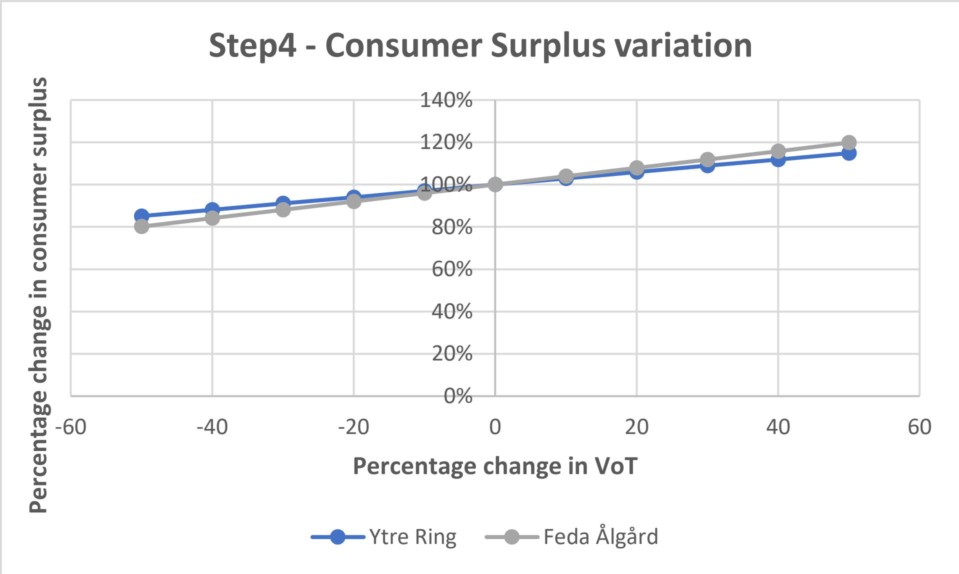

Figure 9-24: Step4 – Consumer surplus variation

The other project, Feda-Ålgård, results in both shorter travel distance and travel time. The main goal of this project is to reduce travel time for the users of the road, as well as improved safety and other factors. With both travel time and length being reduced, this can affect the estimation results differently than the situation for Ytre Ring.

Second, the type of travelers that take advantage of the road differs for the two projects. For Ytre Ring, there will be a mix of shorter and longer trips. Short trips are typically local trips going from one side of the city to another or trips entering the road on the planned intersection with Rv. 9. Longer trips are typically trips going east-west on E18/E39, and hence only travel past the city on their way to their destination. Feda-Ålgård, however, will have a larger portion of longer trips, due to the location between two big cities (Kristiansand and Stavanger) and fewer people living near the road.

The general difference in project and the difference in traffic composition are the two most important factors causing the results from the estimation to be different.

9.6 Section 5 – Traffic composition and modal split

To better understand the traffic situation and the different contributions to the calculated benefit it is interesting to have information about traffic composition and modal split for the two cases. This is investigated in the following, by looking at the reference scenarios for the two cases. The reference scenario has been chosen to make it possible to compare the traffic compositions before and after the implementation of the new projects.

Traffic composition described what types of trips that passes through the count locations. Based on the traffic count locations given in Figure 9-11 and Figure 9-18, data describing the flow composition has been collected and is given in Table 9-30.

Table 9-30: Traffic composition, Ytre Ring and Feda-Ålgård

	Ytre Ring				Feda-Ålgård		
	A	B	E	F	A	D	E
Reference 2022							
TraMod_by trips	6644	3305	38167	2798	3058	2072	127
Other trips	4331	644	12492	113	3290	2807	129
Project 2022							
TraMod_by trips	7905	3729	40411	4589	3662	2170	146
Other trips	4475	716	12791	441	3970	4030	212
Total number of trips							
Reference	10975	3949	50659	2911	6348	4879	256
Project	12380	4445	53202	5030	7632	6200	358
%-TraMod_by trips							
Reference	60.5 %	83.7 %	75.3 %	96.1 %	48.2 %	42.5 %	49.6 %
Project	63.9 %	83.9 %	76.0 %	91.2 %	48.0 %	35.0 %	40.8 %

TraMod-trips here includes the following travel purposes; work, service, leisure, private and deliver/pick-up. Other trips include education, airport, freight and long trips.

Table 9-30 shows that Ytre ring has a bigger portion of TraMod_by-trips compared to Feda-Ålgård. This will affect the benefit calculations, since trips in the different categories are assigned different values for improvement in the network.

For the locations in Ytre Ring, more than 60% of the trips are TraMod_by trips, meaning they are estimated by the demand model. For Feda-Ålgård, less than 50% of the trips belong to this category for the locations given in Table 9-30.

Moreover, it is also relevant to show the share of private car trips compared to the other modes. Table 9-31 shows the modal split for Ytre Ring and Feda-Ålgård. For both cases, car driver is the dominant mode, with more than 60% of the trips. These numbers are valid for the entire model and includes therefore large areas not directly affected by the proposed projects. Moreover, it is worth mentioning that the modal splits are relatively similar for the two models, as can be seen by the shares in Table 9-31.

Table 9-31: Modal split, Ytre Ring and Feda-Ålgård

	Ytre Ring		Feda-Ålgård	
Travel mode	**Number of trips**	**Share**	**Number of trips**	**Share**
Car driver, CD	556462	62%	1172935	60%
Car passenger, CP	61982	7%	135424	7%
Public transport, PT	90204	10%	221882	11%
Walk	155198	17%	325645	17%
Bike	39930	4%	100689	5%

10 Attachment #6 – Valuation studies and results

The basis for appraisal guidelines and the values to be used in transportation models are collected from different valuation studies. These studies are carried out on behalf of transportation authorities based on the demand for such data. Typically, these data will be necessary when considering whether to build large infrastructure projects or not, or when choosing between different alternatives. These studies are therefore an important part of transport analysis and may affect the outcome from such studies.

Valuation studies are carried out by several different countries. The methods used differ from location to locations and consequently, the results are based on different assumptions and approximations. Therefore, it can be difficult to compare values for different countries. However, several studies have been carried out concerning values of time for different areas. Values from different studies have previously been collected, showing that the values differ for the different locations. (Wardman, Chintakayala and de Jong, 2016) (Wardman *et al.*, 2012).

Some general aspects of valuation studies will be presented in the following, together with a selection of studies from around Europe. There are some main differences when it comes to the studies and these will be discussed.

10.1 General about valuation studies

Benefit-Cost Analyses are used around the world in order to decide what projects that should be implemented from a socioeconomic point of view. This concept takes into account benefits and costs of proposed projects and alternatives and makes it possible to rank projects against each other. The BCA is one of the most common appraisal practices in the EU today (Bristow and Nellthorp, 2000).

Benefit-Cost Analyses includes the estimation of time savings and the valuation of these savings. BCA of major road schemes in the UK revealed that travel time savings accounted for approximate 80% of the monetized benefits (Mackie, Jara-Díaz and Fowkes, 2001) This implies that value of time is of great interest to estimate in the most correct way in order to get realistic and reliable estimates of the total benefit produced from projects.

Due to this, a lot of work are being put down to estimate value of time for different countries and areas around the world. National valuation studies have been conducted in several countries in Europe (Jong, 2016). Although these studies differ when it comes to content and scope and results produced vary significantly from country to country, some common aspects can be discussed.

Travel modes
All studies considered in this work include private car as one of the modes. However, the additional modes included vary significantly. Some studies, such as the Swiss study only consider car and public transport (Axhausen *et al.*, 2006) while the Norwegian value of time study includes several different modes such as public transport, ferry, speed boat and train, bus and plane for long trips (Farideh *et al.*, 2010). Since this thesis considers private car only, this is the focus in the analyses and hence the studies are all relevant in this regard.

Travel purposes
One of the other main differences in the studies are the purposes included. Travel purpose is the reason why people travel, why they decide to go from one place to another. Most studies include trips to and from work as their travel purposes. These trips are often recognized as commute. In addition to this it is common to include purposes such as leisure, business, private trips, shopping, education and others. The studies group their travel purposes differently and hence include different trip types in the different categories. This depends also on how comprehensive the surveys used to estimate the values are.

Distance segments
Whether values of travel time should depend on trip length, and if so, what trip length segments that should be used is an ongoing discussion. Some of the studies investigated here use trip length dependent value of time, meaning there is a relationship between travel length and the value of time. France (Quinet *et al.*, 2013) and Germany (Kay, Sauer and Nagel, 2015) both have a relationship between these two variables and the results will be discussed later in this attachment. For the other surveys there is a segmentation of short and long trips. However, the limit between short and long trip vary from 25 to 100 km.

<u>Fixed Values of Time by trip length</u>
The most common way to estimate and present values of time is fixed values for one or a few distance segments. This means that the same value is assigned to trips within the same travel length interval, meaning trips that are assumed to have the same value. However, these intervals can often be very big, and it might therefore be unrealistic to assume all trips in the given interval have the same value. The method is easy since trips are only divided into a few groups based on their travel length.
This method is used in Norway, Sweden, Denmark, the UK and Germany. However, the trip length segments are not identical and vary in length for the different areas. For Norway, there are two alternatives, either 50km or 100km. For Switzerland and the Netherlands, only one trip length interval is given in the valuation studies. Table 10-2, page 97 provides the different values, converted to 2019 NOK.

<u>Continuous Values of Time by trip length</u>
The second method is continuous Values of Time where the value assigned to the trip vary with the length of the trip. For simplicity it is also possible to divide the trips into smaller intervals, e.g. 5-10km, but the number of intervals should be significantly larger than for the alternative with fixed values described above.
France and Germany both have established distance-dependent values of time to use in appraisal. These relationships are designed specifically for the two different situations and described below.

10.2 Valuation Studies

Several valuation studies have been carried out throughout the years. Table 10-1 shows some important information about the different surveys, such as what modes and travel purposes that are included and what distance segments they use. The different studies are discussed below, with focus on the Norwegian valuation study. This is because the two cases analyzed in the paper are located in Norway and the main focus for the analysis is therefore the Norwegian studies.

The two first studies in Table 10-1 considers value of time in Norway, with two different distance segments, 100[1] and 50[2] km respectively. Study number 3 and 4 considers values from Sweden, with the same segmentation of distance band, namely 50[3] and 100[4] km. Thereafter the studies from UK[5], Denmark[6], Switzerland[7], The Netherlands[8], Germany[9] and France[10] are given.

Because the studies are based on different assumptions and include different travel purposes and modes the results are not directly comparable. Despite this, it is interesting to see how the results vary among the surveys. Therefore, the results are given below. Table 10-2 (page 97) and Figure 10-1 (page 98) present the values for the fixed values, while Figure 10-2 (page 100) present the continuous values.

All values are adjusted to 2019 NOK per hour, to make the values more comparable to each other. The values are converted to 2019 NOK by first converting the value to NOK in the given year by using historical exchange rate from (Norges Bank, 2019) and then adjusting the value to today's value by using the inflation calculator (Smarte Penger, 2019).

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1 "Value of time, safety and environment in passenger transport - Time" R. Farideh,S. Flügel, H. Samstad, M. Killi

2 "Value of time, safety and environment in passenger transport - Supplementary study of the values of time" A.H. Halse, S.Flügel, M.Killi

3 "The National Swedish Valkue of Time Study", S.Algers, J.L. Dillén, Transek consultancy, SIKA.

4 "Experiences from the Swedish Value of Time Study" M.Börjesson, J.Eliasson

5 "Provision of market research for value of travel time savings and reliability" Department of transport, UK

6 "The Danish Value of Time Study - Final report" M. Fosgerau, K. Hjort, S.Lyk-Jensen

7 "Swiss Value of Travel time savings" K. Axhausen, et.al.

8 "New values of time and reliability in passenger transport in The Netherlands", M. Kouwenhoven, et.al.

9 "Ermittlung von Bewertungsansätzen für Reisezeiten und Zuverlässigkeit auf Basis der Schätzung eines Modells für modale Verlagerungen im nicht-gewerblichen und gewerblichen Personverkehr für die Bundesverkehrswegenplanung", K. Axhausen, et.al.

10 "Cost benefit assessment of public investments - Final Report Summary and recommendations", Émile Quinet et.al.

Table 10-1: Valuation studies in Europe

#	Country, year	Mode, short	Mode, long	Purpose, short	Purpose, long	short/long (km)
1	Norway, 2010	Car driver (CD), public transport (PT), ferry, speed boat	CD, train, bus, plane, speed boat	work, other private, all private, business, all trips	work, other private, all private, business, all trips	100
2	Norway, 2010, additional study	CD, PT, ferry, speed boat	CD, train, bus, plane, speed boat	work, other private, all private, business, all trips	work, other private, all private, business, all trips	50
3	Sweden, 1994	CD, reg. train, long distance bus, Reg. bus	CD, Air, IC Train, X2000, Reg. train, LD Bus, Reg. Bus	work, other	all trips	50
4	Sweden, 2014	CD, Bus, Train	CD, Bus, train	work, other	all trips	100
5	UK, 2015	CD, Bus, other PT, Rail	CD, Bus, Other PT, Rail	commute, other non-work, emplyees' business	commute, other non-work, emplyees' business	5,20,100
6	Denmark, 2007	CD, Bus, Metro, S-train, Train	CD, Bus, Metro, S-train, Train	Commuter, Education, Leisure, Maintenance, All	Commuter, Education, Leisure, Maintenance, All	25
7	Switzerland, 2006	CD, PT	CD, PT	Commute, Shopping, busniess, Leisure, Total	Commute, Shopping, busniess, Leisure, Total	n/a
8	The Netherlands, 2014	CD, train, bus/tram/metro, all surface modes, air, recr. navigation	n/a	Commute, business, other, all		n/a
9	Germany, 2015	CD, PT, plane, all	CD, PT, plane, all	Work, education shopping, leisure, commercial, non-commercial, all	Work, education, shopping, leisure, commercial, non-commercial, all	50 + cont.
10	France, 2013	CD, car-coach, rail, air, all	CD, car-coach, rail, air, all	professional, personal-holiday, personal-other	professional, personal-holiday, personal-other	cont.

10.3 Fixed Values of Time

Most of the studies in Table 10-1 present their values as fixed values of time, meaning the values are divided into a very limited number of trip length segments that are assigned the same value. This means also that two trips with significant different length can have the same value of time.

Table 10-2 and Figure 10-1 presents the fixed values for these surveys. The different surveys are more detailed described in the following.

Table 10-2: Value of Time work trips by private car, adjusted to 2019 NOK/hr

study #	**Country, year**	**limit short/long (km)**	**VoT short/long (NOK/hr)**
1	Norway, 2010	100	110/245
2	Norway, 2010, additional study	50	103/185
3	Sweden, 1994	50	57/124
4	Sweden, 2014	110	92/110
5	UK, 2015	8/32/161	98/138/191
6	Denmark, 2007	25	150/120
7	Switzerland, 2006	n/a	154
9	The Netherlands, 2014	n/a	89
10	Germany, 2015	50	41/94

Some simplifications have been done in presenting the results:

- The Norwegian studies (study 1 and 2) give the values for work trips with private car.
- The Swedish values (study 3 and 4) are given as work trips for the short segment, but only one category "all trips" are provided for long trips.
- The study from UK provides values based on miles but these are converted to kilometers in the table and figure. The value here are specified that only are valid up to 100 miles, or approximately 161 kilometers. The mode is private car and travel purpose commute, which is assumed to be identical to work trips in the other surveys.
- Study number 6 provides Danish values of time. The limit between short and long trip are at 25 kilometers and the values are decreasing for long trips compared to the shorter ones. The values are also here collected for private car and the purpose of commute.
- The studies for Switzerland and The Netherland do not divide trips into length segments but do only use one value.
- The German study provided both fixed and continuous values of time, the fixed ones are included in the table above.

Figure 10-1 shows that there are variations when it comes to the valuation of travel time for the different surveys. All surveys present values that increase for long trips compared to short trips, except for Demark where values are higher for short trips.

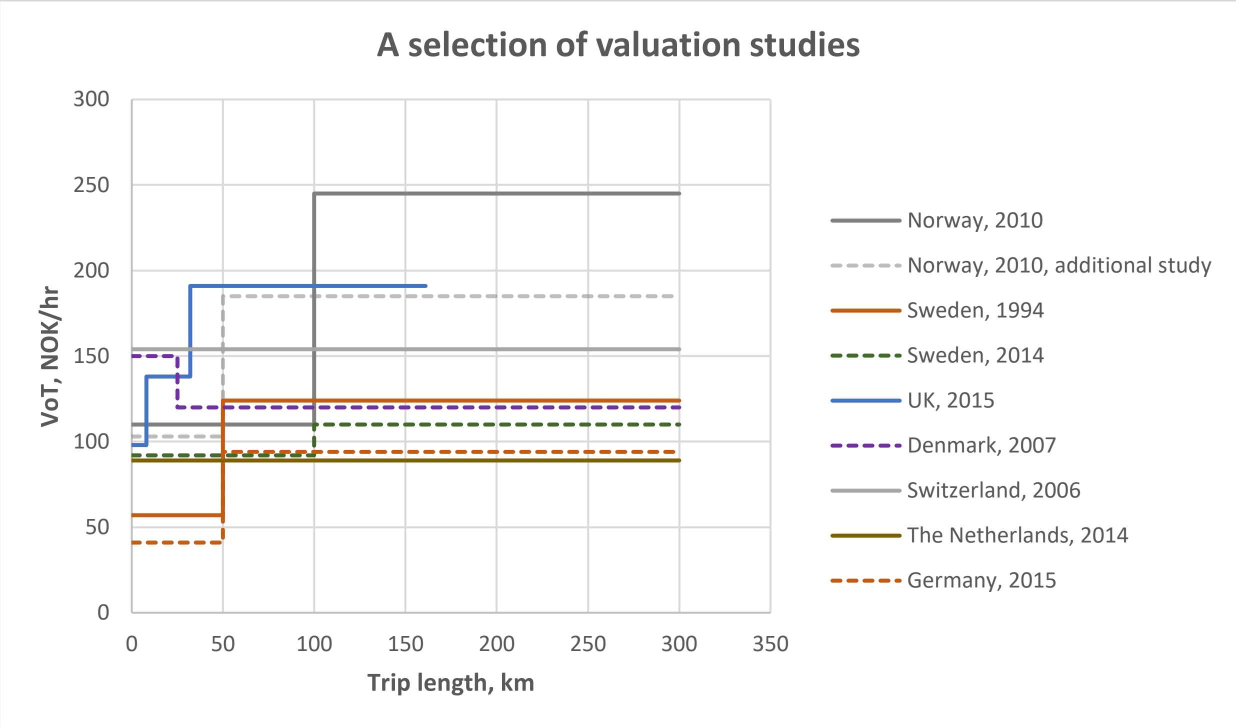

Figure 10-1: Selection of fixed VoT studies

Norway (study 1 and 2)
The Norwegian value of time study carried out by TØI in 2010 gives values of time and travel components to be used in appraisal (Farideh *et al.*, 2010). This study divides between short and long trips at 100km, meaning values of time are estimated for the different travel modes and purposes for trip shorter than 100km and trips longer than 100km.

In addition to this study, another study has been carried out where 50 kilometers is the limit between short and long trips (Halse, Flügel and Killi, 2010). This is done to investigate how much a new definition of short and long trips affect the estimation results. Values of time are known to increase with travel distance and since the definition for short trips is now changed, this means trips in the range of 50-100km will now be part of the long trip category. This cause both short and long trips to decrease their value of time. This is because shorter trips will now contain trips in the range 0-50km and long trips will include trips in the range 50+km with a lower value of time than the trips longer than 100km. This can also be seen from Figure 10-1, where the additional study for Norway has lower values compared to the original study.

The Norwegian values are calculated based on Stated Preference surveys conducted in 2009 with 9280 respondents. These respondents were divided among short and long trips, as well as different travel purposes. The mixed logit model was used to estimate value of travel time for the different groups.

There are several relationships and results from the Norwegian valuation study that is worth mentioning. The first is the reference dependent preferences, that states that the price on an offer will be perceived higher if the offer is reduction in travel time, than the opposite. Second, gender perceive time differently and have different values of time. Women tend to have a lower value of time on short trips with car compared to men. However, for long trips as car driver, women have a higher valuation than men. Third, young and old people have a lower valuation than people in their mid-age. Fourth, value of time is higher for high income groups compared to households with lower income. Fifth, value of time increases with trip length, meaning longer trips have a higher value compared to shorter trips. Sixth, trips to and from work have significantly higher value compared to other trips, except for business trips.

Sweden (study 3 and 4)

The national Swedish value of time study (Algers, Dillén and Widlert, 1994) carried out in 1994 gives values for different modes and travel purposes. As described for the Norwegian valuation study, Sweden do also have two surveys with different definition of short and long trips. The study from 1994 gives values for trips shorter and longer than 50km, while the study "Experiences from the Swedish value of time study (Börjesson and Eliasson, 2014) uses 100 kilometers as the limit.

Although the study from 1994 is old it gives information about how value of time can be divided into different trip length segments and is therefore interesting to see in context with the study from 2014 where values are divided into different trip length segments.

UK (study 5)

Travel time values for use in appraisal for the UK are given by (Stefan *et al.*, 2015). Different values are calculated for different income categories and trip lengths. Trips as commute, other non-work and employer's business are calculated for the following modes; car, bus, other public transport and rail.

Trips are segmented into length intervals, as trips shorter than 5 miles, 5-20 miles, 20-100 miles and longer than 100 miles. Since this study provides some information about different trip length segments, it is more detailed than the other studies in this regard. However, the very limited number of trip length segments is the reason why the study is categorized as fixed values of time.

Denmark (study 6)

The Danish value of time study (Fosgerau, Hjorth and Lyk-Jensen, 2007) presents values for travel time and other travel components for Denmark.

The Danish survey divide short and long trips at 25km, meaning the short trips as defines by the Danes are relatively much shorter than what is the case for Sweden and Norway as described above. The average value of time for in-vehicle time is 67 DKK (2014 DKK).

Switzerland (study 7)

Values of time are presented in "Swiss values of travel time savings" (Axhausen *et al.*, 2006). This study does not differ between different trip lengths and do only present values for car and public transport. However, it is worth to bring the results to the table and see how they differ from the other studies described.

The Netherlands (study 8)
Values to be used in appraisal in the Netherlands are presented by (Kouwenhoven *et al.*, 2014). These values are not divided into trip length segments and do consequently only give one value for all trips, independent of length. The following travel purposes are described; Car, train, bus/tram/metro, all surface modes, air and recreational navigation.

Germany (study 9)
The German survey divide trips into several different travel purposes and modes and provides both fixed and continuous values of time. The report is presented in German. The fixed values of time that are presented are given for private vehicle, public transport, plane and all trips. Several different travel purposes are included, such as work, education, shopping and leisure.

10.4 Continuous Values of Time
Two of the studies given in Table 10-1 provides a continuous relationship between value of time and trip length. This means that value of time is dependent of the distance travelled.

Figure 10-2 presents the continuous relationship for value of time for France and Germany. Both these countries show an increasing relationship between value of time and travel distance. However, the values tend to increase more in the beginning, for trips up to approximate 100 kilometers, before the values have a smaller increase in value by trip length after this.

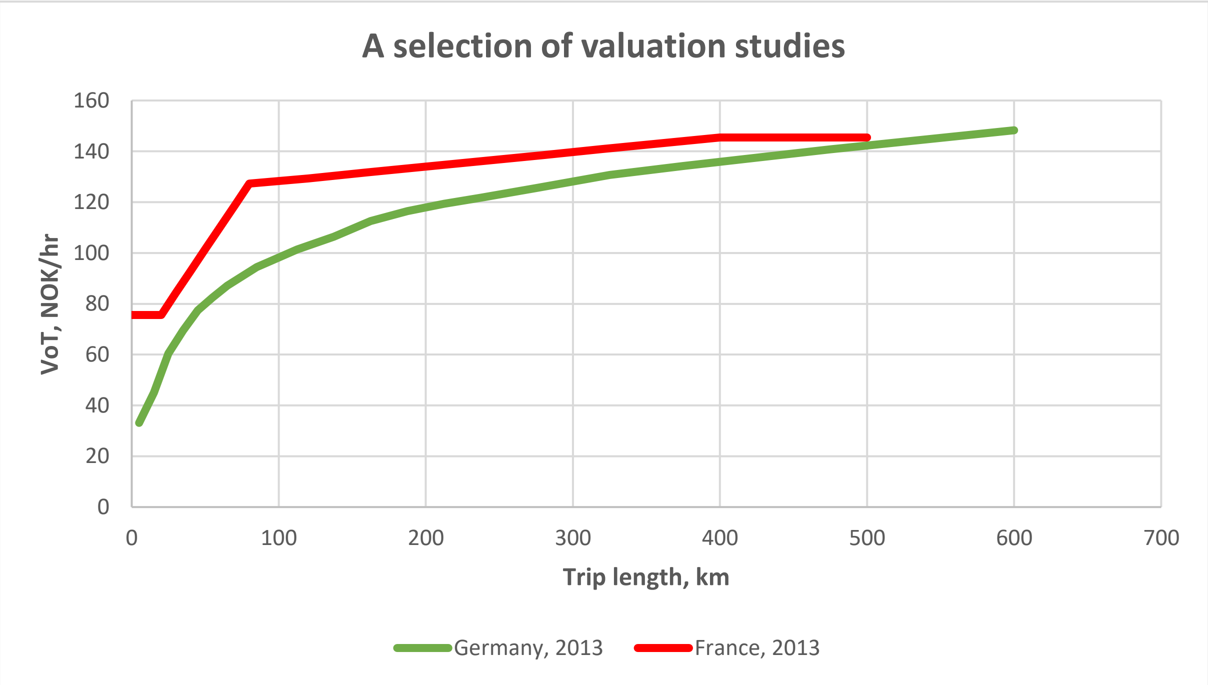

Figure 10-2: Distance-dependent VoT

Germany (study 9)
The same study as described for fixed values above also presents values that are dependent of travel distance. The same travel purposes are used, and the values are estimated based on the same data collected. The values from the German study in Figure 10-2 are given for trips to and from work.

France (study 10)
The French appraisal guidelines present values for professional, personal-holiday and personal-other for the following modes; private car, car-coach, rail and air. Values are given with functions for the distance intervals between 0-20-80-400 kilometers. This is the basis for the graph in Figure 10-2, where the relationship for all trips by car is given.

10.5 Uncertainty

Since the values presented in the papers are found with different estimation techniques and based on data collected from different types of surveys, there will always be uncertainties related to the values.

First, the values are not directly comparable, due to the differences in how the values are estimated. As previous described this makes it hard to compare the values, but still makes it possible to e.g. see how the values varies with travel length.

Second, there are always uncertainties when surveys are used to estimate values that should be valid for the entire populations. This includes representativity among the respondents and is discussed in more detail in attachment #3 – Stated Choice methods.

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11 Attachment #7 – Trip Length Dependent VoT

This attachment describes the implementation of a distance dependent model for value of time in the Regional Transport model in Cube. The procedure is described in detail and results from the implemented model is presented.

11.1 Introduction

The model responds differently to changes in the input parameters for value of time in the different calculation steps in the model. (*Attachment #5 – Sensitivity Analysis in RTM).* This attachment considers the implementation of a new model in step 3, network assignment and step 4, the traveler benefit module. This is because of:

- Distance dependent value of time is performed in the network assignment step by varying the value of time used in the assignment of trips to the network. Previous research (Kim and Yook, 2018), used distance dependent values of time for this purpose in case studies in South Korea to investigate how it affects the calculated benefit. The results show that the distance dependent VoT tends to increase benefit and it would therefore be interesting to investigate whether this is also the case for Norwegian projects.
- The sensitivity analysis revealed that the traveler benefit module is the step where the model is the most sensitive to changes in the input values. Therefore, the new model is implemented in this step, to investigate how the estimation results will be affected.

The Regional Transport Model is built up as follows (*Attachment #4 – Value of Time in RTM*):

1. Network program generates LoS-data from input data provided to the program.
2. Demand model (TraMod_by) runs and calculates origin-destination matrices based on the LoS-data from step 1.
3. Network program assigns the trips based on the origin-destination matrices from step 2. This gives traffic flows on the different links and routes.
4. The traveler benefit module calculates the change in consumer surplus by comparing the cost components (time, distance and direct costs) for the reference and project scenario for all zone relations in the network.

Value of time is included in all the four steps, but the values are not easily comparable to one another. Implicit values are used together with explicit values, introducing some challenges when these values are used in the same process. Furthermore, the Norwegian valuation study is used to estimate some of the values, while other parameters are calibrated in the model. Also, the different steps in the model use different travel purposes, causing the need of aggregation of travel purposes in different groups in the calculation steps.

11.2 Where should a distance dependent model be implemented?

Since there are four steps in the calculation framework, there are also four possible locations to implement a distance-dependent model for value of time. However, some steps might be more interesting than others.

Step 1, LoS-calculations provides information about the travel cost components for all zone-relations in the network along the route with the lowest GC. GC is calculated as the function of time, distance and direct cost components and their weights. Value of time is here given as the relationship between the parameter for time and the parameter for direct costs. Value of time is changed by changing either the parameter for time or the parameter for direct costs. Here, the value for time is increased and decreased and the results analyzed.

Changes in the parameter for time will result in changed generalized costs for the zone relation. How this will affect the skimming procedure depends on the contribution from the distance parameter. If changes in the time parameter cause the route with the lowest GC to change, another route will be skimmed and give input to the demand model. However, as many routes do not have any alternative routes that are close to the existing one in costs, the changes in input values for VoT often cause small changes in route choice from step 1. Consequently, this will cause small changes in the demand model and estimation results.

Step 2, the demand model, estimates travel demand between all zones in the network. Value of time is here included as parameters in the functions estimating trips produced and attracted in the zones. If the change in parameter cause the zones to be more or less attractive, this will cause the travel demand to change and consequently the traffic flows on the routes between zones. These changes in origin-destination matrices can consequently cause the calculated benefit from the project to change.

Step 3, network assignment, assigns trips to the network based on generalized cost calculations. As described for LoS-calculations above, value of time will affect the GC of available route choices and hence what route that will be chosen. However, as for step 1, many routes do not have any alternative when it comes to what route to use and will hence be little affected by changes in the input parameters. Small changes will be expected due to minor route changes in areas with a tight network of possible routes, such as city centers.

Step 4, traveler benefit module, calculate the benefit of infrastructure improvements by using explicit values of time. This means that the values are given as direct values and multiplied by changes in time, distance and direct costs for the trips in the network. Followingly, increase or decrease in the valuation of these savings will directly affect the estimated benefit.

Based on the sensitivity analysis and the argumentation above, some conclusions can be drawn:

- Step 1 is very little affected by changes in the input parameters. Therefore, the implementation of a distance-based model will probably cause small changes in the estimated results. A distance-dependent model is therefore not implement in this step.
- Step 2 results in changes in the estimated benefit, but the sensitivity analysis shows that the size of the affect varies with type of project. However, since the sensitivity analysis is only performed on two projects, this should be more

carefully investigated. Despite this, a distance-based model is not implemented in step 2 in this work. This is because implementing such a model in the demand model is a complicated process and outside the scope of this master thesis.

- Step 3 behaves quite similar to step 1, and the changes in the sensitivity analysis are small. Despite this, a distance-based model is implemented in this step. This is because research from South Korea (Kim and Yook, 2018) have previous implemented a distance-dependent model for VoT in the network assignment step and observed changes in the calculated benefit. It is therefore interesting to investigate how this will affect the Norwegian projects and to see if the consumer surplus is affected in the same way here.
- Step 4 cause the most changes in the sensitivity analysis and should therefore be included in the analysis of distance based VoT.

11.3 Measurements for changes in calculated benefit

To measure the effects from changes in the input values for VoT, one unit must be chosen as the measurement unit. Here, consumer surplus is chosen.

Consumer surplus shows the change in benefit for the users in the network, caused by changes in the transport network and travel demand between zones. For this paper, it will show changes in benefit for car users caused by improvements in the road network.

When only car users are included in the benefit calculations, the benefit consists of changes in time, distance and direct costs for the car travel purposes. Table 11-1 shows the travel purposes for network assignment and the aggregated travel purposes used in the traveler benefit module. (Purposes translated from Norwegian, a translation is provided in chapter 3). As Table 11-1 shows, there are more purposes in the network assignment step and these are aggregated in the benefit module to better correspond to the purposes in the valuation study.

Table 11-1: Aggregation of trip purposes RTM to traveler benefit module

Purpose in RTM	**Purpose in benefit module**
Work	to/from work
Service	service
Leisure	Leisure
Private trips	Leisure
Pick-up/deliver	Leisure
Education	Leisure
Airport	Airport
Long trips	Work, Service, Leisure
Freight	Freight

The different travel purposes do have their own values when it comes to the valuation of time savings in the network. The values do also vary in the different calculation steps. This will be further discussed in the two sections below.

11.4 Description of analysis procedure

The implementation of a model for distance-dependent VoT is performed in four operations, as described in Table 11-2.

Table 11-2: Analysis procedure, distance-dependent model

Scenario	Step 3	Step 4
1	Fixed VoT	Fixed VoT
2	DD VoT	Fixed VoT
3	Fixed VoT	DD VoT
4	DD VoT	DD VoT

- Scenario 1 describes the basic scenario where traditional VoT is used in both step 3 and step 4. The values used here are given in Table 11-3 and Table 11-5 below.
- In scenario 2 is a model for distance-dependent VoT introduced in the third step, while the fourth step has fixed values. Scenario 2 gives therefore the effects of changing the parameters for VoT in the network assignment step only.
- Scenario 3 is the opposite of scenario 2, since a fixed VoT is used in step 3 and a distance-dependent VoT is used in step 4. This scenario consequently shows the effects of implementing a distance-dependent model in the traveler benefit module only.
- Finally, step 4 gives the effects of implementing a distance-dependent model in both the network assignment step and the traveler benefit module.

This procedure is performed for both cases and the results analyzed in the following.

11.5 Distance-dependent VoT in step 3, network assignment

The third step in the Regional Transport Model (Tørset, Malmin and Bang, 2013) assigns trips to the network based on the calculated demand from the demand model (*Attachment #4*). Trip matrices from the demand model in step 2 gives information about travel demand between the different zones in the network. However, where the trips go, the route choice, is decided in the network assignment step, based on GC for the available route choices. GC is built up by three costs components; time, distance and direct costs such as tolls etc. Zone-relations in the network may have several different routes that can be chosen to reach the destination. What route that is chosen depends on the composition of cost components and their weights.

In RTM today, network assignment for private car trips is simplified performed as follows (Malmin, 2013). Since the model for distance dependent VoT later described is considered on the daily basis, this procedure is described for the existing model)

1. Network program reads the car network
2. Choose whether trips are assigned on a daily or hourly basis.
3. On the daily basis, work trips are assigned to the network partly capacity dependent, meaning some delays are accounted for, while other trips are performed independent of capacity.
4. Network assignment is performed in iterations by minimizing GC between the different zones.
5. Matrices describing costs for the different travel purposes for use in the traveler benefit module are produced.

The three cost components; time, distance and direct costs, have different values assigned depending on travel purpose. Table 11-3 shows the values used in the network assignment procedure today.

Table 11-3: Cost components, step 3, network assignment

Purpose	Time (NOK/hr)	Distance (NOK/km)	Direct costs (NOK/(NOK)
Work	72	0.7	0.3
Service	240	0.7	0.3
Leisure	96	0.7	0.3
Long (NTM)	300	0.7	0.3
Freight	540	3	0.5

The values presented in Table 11-3 shows fixed values of time, meaning the value is assigned independent of the length of the trip. Work, service and leisure are trips estimated by the demand model (TraMod_by). Leisure trips here includes the three travel purposes leisure, private and pick-up/deliver from Table 11-1. Long and freight trips are fixed matrices provided to the model.

Several simplifications have been done in the work of implementing the model in the existing framework.

- Only private car trips have been analyzed, meaning only the benefit from trips performed by private car as driver are considered. Of course, trips by other modes will contribute to the total benefit produced and hence the benefit calculated in this paper will be a great underestimation of the total benefit from projects. However, the goal is to show how the calculated benefit from infrastructure projects may vary when value of time is varied by trip length and not to give a full benefit estimation for the selected projects.
- Network assignment in the new model is performed based on time costs only. This means that the route with the shortest travel time is selected and that the other cost components are neglected. This can cause some challenges and errors in the estimated, especially in projects where travel time and distance is changed in different directions. This is the case for Ytre Ring, where travel distance is increased while travel time is reduced due to the higher speeds on the new road.
- Only the value of time is changed in the estimations, leaving the values for distance and direct costs unchanged.
- Only the time component of the total benefit is considered. Since time is the only component that is considered in network assignment and changed in the different scenarios, only benefit caused by changes in time is considered and analyzed. This means that benefit caused by shorter travel distance or less direct costs (tolls etc.) are not included in the benefit.

11.6 Step 3 – model structure

The structure of the new distance-dependent model in step 3 is described in the following.

Matrix operation reads travel matrix and cost matrix for the given scenario as shown in Figure 11-1. The travel matrix describes travel demand between all zones in the network, divided in different travel purposes. The cost matrix is the LoS-matrix calculated in the first step in the RTM model. This matrix gives the value for the cost components for car driver, used in the network assignment operation.

Matrix divides trips into trip length intervals based on the distances in the LoS-matrix. Three output matrices are produced: One giving trips from TraMod_by in length intervals 0-70km+ ("CD, TraMod_by, int"), one giving other trips total ("CD Fixed") and one giving other trips in trip length intervals (0-70km+) ("CD, Fixed, int").

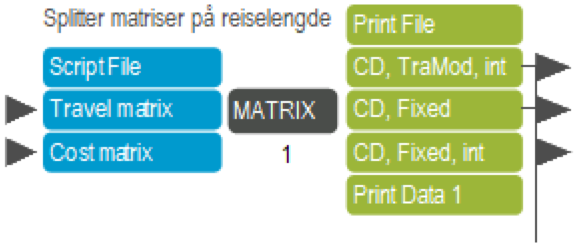

Figure 11-1: Distance dependent VoT, step3, operation1

In operation 2, the highway program assigns the trips to the network. TraMod_by trips are assigned to the network in trip length intervals, meaning the different trip length segments are assigned separately. This makes it possible to assign different value of time to the different trip length intervals, meaning a distance dependent relationship between travel length and VoT is introduced. Trips from the fixed matrices are assigned in one operation for each travel purpose respectively. Consequently, one value is assigned to all trips with the same purpose independent of travel length. Figure 11-2 shows the setup for the procedure. The output files are cost matrices to the traveler benefit module ("TNM, CD") and network with assigned trips ("CD, assigned net"). Values used for the network assignment are given in Table 11-3. Since only time costs are considered in the network assignment, time costs from the table are used.

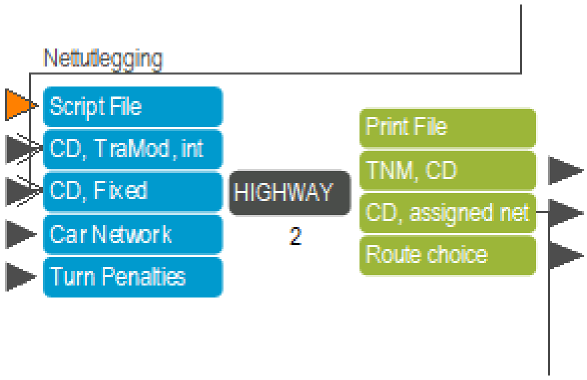

Figure 11-2: Distance dependent VoT, step3, operation 2

Only work trips and leisure trips from the demand model are considered in the distance-dependent model. A relationship between VoT and travel distance has been established. The background for the values is the values used for short trips today, as given in Table 11-3. These values are thereafter increased in a stepped manner up to trips longer than 70km. Trips above this limit are assigned the same value. Table 11-4 presents the models.

Table 11-4: Distance dependent VoT, step3

Upper dist. (km)	Work (NOK/hr)	Leisure (NOK/hr)
10	72	96
20	85	109
30	98	122
40	111	135
50	124	148
60	137	161
70	150	174
70+	163	187

Figure 11-3 shows the relationship between value of time and travel length graphically, based in the table above.

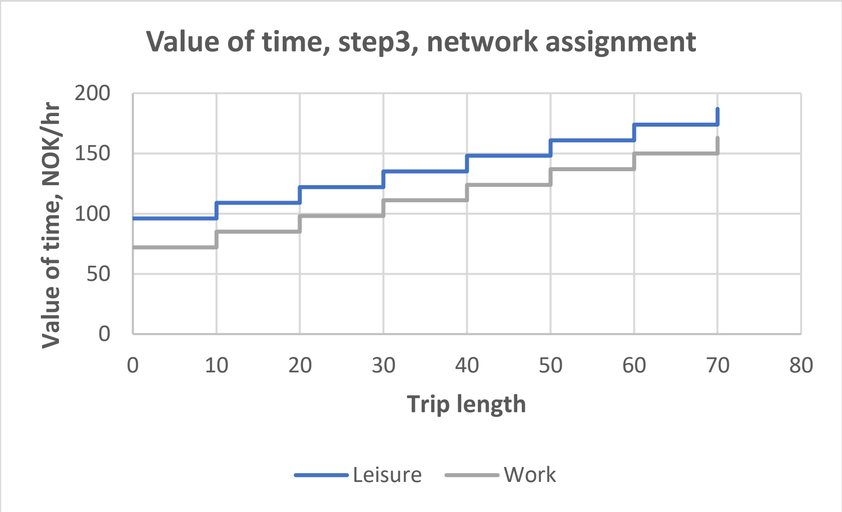

Figure 11-3: Distance dependent VoT, step3

The last operation in step 3 is performed in "network", as given in **Figure 11-4**. Here, the car network is modified by changing the names of the different car volumes to the names of the corresponding travel purpose (work, service, leisure, NTM or freight) and the trip length segment. This makes it possible to analyze the final car network and identify what type of traffic the link volumes consist of.

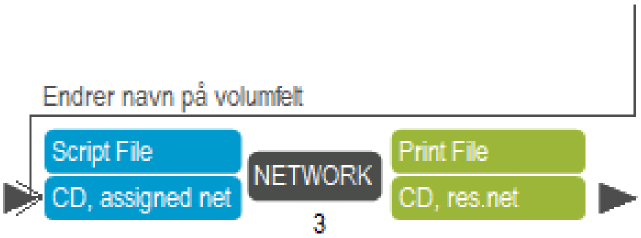

Figure 11-4: Distance-dependent VoT, step 3, operation 3

11.7 Distance-dependent VoT in step 4, traveler benefit module

Benefit calculations are done using the results from the previous step, network assignment. The benefit from projects are calculated based on differences in the cost components for the reference and the project scenario. For the model implemented here, changes in travel time between the zones are considered and giving the benefit.

- Travel volumes for the basis scenario and the project scenario for all zone-relations in the network is stored in travel matrices from the demand model.
- Matrices describing cost components between the zones are calculated in the network assignment step and used as input in the traveler benefit module.
- Total benefit is built up by consumer surplus for the transport users minus correction factors. Consumer surplus is built up by benefit for existing users and benefit for new users of the transport facility. The correction factors are related to the difference between vehicle costs in the model and official vehicle costs. The correction factor is for simplicity neglected in this thesis.

Table 11-5 shows the values for private car used in the traveler benefit module today.

Table 11-5: Traveler benefit module, values CD

NAVN	Work	Service	Leisure
CD	99	444	84
M-long CD	215	444	167
Long, CD	215	444	167

11.8 Step 4 – model structure

The distance-dependent model in step 4 is structured as follows.

Loop indicates that the pilot and matrix in calculation order 2 and 3 are looped through multiple runs. This is done to make it possible to assign different values to the different trip length intervals and travel purposes. The travel purposes work, service and leisure are considered. These three travel purposes all have eight trip length intervals, giving 24 loops in the program. Value of time can therefore be set individually for these 24 loops.

Values of time are given in the script file in the pilot program. The values must be changed in this script and are used in the matrix operation.

The matrix program takes in trip matrices for the basis and project scenario. These matrices give information about travel demand between the different zones for the two selected scenarios. Furthermore, LoS-matrices for the same two scenarios are taken as input. These matrices give value of the travel costs components divided in travel purpose and length segments. Thereafter, the consumer surplus is calculated as described in attachment 2.

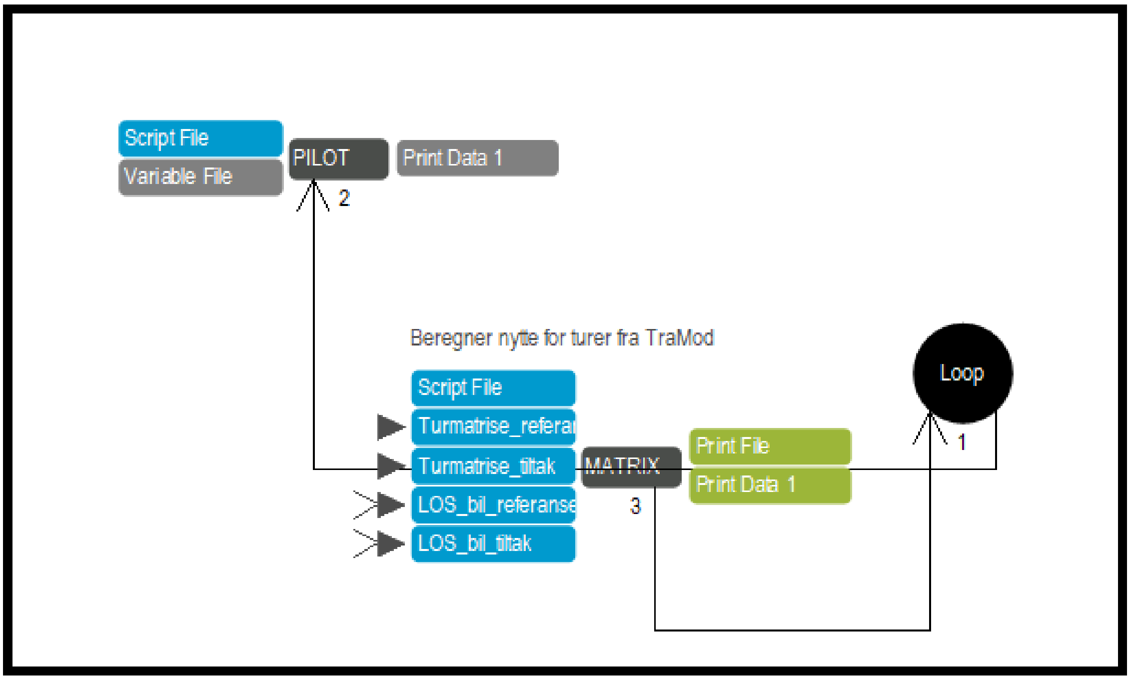

Figure 11-5: Distance-dependent model, Step4, operation1

As for the network assignment step, values for work and leisure trips are varied by trip length. The values are given in Table 11-6. The background for these values are the values used in the models today, as given in Table 11-5. These values (Work=99 NOK/hr and Leisure=84 NOK/hr) are increased in a stepped manner up to the values for these purposes for long trips (Work=215 NOK/hr and Leisure=167 NOK/hr).

Table 11-6: Distance-dependent VoT, step 4

Upper dist. (km)	**Work (NOK/hr)**	**Leisure (NOK/hr)**
10	99	84
20	116	96
30	133	108
40	150	120
50	167	132
60	184	144
70	201	156
70+	215	167

A graphical representation of the values is given in Figure 11-6.

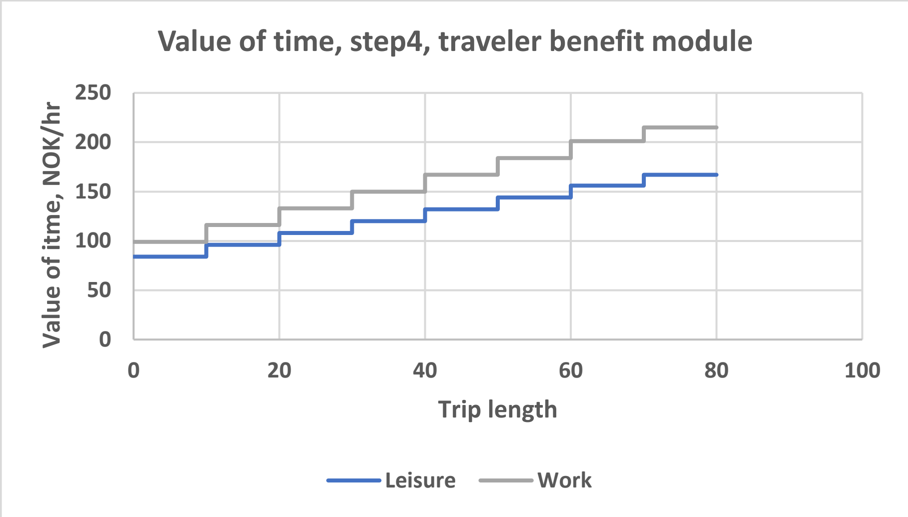

Figure 11-6: Distance-dependent VoT, step 4

Trips from the fixed matrices, those not estimated by the demand model, contribute to the calculated benefit. This contribution is calculated in the matrix operation described Figure 11-7. The input is also here trip volumes for car driver for the two scenarios and corresponding LoS-matrices giving information about the cost components.

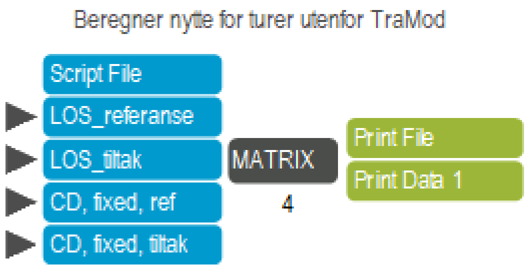

Figure 11-7: Distance-dependent model, step4, operation2

11.9 Analysis of results

Since the trip matrices going into the network assignment is the same independent of value of time, these will be unchanged for all scenarios. This means that the number of travelers in the different travel purposes and trip length segments will be unchanged of VoT in step 3 and 4.

Number of travelers in the segments in the different length segments are interesting to investigate to better the understanding of the trip composition in the network.

For both of the cases, the opening of the new road project tends to increase the number of longer trips, while the number of shorter trips tends to remain at a stable level.

Table 11-7 shows the share of trips estimated by the benefit module, TraMod_by and trips from other. Table 11-8 shows what travel purposes that are included in the two categories.

Table 11-7: Trip distribution, Ytre Ring and Feda-Ålgård

Project	Trips	%-distribution
Ytre Ring, TraMod	501712	90.2 %
Ytre Ring, Other	54750	9.8 %
Ytre Ring, total	556462	
Feda-Ålgård, TraMod	1092293	93.4 %
Feda-Ålgård, Other	76876	6.6 %
Feda-Ålgård, total	1169169	

Table 11-8: TraMod_by and other trips

TraMod_by	Other
To/from work	Education
Service	Airport
Leisure	Freight
	Long trips

11.9.1 E18/E39 - Ytre Ring:

Distribution of trips among travel purposes for the reference scenario for Ytre Ring is presented in Table 11-9. The table shows that most of the trips are either work trips or leisure trips. The other categories are vanishingly small compared to the two categories mentioned.

Table 11-9: Ytre Ring, trip distribution

Travel purpose	Share
Work	20.2 %
Service	7.6 %
Leisure	62.3 %
Education	1.0 %
Airport	1.7 %
Freight	4.2 %
Long trips	3.0 %

When it comes to trip length distribution among the different categories, they vary significantly. In general, most of the trips are located in the shorter segments, as shown in Figure 11-8. This table shows total number of trips in the different intervals up to 70km and one category for trips above 70km. Figure 11-9 shows the trip length distribution for trips estimated by TraMod_by. Both figures show that trips in the shorter segments, and especially in the interval 0-10km dominates the traffic composition.

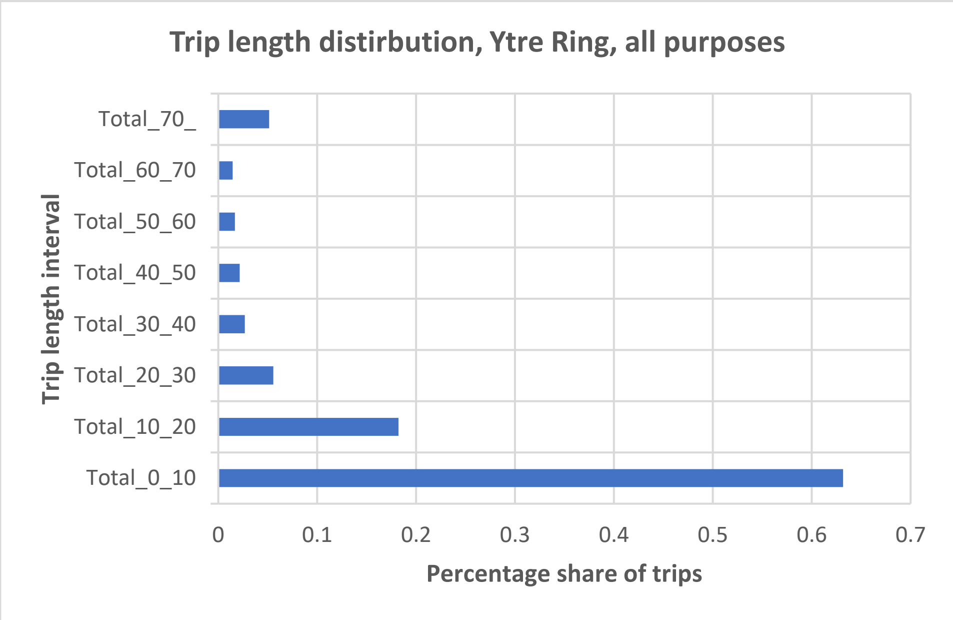

Figure 11-8: Trip length distribution, Ytre Ring, all purposes

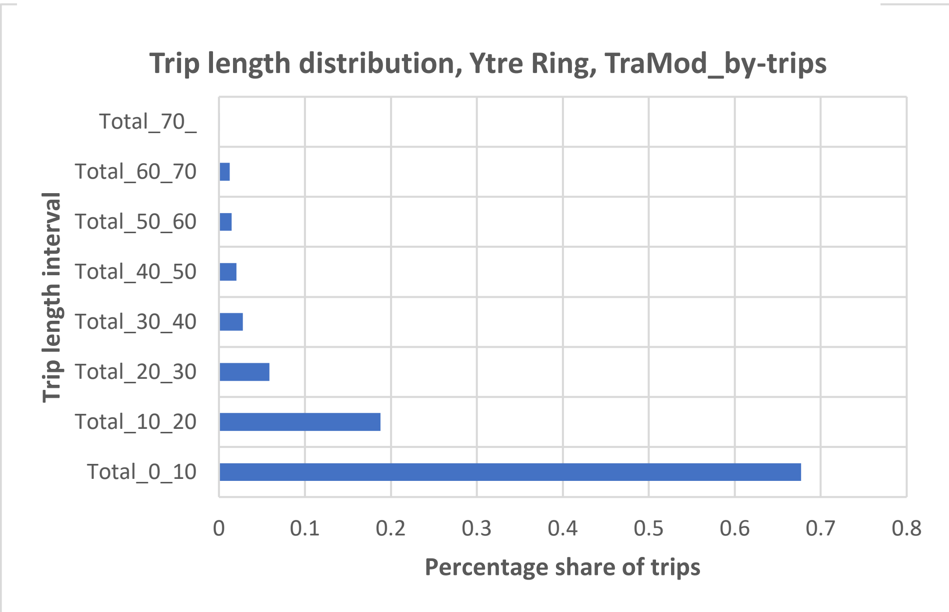

Figure 11-9: Ytre Ring, trip length distribution, TraMod_by-trips

11.9.1 Benefit calculations for Ytre Ring

Table 11-10 gives the results from benefit calculations for Ytre Ring. Benefit from TraMod_by-trips include benefit from work trips, service trips and leisure trips. As previous explained these trips accounted for more than 90% of the total trips in the network. Benefit from the other travel purposes are given as "Benefit other" in the table.

For the project Ytre Ring, it is clear that benefit from TraMod_by-trips account for more than 66% of the benefit in the basis scenario. Scenario 2, where a distance-dependent model is implemented in the network assignment, benefit is on the same level. The increase of 0,01 % indicates that the effects of this is vanishingly small.

Scenario 3, where the distance-dependent model is implemented in the traveler benefit module, cause the calculated benefit to increase more than 26% compared to the basis scenario.

Finally, scenario 4, where the distance-dependent model is implemented in both steps does not increase the calculated benefit significantly.

Table 11-10: Benefit calculations, Ytre Ring

Scenario	Benefit TraMod_by	%change in TraMod_by	Benefit other	Total benefit	% TraMod_by
1	5266576	0.00 %	2649484	7916059	66.53 %
2	5268875	0.04 %	2649484	7918358	66.54 %
3	6662257	26.50 %	2649484	9311740	71.55 %
4	6666112	26.57 %	2649484	9315595	71.56 %

For this project, a distance-dependent model has small effects if it is implemented in the network assignment step. However, if the model is implemented in the traveler benefit module, the effects are significant and shows that such a model will result in more benefit calculated from the project.

11.9.3 E39 Feda-Ålgård:

Distribution of trips among travel purposes for the reference scenario for Feda-Ålgård is presented in **Table 11-11**. As described fur Ytre Ring above, Feda-Ålgård does also mainly have trips in the work and leisure category.

Table 11-11: Feda-Ålgård, trip distribution

Travel purpose	Share
Work	21.5 %
Service	7.8 %
Leisure	64.2 %
Education	1.1 %
Airport	0.9 %
Freight	2.7 %
Long trips	1.9 %

As for Ytre Ring, shorter trips dominate the trip length distribution for Feda-Ålgård. Figure 11-10 and Figure 11-11 present the trip length distribution for Feda-Ålgård, for all purposes and for TraMod_by trips, respectively. More than 60% of the total trips are in the interval 0-10km, and almost 70% of the trips estimated by TraMod_by are in the same interval.

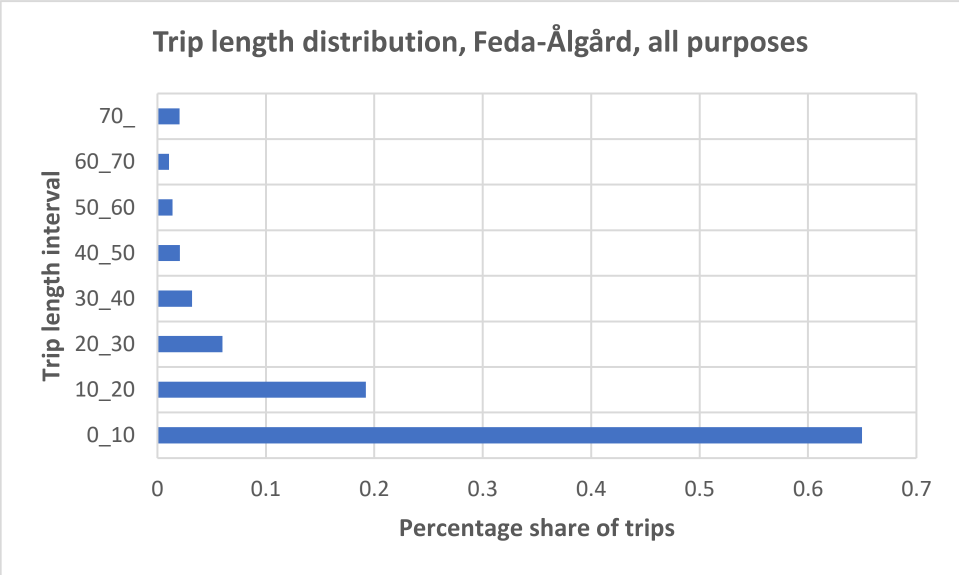

Figure 11-10: Feda-Ålgård, trip length distribution, all purposes

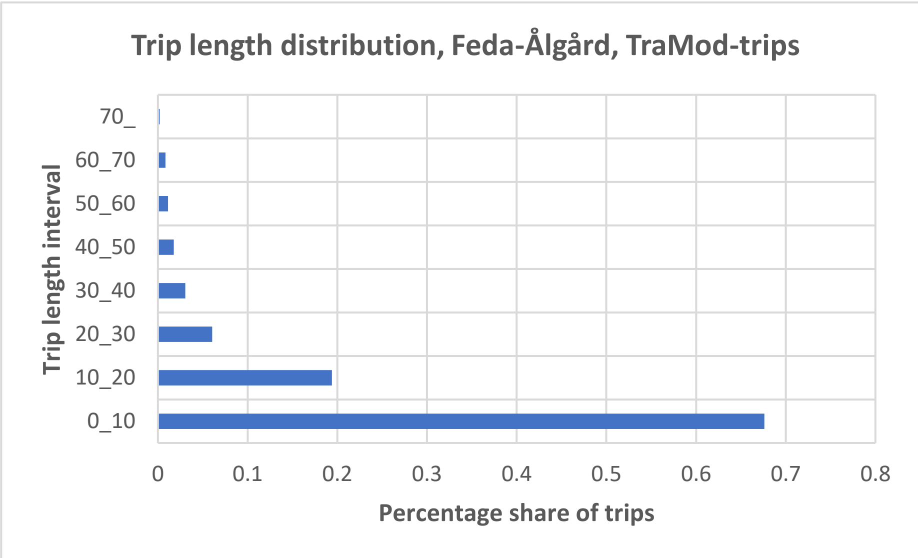

Figure 11-11: Feda-Ålgård, trip length distribution, TraMod-trips

11.9.4 Benefit calculations for Feda-Ålgård

Table 11-12 shows the results from the implementation of the distance-dependent in step 3 and 4 in the model for the project Feda-Ålgård.

For this project, benefit from TraMod_by-trips do not dominate the benefit as was the case for Ytre Ring. Here, calculated contribution to the benefit from TraMod_by-trips is approximately 28% in the basis scenario and increase to approximate 37% when the distance dependent model is implemented in the traveler benefit module.

The table also shows that the implementation of a distance-dependent model in the network assignment step leaves the consumer surplus almost unchanged, an even decreases the benefit from the project.

Table 11-12: Feda-Ålgård, benefit calculations

Scenari o	Benefit TraMod	%change in TraMod	Benefit other	Total benefit	% TraMod
1	12654971	0.000 %	33082948	45737919	27.67 %
2	12649492	-0.043 %	33082948	45732439	27.66 %
3	19783313	56.328 %	33082948	52866260	37.42 %
4	19773945	56.254 %	33082948	52856892	37.41 %

As presented in **Table 9-29**, Ytre Ring have significantly more TraMod_by trips and it is consequently naturally that these trips contribute more to the calculated benefit in this project. For Feda-Ålgård, the situation is different. Traffic composition shows that the share of TraMod_by trips in this model is significantly lower than form Ytre Ring. Therefore, it is naturally that the share of benefit caused by TraMod_by trips is lower for this project.

The implementations of a distance-dependent model in these two steps in RTM shows that:

- Network assignment step is almost unchanged for after the distance-dependent model is implemented. The sensitivity analysis showed similar results and the conclusion is that the RTM model is not sensitive to changes in the input values of time in this calculation step for these two projects.
- The traveler benefit module shows different results. The results are highly dependent on the value of time used in the estimations. As explained in the sensitivity analysis, the sensitivity of the results depends on e.g. project type and traffic composition. This can also be observed for the implementation of the distance-dependent model, meaning how the benefit is affected depends on traffic composition and the share of different trip in the networks.

12 Attachment #8 – Literature Search Strategy

For this master thesis, an extensive literature review has been performed. A great portion of this literature was collected during the pre-study report in the fall semester of 2018. The pre-study report has therefore been important as background data for the work done in the spring semester. However, a lot of the literature has also been collected during this semester, when the scope of the master thesis has been defined in more detail.

The software Mendeley (*Mendeley*, 2018), is a free reference manager and has been used to collect and store all literature used in this paper. This software allows for easy storage of and access to the material and makes the referencing work more efficient.

12.1 Literature search strategy

To collect literature, the following sources have been used:

- Google Scholar: A simple and efficient freely accessible search engine to find several different types of literature.
- Elsevier: A platform including multiple journals relevant for transportation, such as "Journal of Economic Behavior and Organization", "Economic Modeling", "Regional Science and Urban Economics" and "Transportation Research Part A, B, D, E"
- JSTOR: A large database with different journals relevant for transportation research, such as "Journal of Transport Economics and Policy" and "Journal of Political Economy".
- Oria: A search engine that allows for search in the literature in the library of NTNU.

The following keywords/phrases are the main ones used to find relevant literature:

- Transportation
- Value of time
- Value of time in transportation systems
- Value of travel time
- Value of travel time in transportation systems
- Benefit Cost analyses
- Transportation modeling
- Travel time savings
- Value of travel time savings

These keywords have been used individually and in combinations to find relevant literature. Also, large amounts of the literature have been found by looking at the reference list of other papers. When doing this for several papers, key papers in the field are identified.

The literature search strategy used can be described as a qualitative literature search where large quantities of literature has been reviewed and the most relevant has been added to the library in Mendeley. Criteria for relevance is listed in the following:

- Valuation studies from different countries around the world and their estimations of value of time in transportation models.
- Technical documentation of the transport models used in Norway, especially RTM and the implementation in the software Citilabs Cube.
- Literature considering Benefit-Cost Analyses and the different elements included in such analyses.
- Theoretical background for the appraisal procedure used in Norway and the guidelines presented by Statens Vegvesen.
- Literature discussing how value of time varies among different parameters, especially how different travel distances affect the values.
- General literature considering value of time and the importance for Benefit-Cost Analyses.

A flowchart for the literature search strategy is given in figure 12-1 and described below. The layout for the strategy is inspired by Monash University (Monash University, 2019).

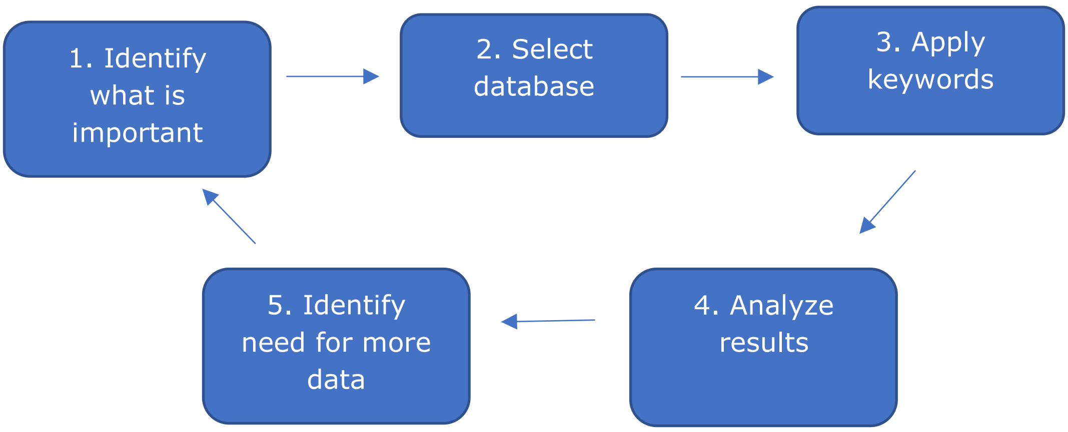

Figure 12-1: Literature search strategy flow chart

1. Identify what aspects that are the most important to collect information about. This is highly related to the research questions and includes relevant background information for the study. Define some relevance criteria, meaning what elements must be satisfied in order to be considered as relevant.
2. Select the database where the search is to be performed.
3. Apply one or more of the keywords to search for relevant information.
4. Analyze the search results. Identify the articles satisfying one or more of the relevance criteria.
5. Identify the need for more information on the topic and possibly the need for new and more specific keywords to find results in better correspondence with the relevance criteria.

The literature search has been an ongoing process throughout the semester and work with this thesis. The process has been important to identify what knowledge is important, what we know today and what knowledge that is needed. The scope of the project and the research questions have been adjusted throughout the process after getting more knowledge and information in the field.

12.2 Bibliography

Mendeley (2018). Available at: https://www.elsevier.com/solutions/mendeley (Accessed: 18 December 2018).

Monash University (2019) *Researching for your literature review: 4. Search strategy*. Available at: https://guides.lib.monash.edu/researching-for-your-literature-review/4 (Accessed: 28 May 2019).

13 Attachment #9 – Limitations

The analyses performed in this thesis are simplified and calculations limited to certain aspects. This is done to narrow down the scope of the study and hence be able to go in depth in the selected topics. Moreover, practical feasibility of the projects also made certain simplifications necessary.

The simplifications have previously been described in the attachments above. However, this attachment provides an overview the most important limitations.

13.1 Simplifications in the sensitivity analysis

The sensitivity analyses are performed for two proposed road projects. These projects have previously been analyzed and this thesis use the previous developed models for the analyses. As transportation models are a simplification of the real world, errors may occur in the models. However, the correctness of the model is not our concern in this thesis, but rather how the model behaves when input parameters are changed.

The transportation models used in the previous analyses of the projects include large amounts of data and variables. Several simplifications have therefore been done in this master thesis. First, the study considers only trips as car driver. The share of these trips in the network is 62% for Ytre Ring and 60% for Feda-Ålgård, as given in attachment 5.

Not including car passenger, freight, public transport, walk and bike trips in the sensitivity analysis will of course lead to errors in the estimates when it comes to calculated benefit. Despite this, since the goal of this thesis is to investigate the changes in calculated benefit because of changes in the input parameters for VoT, this is still possible although not all trips are included. Other travel modes are also included in the analyses, but they are assigned traditional values. These trips will therefore have the same VoT for all scenarios.

Second, traffic assignment is performed independent of capacity. This means that traveling speeds and travel times on the links are not affected by the number of cars on the link. Traffic assignment is performed in one iteration where all trips are assigned to the same route, the one with the lowest generalized costs. If the opposite had been the case, traffic volumes had been assigned in portions and speed on the links had been recalculated between each iteration based on traffic flow on the link. This can cause the route with the lowest GC to change during the assignment procedure.

This second assumption might not be realistic since traffic volumes often will affect travel speeds on links. However, this will vary from project to project and be dependent of project type.

Third, only private user benefit is considered in the traveler benefit module. In the models today, a correction factor is included to adjust for differences in costs in the model and costs experienced in the transport network. For simplicity, this correction factor is not included here.

13.2 Simplifications in the distance-dependent model

The simplifications described above are also valid for the distance-dependent model. In addition, some other simplifications have been done.

Network assignment in the proposed model is performed by considering time only. The existing model use time, distance and direct costs to calculate the total costs of the different route choices and hence decide what route to assign the traffic. For simplicity, traffic is assignment is performed considering time only.

Several travel modes and purposes are included in the models. As previous described, only trips performed as car driver are included. This thesis considers trips estimated by the demand model, more specific work and leisure trips. Table 11-9 and Table 11-11 shows that these two trip purposes make up the most of TraMod_by trips and hence are the two most interesting purposes to investigate. Furthermore, Table 11-7 shows that TraMod_by trips covers more than 90% of the trips in the network and hence dominates the travel purpose distribution.

Although only trips as car driver for the travel purposes work and leisure are considered in the analyses, the other modes are included with the traditional values. This is done to compare the benefit from the new models to the benefit calculated for the other trips using the traditional methods.

14 Summary and conclusion

Transportation analysis includes several different aspects and is important in many situations. The analyses are used as basis for huge project decisions and affects everyone either indirectly or directly. Since these projects often includes the use of huge amounts of public money, it is very important to make sure the decisions are performed objectively and based on a solid decision basis.

As discussed in this thesis, the Benefit-Cost Analysis is used for these purposes today. One fundamental element in these analyses is the valuation of travel time savings and what values that should be used for appraisal. This master thesis considers this fundamental idea.

The overall goal of this master thesis is to bring the modeling procedure closer to reality, meaning closer to the situation experiences by the travelers. By doing this, the models will better replicate the actual transport situation and hence provide a better basis for decision makers. This will again result in better use of public money and make sure money are spent in the most efficient way.

Several decisions have been made during this work. These decisions are related to the different parts of the thesis, described in the attachments above. All the different choices are necessary to narrow down the scope of the thesis and hence be able to go in depth in the selected topics. However, the choices cause some aspects to be left out of the discussion and also bring uncertainty to the table. What aspects that should be considered and what should be left out is debatable and including other aspects in the analyses may change the results. Therefore, it is important to document the analyses, as done in the attachments above, so it is possible to re-do the studies and change certain aspects if needed.

Because of all simplifications and limitations related to the study, drawing conclusions with certainty is not possible. However, the master thesis provides some useful findings and results that can be used in future work in the field. Moreover, the thesis also identifies areas where more research is needed and hence should be considered in the future.

When coming up with new models, one must always ask the questions if the new model is worth implementing. This means, does the model provide new and useful information or does the model consider new topics that should be included in the analysis? If yes, then the model should be included. However, if the answer is no, the model might just lead to more work, more frustration for the model users and more complicated results for decision makers. In this case, the model will not do any good and should not be implemented.

As this master thesis deals with a relatively new phenomenon in the field of transportation analysis, the topic should be investigated in more detail in the future to see the consequences of implementing such models. When this is done, the decision can be drawn whether a similar model should be implemented in the transportation framework or not.

However, based on our current knowledge, retrieved from the analyses performed in this thesis, a distance-dependent model should be implemented in the traveler benefit module. The demand model should be investigated in more detail and implementing a distance-dependent model in this step will most likely affect the estimation results. Based on this, the model should also be implemented in this step.

The two other steps, LoS-calculations and network assignment have shown to be little sensitive to changes in the input parameter and hence such a model in these steps will not cause big changes to the estimation results.

Finally, it is important to take into account that the analyses performed here, and the results presented are based on two projects only. Therefore, before any conclusions are drawn, more cases should be considered to make sure the results are valid for all projects.

Olav Vestøl

The impact of distance-based value of time on transport models and benefit-cost analyses: A Norwegian case study

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