Norway High Speed Rail Assessment Study: Phase III

Model Development Report

Final Report

25 January 2012

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1. Introduction

1.1. Background

Jernbaneverket has been mandated by the Norwegian Ministry of Transport and Communications to assess the issue of High Speed Rail (HSR) lines in Norway. There is a National Transport Plan covering the period from 2010-2019 which includes relatively minor enhancements to the railway network. The ministry wishes to understand if going beyond this and implementing a step change in rail service provision in the form of higher speed concepts could "contribute to obtaining socio-economically efficient and sustainable solutions for a future transport system with increased transport capacity, improved efficiency and accessibility".

Previous studies have been carried out looking into HSR in Norway and there are various conflicting views. The aim of this study is to provide a transparent, robust and evidence based assessment of the costs and benefits of HSR to support investment decisions.

The study has been divided into three phases.

- In Phase I, which was completed in July 2010, the knowledge base that already existed in Norway was collated, including outputs from previous studies. This included the studies that already were conducted for the National Rail Administration and the Ministry of Transport and Communications, but also publicly available studies conducted by various stakeholders, such as Norsk Bane AS, Høyhastighetsringen AS and Coinco North.
- Phase II, which was completed in February 2011, identified a common basis to be used to assess a range of possible interventions on the main rail corridors in Norway, including links to Sweden. The work in Phase II included the development of tools suitable for assessing HSR within Norway.
- In Phase III the tools and guiding principles established in Phase II have been used to test scenarios and alternatives on the different corridors. This has resulted in assessments of alternatives and has enabled recommendations for development and investment strategies in each corridor. With regards to demand and revenue forecasting a number of additional developments have been undertaken to the tools developed during Phase II.

1.2. Purpose of the report

This report is a component of the Phase III work. During Phase II an annex to the Phase II Demand Forecasting report was included providing technical details in developing the forecasting model. This annex builds on the previous annex, including details of further development undertaken during Phase III. This report represents a single document containing the full scope of model development undertaken during both phases, representing the final version of the model.

1.3. Structure of the report

The rest of this report is set out as follows:

Chapter 2 provides a contextual overview of the market analysis contract including its key outputs and challenges. This section also describes the developments undertaken during Phase III, and the requirements for those developments;

Chapter 3 describes the forecasting approach taken and provides an overview of the mode choice modelling structure and the framework within which this sits. The section also describes the model's coverage in terms of its zoning structure and segmentation with relation to modes, markets and time periods.

Chapter 4 gives a detailed description of the key elements of the new model developed for the testing of high speed alternatives. This provides specific details on the modelling framework and the development of the detailed inputs feeding into the mode choice model. In particular this concentrates on the forms and origins of the:

- Demand matrices;

- Generalised cost matrices including station access; and
- Mode choice parameters and equations.

Chapter 5 covers validation and performance of the above model;

Chapter 6 describes the development use of a separate gravity model used to forecast HSR trips of under 100km;

Chapter 7 describes the use of the existing NTM5 model for the testing of Scenarios A and B; and

Chapter 8 presents the report conclusions.

2. Overview

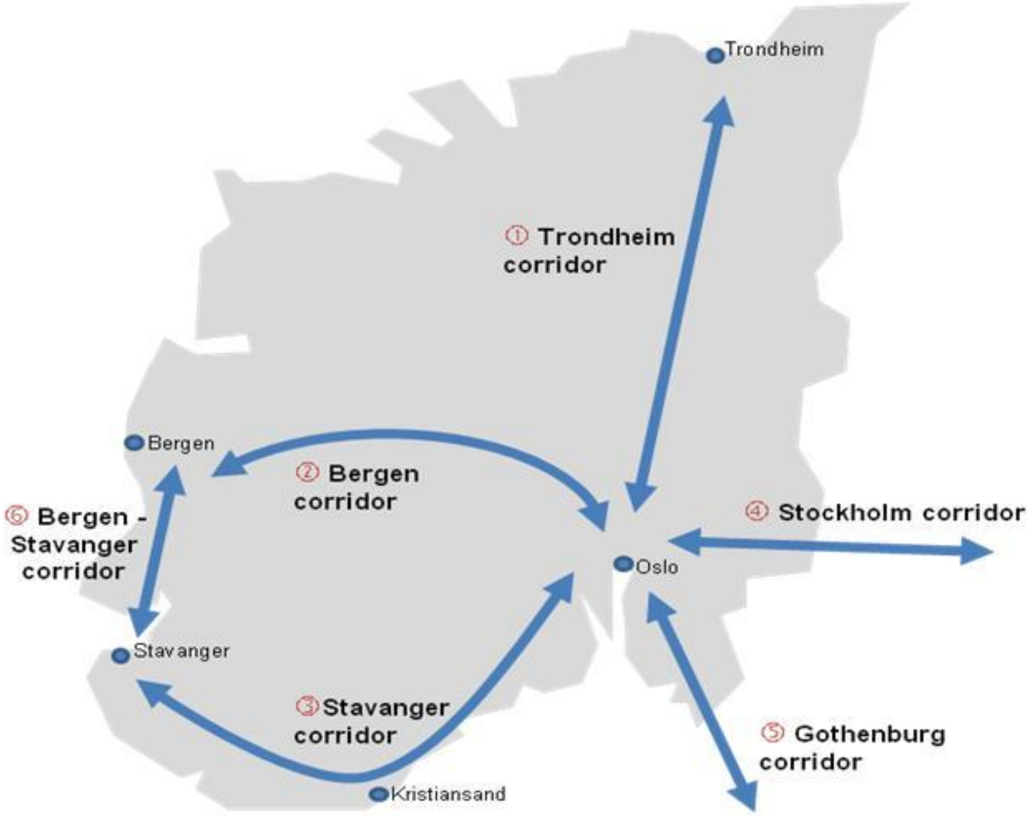
This section explains the context of the market analysis, setting out what the forecasting model must achieve, including its key outputs, and the key modelling challenges, these were previously provided in the Phase II report. The section goes on to describe the changes that were required during Phase III of this study, and details why these additions were required.

2.1. Corridors

Model development and forecasting has concentrated the potential of six high speed corridors identified below and shown in Figure 1:

- Oslo – Bergen;
- Oslo – Kristiansand – Stavanger;
- Oslo – Trondheim;
- Oslo – Gothenburg;
- Oslo – Stockholm; and
- Bergen – Stavanger.

Figure 1. Notional corridors studied (alignments may vary or be combined)



2.2. Key model outputs

In modelling terms, the challenges faced required a wide range of different forecasting options to be addressed. In conjunction with other contracts, alternative assessment will assist in making trade-offs between engineering, environmental and economic costs and benefits. The key range of forecasting outputs required as part of this study included:

- The potential passenger volumes and revenues for different high speed lines in Norway;
- The potential market segments (journey purpose, current mode of travel, for example) within these high speed lines;
- The trade-off between making additional stops to serve residents of intermediate towns, and slowing down journeys between the major cities;
- The sensitivity of demand to changes in high speed rail service frequency; and
- The impact of premium fares on passenger demand and revenues.
- The impact of running multiple service patterns on a potential high speed line (for example an express and a stopping service).

Following on from the main demand considerations in terms of a high speed rail service specification, the contract was then required to analyse the basic factors and extras that are required for passenger to choose a high speed rail service over other means of transport. This includes the following factors:

- Passenger comfort (seating, space, air, light etc.);
- Services on board the train (quiet zones, power points, serving of food and beverages, restrooms, mobile free zones and others);
- Station structure / facilities: Modality and the ability of easy transfer to other means of transport and local transport;
- Personal security on board; and
- Security of and access to personal belongings (luggage racks, luggage rooms etc.)

Finally due to the Norwegian topography, most of the potential corridors will have a high proportion of tunnels. An assessment was required as to how a high proportion of travel through tunnels would impact on passengers' travel preferences.

2.3. Modelling and forecasting challenges

Each analytical challenge required the forecasting approach to include an understanding of, and to take account of, different behaviours associated with the introduction of high speed rail services. Given the required model outputs the market analysis contract had to:

- Develop an understanding of passengers' perception of high speed rail relative to other modes as passengers may inherently prefer some modes to others. The model was required to account for the possibility that, excluding the impact of different passenger income profiles, the value of travel time may vary between modes;
- Accurately forecast the impact of large incremental changes in rail journey times. This required high speed rail to be considered as a 'new mode';
- Consider the separate reactions, and varying behaviour, of passengers travelling for different journey purposes. Currently the mode share of passengers travelling on different journey purposes varies between market segments. The modelling accounts for these differences by incorporating how passengers' willingness to pay for journey time improvements, and how fare structures vary between market segments into the model.
- Be suitable to analyse the impact of numerous timetable related features on passenger demand and revenue. This required an understanding as to how different aspects of timetable related service provision are valued relative to one another. For instance, through incorporation of parameters developed from stated preference analysis, the model is able to offset the impact of an increased service frequency against a reduction of in-vehicle travel time;
- Consider the impact of different station locations on potential passenger demand. The forecasting accounts for the different accessibility levels of alternative station locations through the incorporation of an access model;

- Provide forecasts of generated demand as well as abstraction from existing modes. The model accounts for the levels of suppressed demand for long distance travel in Norway and how much this varies between different market segments.

2.4. Requirements for Phase III model development

Although each of the above analytical challenges was considered in the model as developed at the end of Phase II, it was identified at this stage that further model development was desirable. These requirements are described below, with full details of their development incorporated into the subsequent sections:

- The implementation of a dual nesting structure. During the course of this study the emphasis has evolved from concentrating largely on long-distance end-to-end trips (e.g. Bergen-Oslo) to providing a parallel consideration for intermediate movements (e.g. Bergen-Kongsberg, Kongsberg-Oslo). Having been developed with the longer distance trips in mind this left the Phase II model with weaknesses when forecasting the later type of 'intermediate' movement. In essence the model had been calibrated to provide the best mode choice representation for long distance trips where air travel is available. On a number of intermediate movements, where air was not a feasible option, this was resulting in high speed rail movements being underestimated. During this phase a duel modelling structure has been investigated, and incorporated into the model. This continues to provide an initial mode choice against air on long distance trips however, where air is not a feasible option a second nest is applied providing an initial mode choice against the current rail service.
- Improved data on baseline passenger movements on the Swedish corridors. At the end of Phase II the data incorporated into the base matrices for international trips made by highway or rail was sourced from the TransTools model. Taking the granularity of this model into consideration this data was considered to be less accurate than that incorporated for the domestic Norwegian corridors. During this phase further data from additional sources has been incorporated into the mode choice model. This has primarily been in the form of existing Sampers matrices provided from KTH, Kungliga Tekniska Högskolan,
- An examination into transfer passengers to Gardermoen airport. The Phase II model produced forecasts for the mode shift of transfer passengers to\from Gardermoen airport. However, these forecasts were considered through incorporating transfer passengers into the main 'business' and 'leisure' market segmentation. As transfer passengers accounted for a significant section of the market a separate estimation was investigated considering transfer passengers as a separate market. This was deemed necessary as transfer passengers, by definition, are already planning to make an onwards trip by air. Consequently it was considered that these passengers could have a different perception of the choice between high speed rail and air for their original trip. The results of this investigation found no observable difference in the propensity of transfer passengers to travel by HSR. Consequently transfer passengers continue to be incorporated within the 'business' and 'leisure' market segmentation.
- Functionality to allow for competitive response. The Phase II mode allowed only for scenarios to be tested examining different high speed rail service provision on the corridors. For instance the model allowed high speed alternatives to be selected varying the corridor in question, the stops en-route and the high speed rail journey times, headways and fare. In order to allow for the model to test the impact of a competitive response from other modes (e.g. a reduction in air fares) the Phase III model has been developed to allow for incremental changes to be made to the service provision of other modes. For instance, as an example, this allows for the user to select a percentage change in air fares or a percentage change in car journey times; and
- During Phase III an additional requirement was added to allow for additional routes and potential high speed stations to be considered within the mode choice model.
- The Phase II report also noted that the that the mode choice model only accounts for trips with a total distance of more than 100km. Giving consideration to the alternatives required for testing within Phase III this can understate the market for travel between intermediate stations (although generally these are low revenue trips, with smaller time savings over existing modes.) Consequently during Phase III a separate gravity model has been developed which estimates the number of intermediate trips of less than 100km for a selected HSR alternative. This has been developed as a separate 'stand alone' model; the development and functionality of this model are described in Section 6 of this report.

The remainder of this report updates the original Phase II report to account for the above developments. The aim of this report is to provide a full description of the entire model development leading to the final model, rather than to act a standalone description of Phase III development.

3. Modelling Overview

This section describes the forecasting approach taken and provides an overview of the mode choice modelling structure and the framework within which this sits. The section also describes the model's coverage in terms of its zoning structure and segmentation with relation to modes, markets and time periods.

3.1. Forecasting approach

Having considered the requirements and challenges of the market analysis (outlined in Section 2 above) we evaluated which of the possible technical approaches would be most appropriate. The possible approaches considered and rejected are outlined below, ending with our implemented approach, which is then described in more detail.

We understood that modelling tools used in previous work were subject to some methodological criticism (e.g. TRANSTOOLS and NTM5). Whilst useful in understanding cross-border strategic-level movements (e.g. between Norway and Sweden) the TRANSTOOLS model was considered too strategic to replicate the impact of HSR on local level traffic patterns. Whilst more detailed in its zoning the NTM5 had been criticised in terms of some of its parameter estimation methods e.g. sensitivity to changes in service frequencies. The combined weaknesses of these tools therefore reduce validity in terms of replication of observed traffic patterns, which could have weakened the credibility of any forecasts for high-speed rail.

An option was considered to revisit and strengthen the existing tools (e.g. based on a review of parameter estimation methods). However, based on our experience of high speed rail forecasting it was considered that this would not be as accurate and reliable as a bespoke model framework based on historical station-to-station and airport-to-airport data, and stated preference / willingness to pay surveys. This enables a detailed understanding of current rail travel patterns based on firm data, and accurate representation of station and mode-choice.

Given the challenging timescales, we also considered the possibility of a simple incremental elasticity-based demand forecasting approach (given that the approximate speeds of 200kph considered by the original study are not as fast as some high-speed services currently in operation around the world). This would have been combined with simple mode-share and station access calculations based on surveys and GIS analysis. However, we rejected this approach because elasticities are only reliable for small incremental changes, and existing rail speeds in Norway are some of the slowest in Europe, meaning that an increase to ~200kph is significant.

Based on the above, we have concluded that in order to provide a convincing and objective assessment of the current and future market for high speed rail in Norway in the timescales, the development of a new bespoke framework of tools was required. The adopted framework is spreadsheet and GIS-based and includes the following key elements:

- Detailed demand and travel costs matrices;
- Exogenous and endogenous growth forecasting;
- Logit modelling for mode-choice based on stated preference/willingness to pay surveys; and
- GIS-based station-choice analyses drawing on a simple network model to calculate access times.

Many detailed transport demand modelling studies frequently use route-choice network models to represent the complexities of passenger choices in routing through the network. However, a full network-based routing/assignment has not been considered necessary for this study. Given that the high speed corridors to be assessed limit the number of long distance routings, most variation in routing will be driven by mode and station choice. Consequently, we have developed a simple network model to calculate access times, as described in Section 4 'Model Development'.

As the study has been required to consider the possibilities of incremental development of the existing railway a dual forecasting approach has been developed. This approach uses the bespoke model described above to assess full 'high speed' rail implementation. This model has been supplemented with a separate gravity model which forecasts shorter distance trips where journey are less than 100km, this has been necessitated by the lack of base travel data for trips of less than 100km. NTM5 model has been used to assess the impacts of small scale incremental changes to the conventional rail network. This mixed methodology has been adopted because of reservations about using the NTM5 for modelling large step-change improvements in rail levels of service.

Although not being used for high speed the NTM5 is an established model which has been audited and accepted as broadly suitable, therefore it will be retained for the relatively minor timetable improvements of Scenarios A and B (as defined in the Jernbaneverket presentation of 21.10.10) which represent much smaller improvements in the existing long-distance rail services.

The remainder of this document primarily concentrates on the development of the bespoke model to asses full ‘high speed’ rail implementation. Hereafter this is referred to as the Norwegian High Speed Rail Demand Model (NHSRDM). The methodology and application of NTM5 for assessing the impact of upgrades to classic rail lines is briefly discussed in Section 7 of this report with more detail presented in Appendix B.

3.2. Key features of the NHSRDM

The NHSRDM was been developed with the following features:

- Full mode choice between high speed rail, car, rail and coach for strategic flows across Norway on the basis of the overall utility in the cost of travel by high speed rail;
- Annual demand forecasting (for the years 2018, 2024, 2043 and 2060);
- High Speed Rail annual revenue forecasting (for the years 2018, 2024, 2043 and 2060);
- High speed station choice based on an incorporated accessibility model;
- Different demand responses based on travel for work and non-work purposes; and
- Responses to changes in high speed; journey times, average fares, headways, accessibility and % of time in tunnels.

Developments undertaken in Phase III allow for the incorporation of full mode choice based on incremental changes in the utilities of other modes. This includes options to change:

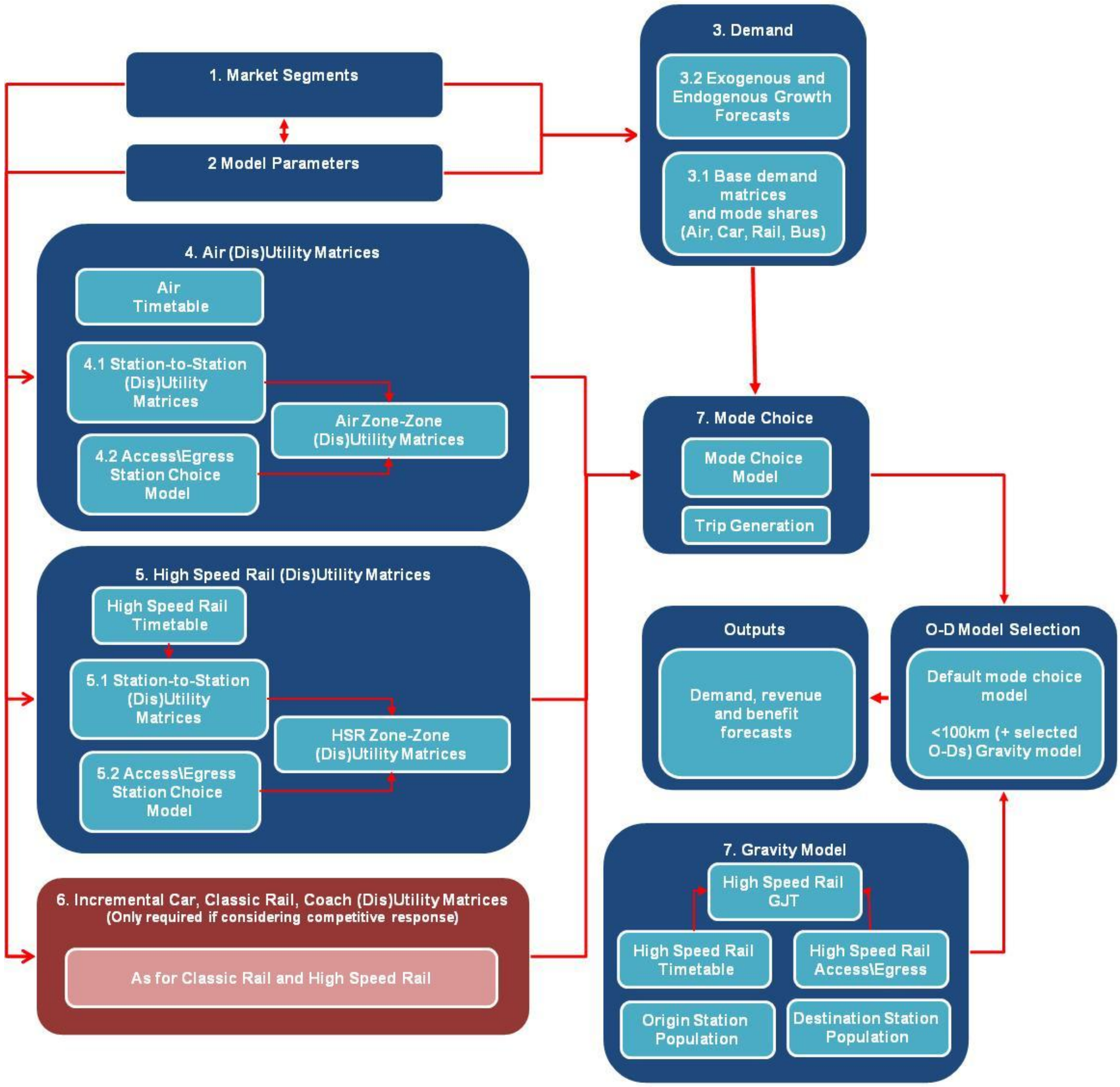
- Air fares and service frequency;
- Classic rail service frequency, fares and journey times;
- Bus service frequency, fares and journey times; and
- Highway fuel costs, toll charges and journey times

The model provides a range of outputs to inform scheme development and decision making as summarised in Appendix E.

As described above the modelling framework includes the key elements of detailed demand and travel costs matrices, exogenous and endogenous growth forecasting and logit modelling for mode-choice based on stated preference/willingness to pay surveys.

Figure 2 below shows how the separate elements fit together in the modelling framework. This includes both a flow chart of the key elements of the NHSRDM and of the gravity model.

Figure 2. Modelling Framework



Section 4 provides a full description of each of the key elements of model construction shown in Figure 2. The remainder of this section provides an overview of the stated preference surveys, mode choice model structure, and the scope of the model.

3.3. Stated preference surveys

The mode choice model is based on the results of stated preference/ willingness to pay surveys designed and undertaken by our partners RAND. The surveys allowed travellers to express their preferences between carefully designed combinations of basic factors influencing choice. By pooling the data across individuals using different existing modes the survey was been used to infer where a high-speed rail service fits in a nested model hierarchy, and to provide the parameters required for assessing mode choice within this hierarchy.

The first experiment from the stated preference surveys presented respondents with a choice between their current mode and new high speed rail alternative and covered:

- fares, in which a range of levels will be presented, facilitating analysis of willingness to pay and the representation of non-linear effects;
- travel time in high-speed rail and extensions;
- high-speed rail frequency;
- access modes and times to reach the high-speed rail system, together with the ease of access at the stations and issues of security in the access stage; and
- any interchanges required during the high-speed rail journey or extensions.

A second experiment within the stated preference surveys covered aspects of the high-speed journey that are of less central importance but nevertheless influential, for example:

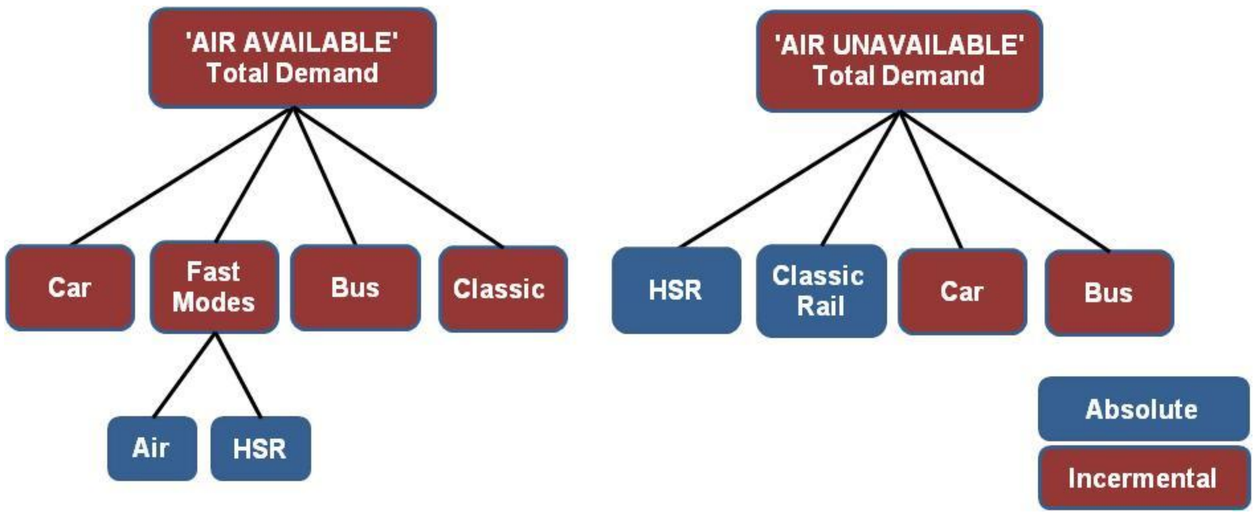
- passenger comfort, including seating space and quality;
- power supply, wifi connection and any other provisions necessary to allow continuous work during the journey;
- other services on board the train, such as provision, delivery and pricing of refreshments; and
- luggage security and access, e.g. in luggage rooms.

The results from this experiment, providing analysis into passenger willingness to pay for different, service related, aspects of the journey, are incorporated into the mode choice model in the form of model parameters. Between any given origin and destination these parameters allow a 'utility of travel' to be calculated for each mode within the model. It should be noted that the model parameters have been revised during Phase III as a result of additional analysis.

3.4. Form and structure

The data from the stated choice experiments have been used to estimate models of mode-choice for work and non-work related travel. Although model parameters are different for each of the above market segments the model structures are the same and take the form of a hierarchical logit model as shown below in Figure 3.

Figure 3. Mode choice structure



As Figure 3.2 shows, the model operates on a dual nesting structure depending on whether air is an existing option for travel. This second structure is utilised within the model when air obtains less than 5% of the air:rail mode share, rather than when air obtains no mode share. This is because the initial structure becomes less reliable when the absolute mode choice is made against a 'marginal' mode where there will be greater uncertainties between the observed mode share and the formulated cost of travel.

The model operates incrementally, i.e. reflecting changes in demand and mode share as a result of changes in modal travel costs. The "test case" represents the impact of the alternative test relative to the "base case" (sometimes described as a reference case or Do-Minimum) network and demand. In this incremental structure the mode shares pivot around the base mode share as a result of changes in generalised costs. To accommodate a new high speed rail mode into this structure, the air\high speed rail sub-nest uses an absolute model. This methodology has also been used in the implementation of the structure where air is unavailable by artificially nesting HSR with classic rail and using a scale parameter of 1.0. This process not only estimates the shift in demand between modes but also estimates induced (generated) demand growth, driven by the composite cost of travel for all modes. This permits generated trips to occur as a result of a step-change in transport services.

The hierarchical structure works such that the modes forming a subset of a category higher in the model are combined to reflect a “composite cost” of choices lower in the hierarchy. This cost calculation starts at the bottom of the hierarchy and works its way up the levels, adding one more choice into the composite cost at each level. Thus the addition of a high speed rail service will reduce the composite cost of ‘fast modes’ which previously only consisted of air travel. Choice calculations are then made down the hierarchy such that with the addition of a high speed rail service the ‘fast modes’ nest will abstract demand from car, classic rail and coach travel. The level of abstraction is dependent of the mode choice sensitivity parameters used at each level.

3.5. Benefits of form and structure

The incremental structure offers the benefits of fully utilising the observed trip matrix so that the complexities of the base matrix are retained in the model. The observed matrix reflects not only the pattern of trip ends and the costs of travel between them, but also the cumulative impact of past travel decisions. It would be very difficult to calibrate an absolute trip distribution model, based on current costs and trip patterns to reproduce the observed pattern of travel. Furthermore the incremental structure would also allow for the base matrix to be updated without altering the forecasting model since the parameters controlling the mechanisms remain independent of the calibration of the base model.

Another major advantage of this structure is that full matrices of the existing levels of service are not required for all alternatives beyond the absolute choice. For these modes only estimates of the existing market shares and proposed changes in modal dis-utilities are required.

At the same time, it should be noted that the joint incremental / absolute mode choice structure does have weaknesses. While it provides a more accurate of mode shift for larger movements – as it reflects the existing observed mode shares – the model can tend to under-predict smaller movements where there few existing movements exist. This has been mitigated using the structure above whereby a dual structure is used nesting high speed rail with classic rail where air travel is not a realistic option for travel.

3.6. Scope of the model

3.6.1. Introduction

The model considers the trade off in demand in long distance journeys between rail, air, bus, car (and for the Bergen-Stavanger route – ferry). Due to the strategic nature of the proposals considered, the model concentrates on the trade off of long distance demand between modes on the whole day level. With relation to generalised cost the time period 06:00-23:59 has been used when considering the frequency and stopping pattern of trains. The model forecasts demand and mode share for the years 2018, 2024, 2043 and 2060.

3.6.2. Model zones

The model is concerned with strategic movements between major urban centres in Norway, plus long distance cross-border travel to/from Sweden. A zoning system was created specifically for this project with the purpose of modelling the movements of passengers under a series of scenarios for potential high speed rail routes.

The zoning system has been designed to have the greatest level of detail in the main Norwegian cities where most of the demand is expected to originate. This allows consideration to be given to the effect on demand of alternative station locations in areas with the highest population densities.

Municipalities with low populations have been grouped into zones with resident populations of over 25k and generally closer to 60k.

In total the model area has 113 zones; this includes 104 area zones within Norway, 8 area zones within Sweden and a ‘point’ zone for Gardermoen Airport. The airport zone was added as a node with zero population, separate from the zone within which it sits. This is due to its status as a vital international gateway, and HSR could abstract significant volumes of domestic air journeys for passengers currently transferring to (long distance) international flights.

The zoning system is described in more detail in ‘TN2 Proposed Zoning System’ which is appended to this document.

3.6.3. Model segmentation

Segmentation is the dividing of the travel market into categories that recognise that travellers with different attributes are likely to display different responses to given market stimuli. For example, a fast rail service charging premium fares may appeal more to well-paid businessmen who currently fly than to family groups looking for a leisure trip who currently use their car. Segmentation within the model development has considered the objectives of the study, model structure, data available and outputs required.

The most important segmentation for long-distance travel is between business and leisure travellers, this has been maintained throughout the model including estimation, base matrices, forecasting and appraisal.

Following SP model estimation the next most important segmentation was found to be on the basis of income. This was both expected on theoretical grounds and has been found in major value-of-time studies. As an example, the average value-of-time for existing air passengers in Norway is higher than the average value-of-time for rail passengers. This is likely to be due to the existing income profiles on each mode; higher income passengers being more likely to pay a premium fare to obtain a faster journey. Consequently income segmentation has been included in the estimation process. This is not explicitly included in the initial implementation of the model as base matrices are not split by income segmentation. However, the income segmentation is accounted for by demand weighting the cost coefficients by income band using data from the Norwegian National Travel Survey[1]; this avoids potential biases that might otherwise have resulted from the survey respondents.

[1] Dataset provided from the Norwegian National Travel Survey, 2005.

4. Model Development

This section gives a description of each of the key elements of model construction including the demand matrices, generalised cost matrices (including station access\egress times) and the model formulation.

4.1. Demand matrices

Early in the project, demand matrices from the NTM5 model were made available to Atkins by TØI and Statens vegvesen (the Norwegian Public Roads Authority) containing daily demand which is annualised by a multiplication of 365. The matrices are based on the Norwegian National Travel Survey, with future changes linked principally to regional population projections. The demand matrices within the NHSRDM Norwegian area zones are based upon the matrices received although they have drawn on additional data reviewed from Avinor and NSB. The eight area zones outside of Norway and the point zone, representing Gardermoen, are not included in the NTM5 matrices. Avinor data has been used to create base matrices for transfer passengers at Gardermoen. During Phase II demand on the Swedish corridors was sourced from TransTools, while during Phase III this was based on Sampers matrices adjusted and calibrated to 2007 and an Intraplan processed matrix for 2005, provided by Kungliga Tekniska Högskolan (KTH). This data allows demand on the Swedish corridors to be analyses to a much finer level of detail and has been used to update matrices on the Swedish corridors during this phase.

This section describes the information provided in the matrices received and the methodology for:

- Converting the NTM5 matrices to the 113 x 113 zoning system;
- Adjustment of rail and air matrices with additional data received;
- Calculating exogenous growth for future years travel demand; and
- Producing matrices between the non-Norwegian area zones and the other zones within the model.

4.1.1. Market segmentation

A total of six full sets of matrices were provided, ranging from 2010 to 2060, with 5 transport modes included in each set:

- Classic rail;
- Air;
- Car driver plus passengers;
- Coach/bus; and
- Ferry.

Segmentation by journey purpose is as follows:

- Business (i.e. work-related);
- Leisure;
- Visits; and
- Other private trips.

As described above in market segmentation the last three (non-work) related journey purposes (listed above) were aggregated together. This maximised the statistical significance of results in estimating the effects on high speed rail demand of variation in fares, journey times and other journey quality attributes by mode.

4.1.2. Trip inclusion

As NTM5 is confined to modelling long distance travel, all journeys between zones with centroids less than 100 kilometres apart are omitted. Given that the proposals for high speed rail are intended to improve services between Norway’s major cities, and to/from Sweden, this absence of data does not present any significant difficulties. However, this does prevent the model from forecasting demand for some movements between intermediate stations where distances are less than 100km. In order to forecast the number of trips of less than 100km made by high speed rail a separate gravity model has been developed. This forecasts demand directly based on the population served by each station and the generalised time between stations under different alternatives. This is discussed in full in Section 6 within this report.

4.1.3. Zoning

Each of the NTM5 demand matrices supplied by TØI has 1428 zones. This is at a much higher granular spatial structure than is optimal for assessing strategic movements between major urban centres.

As explained in Section 3.6.2 above, a zoning structure has been created specifically for this project with the purpose of modelling movements of passengers under a series of scenarios for potential high speed rail routes. The preparation of the demand matrices for all modes involved initial conversion from NTM5's 1428 zones to Atkins' 113 zones. GIS was used to match NTM5 zones to their parent Atkins zones, and then the statistics package SPSS was used to sum NTM5-NTM5 flows into demand between Atkins zones.

4.1.4. Adjustments to NTM5 matrices

As a report by Rekdal (2006)[2] highlighted a few significant deficiencies in the matrices, and in particular with the air matrices, it was decided that data received from Avinor and NSB be used to improve NTM5's air and rail matrices, respectively. This is explained in the next two subsections. However, the NTM5 matrices represent the only data received to date estimating travel between ultimate origins and destinations, rather than between stations or airports; consequently the NTM5 matrices continue to play a key role in the Norway HSR modelling and forecasting.

For air and rail, separate demand data were made available by Avinor and NSB respectively. As these data sets are based on passenger counts and ticket sales on the main high speed rail corridors, it was decided that the NTM5 matrices for 2010 were to be controlled to match, wherever this was possible.

4.1.4.1. Air

For air, Avinor supplied passenger count data for 2009 for the main domestic air corridors, plus Oslo-Stockholm and Oslo-Gothenburg. A division of demand between business, non-business and transfer passengers was applied using summary data from the National Air Travel Survey (NATS).

The Avinor data are summarised in Table 1 as follows:

Table 1. Avinor air passenger journeys (2009)

Flow	Business Travel (k)	Business % (of non-transfers)	Private Travel (k)	Private % (of non-transfers)	Business + Private (k)	Transfers (k)	Transfers - % of total jnys
Gardermoen - Trondheim	560	55%	450	45%	1,010	510	34%
Gardermoen - Bergen	610	60%	410	40%	1,020	465	31%
Gardermoen - Stavanger	495	60%	330	40%	825	395	32%
Gardermoen - Kristiansand	160	71%	65	29%	225	220	49%
Stavanger-Bergen	280	71%	115	29%	395	105	21%
Gardermoen – Gothenburg	21	91%	2	9%	23	1	4%
Gardermoen - Stockholm	335	63%	195	37%	530	170	24%

In addition to the above flows adjustments have also considered flows to/from the Oslo area via Sandefjord Airport, Torp, which is the largest commercial airport in Norway not owned by the state through Avinor.

[2] *'Evaluation of the Norwegian long distance transport model (NTM5):Main report'*

Compared to Gardermoen domestic arrivals/departures at Torp are relatively minor (<5% of Gardermoen demand). They have also considered domestic air trips via Haugesund.

For the flows entirely within Norway, the air demand estimated by NTM5 for 2010 was controlled to the corresponding Avinor total shown in Table 2 using the following methodology.

- Catchment areas for each of the airports were estimated using access times within the models level of service. A zone is associated to the closest airport in terms of drive time.
- The catchment areas were combined to estimate airport-airport journeys in NTM5, retaining NTM5's journey purpose division and its distribution between zones.
- Summing across journey purposes, the airport-airport flows in NTM5 were matched to the corresponding Avinor total for 2009.

Table 2. Adjustment factors applied to NTM5 matrices

Avinor (2009 actual) / NTM5 (2010)	Non-Business	Business
Oslo - Trondheim	1.40	0.93
Oslo - Bergen	1.31	0.73
Oslo - Stavanger	1.81	0.78
Oslo - Kristiansand	0.68	0.73
Stavanger- Bergen	1.92	1.07
Oslo -Haugesund	1.12	0.89
Sum	**1.14**	**0.90**

NB: A figure of 1.05 indicates that the Avinor flow is 5% higher than the corresponding NTM5 figure.

The adjustments applied to the NTM5 air matrices are summarised in Table 2. The figures for Kristiansand – Oslo confirm the assertion by Rekdal (2006) that 'there seems to be too many short trips by air' (page 4).

Finally, it should be noted that the passenger count data supplied by Avinor does not allow a division of journeys between those produced in Oslo (i.e. trips by Oslo residents) and trips produced in the other cities. As future demand growth is based on NTM5 matrices (Section 4.1.5) this division is not essential to the main forecasting exercise or the HSR business case.

4.1.4.2. Rail

The rail journey data supplied by NSB was a subset of the matrix NSB uses in its transport model for the long distance market in Norway. The data supplied remains confidential, so we are unable to publish flows within this report. The axes of the matrix are station zones (see below) and each cell contains annual origin-destination journeys summed across all travel purposes and ticket types, and without separation of trips produced and trips attracted. Journeys of less than 100km are not included.

NSB has produced the matrix from ticket sales data, supplemented by passenger counts. As such, it represents the most accurate and detailed source of current long distance rail demand data for Norway.

In controlling the NTM5 rail matrices to the NSB data, a similar approach was adopted to that for the air matrices using the Avinor data, as outlined above. That is, the NTM5-based rail demand matrices were initially re-grouped to match NSB's station groupings. Then, uplift factors were calculated for each NSB-NSB zone pairing to be applied to the corresponding cells in the NTM5-based matrices. These factors were estimated on the basis of the ratio of NSB demand to NTM5 demand (i.e. after summing across the NTM5 journey purposes).

In summary, NTM5 is used to distribute station-to-station journeys between flows, and to divide by journey purpose, whilst the total rail journey volumes are determined by the NSB data.

The names of the 27 NSB station groupings are listed below.

1. Arendal
2. Arna
3. Asker
4. Bergen
5. Bryne
6. Drammen
7. Egersund
8. Fredrikstad
9. Hamar
10. Kongsberg
11. Kristiansand
12. Levanger
13. Lillehammer
14. Lillestrøm
15. Lysaker
16. Mandal
17. Mosjøen
18. Moss
19. Oslo S
20. Ski
21. Skien
22. Stavanger
23. Steinkjer
24. Stjørdal
25. Tønsberg
26. Trondheim
27. Voss

4.1.5. Exogenous growth

In the absence of detailed information on forecasting parameters by mode, it was decided to use the future year matrices from NTM5. The NTM5 matrices were provided for the following years: 2010; 2014; 2018; 2024; 2043; and 2060. The first forecast year used in the modelling is 2024 which is the assumed opening date. Meanwhile the final year, 2060, allows for demand growth throughout a 40 year appraisal period.

Correspondence with TØI has revealed that the NTM5 future year matrices are based on national data for economic growth, and regional data for population. In addition, income elasticities are not inputs to NTM5, but can be derived from the model for each mode, with the indirect effect of changes in car ownership exerting a significant effect.

As noted elsewhere, the NTM5 'Do Minimum' future year matrices allow for a number of improvements to the road and rail networks, based mainly on the Norwegian National Transport Plan (2010-2019). For rail, the timetable improvements are predominantly associated with provision of double track, mostly in the intercity network around Oslo. The road and rail enhancements assumed to be delivered in the NTM5 Do-Minimum future year matrices are listed in TN6 Scenarios Testing Note.

Although the use of NTM5 future year matrices was not envisaged at the outset of work, this approach ensures maximum compatibility of the Do Minimum growth forecasts in the HSR assessment with the appraisal of other Norwegian transport schemes. Finally, it is worth emphasising that reservations about NTM5 matrices aired by NSB and Statens Vegvesen, primarily concern the scale of long-distance car journeys in the base year (2010), rather than any doubts about the methodology underlying future year growth.

4.1.6. Sweden\Norway international demand

International journeys are not included in the NTM5 matrices and have been added to the NHSRDM from other sources. The volume of passengers between Norway and each area zone within Sweden has been taken from the Sampers model incorporating demand into the six area zones within Sweden.

As for domestic trips sourced from the NTM5 base matrices the cross border trips have been adjusted to match direct count data on major flows where available. Adjustments have included:

- total air flows between Stockholm and Oslo using Avinor count data; and
- total car, bus, air, rail flows between Gothenburg and Oslo using totals quoted in 'Kollektivtrafik Goteborg Oslo Regionen', Sweco 2007.

Distribution of these trips within Norway is assumed to be proportional to the overall distribution taken from the NTM5 matrices. For use in this study Sampers matrices have been received for 2007. Trip rates have been adjusted using national Swedish growth to 2010 with average growth from the NTM5 matrices applied beyond this point.

4.1.7. Gardermoen air transfer passengers

As with international travel, transfer passengers are not accounted for in the NTM5 matrices and have been added to the NHSRDM matrices from other sources. The volumes of transfer passengers to Gardermoen from the other major Norwegian airports are based on Avinor passenger counts in 2009. The distribution of these trips between the zones within the catchment areas of the airports at Bergen, Trondheim, Stavanger and Kristiansand airports uses Avinor survey data, with the assumption that the pattern of airport access (i.e. the places of residence) of transfer passengers reflects that of those making non-transfer trips.

The model allows for passenger to use all transfer passengers destined for Gardermoen station to use high speed rail. This is achieved through interchange in Oslo onto the airport express train.

It is assumed that 'Do Minimum' growth in transfer journeys to/from Gardermoen is 2.1% per annum; i.e. the same rate applied by Avinor when forecasting non-transfer domestic air travel.

4.2. Utility of travel

4.2.1. Introduction

The underlying principle in disaggregate demand models is that of discrete choice. In summary this means that individuals make their travel choices out of a finite number of discrete alternatives, each with their own utility or level of service. The utility combines the various features of each alternative to give one measure of utility which is consistent across all the alternatives within the set of choices available. With regards to travel, utility includes elements such as travel time and distance, but can also include other quantifiable elements such as the ability to make a return journey in one day, or even qualitative elements relating to service quality. As the components of travel are perceived as a cost the combined valuation is negative, giving a disutility of travel.

The valuation or perception of a utility is affected by the characteristics of each traveller. Consequently demand is segmented as described in Section 3.6.3 to allocate passengers into segments having a similar perception of utilities.

The concept of utility assumes that there is a method for combining the various features of all the alternatives to give one measure of utility which is consistent across all the alternatives within a set of choices. The general formulation for this is:

$$V_p = \sum_n \beta_n x_n + \varepsilon_p$$

Where the utility V_p of choice p is calculated as the sum of the set of cost components x_n weighted by coefficients β_n plus a constant component ε_p used to represent variations in the situation or tastes of individual travellers or unobserved elements of the alternative choices.

4.2.2. Formulation of utility

For the NHSRDM the methodology for combining the set of cost components is provided by the models estimated from the SP surveys as shown in Section 4.4. The specific formula used to calculate the cost utility of each mode is identical to that presented as the end of Phase II and is as follows:

4.2.2.1.1. High Speed Rail

$$U_{HSR} = \beta_c C + Log(\beta_{lc} C) + \beta_t T + \beta_a A + \beta_w W + \beta_u U + \beta_s \frac{1}{S} + \beta_i I + \beta_r + \varepsilon_p$$

Where:

- U_{HSR} is the high speed rail utility
- C is the total cost of the journey
- β_c is the cost coefficient
- βl_c is the log cost coefficient

- T is the time spent in the train
- β_t is the in-vehicle time cost coefficient for high speed rail
- A is the access\egress time from the ultimate origin/destination from/to the rail stations
- β_c is the access\egress time coefficent
- W is the time spent waiting
- β_w is the wait time coefficent
- U is the % of time spend in tunnels
- β_u is the tunnel coefficient
- S is the number of high speed services in each day
- β_s is the frequency coefficient
- I is the number of interchanges required
- $\beta_i$is the interchange coefficient
- $\beta_r$is the coefficient applied if a return journey can be made within 6 hours
- ε_p is the alternate specific constant of HSR compared to air

4.2.2.1.2. Air

$$U_{Air} = \beta_c C + Log(\beta_{lc} C) + \beta_t T + \beta_s \frac{1}{S} + \beta_r$$

Where:

- U_{air} is the air utility
- C is the total cost of the journey
- β_c is the cost coefficient
- βl_c is the log cost coefficient
- T is the time spent travelling door-to-door
- β_t is the door-to-door travel time co-efficient for air
- S is the number of flights per day
- β_s is the frequency coefficient
- $\beta_r$is the coefficient applied if a return journey can be made within 6 hours

Examples of the calculated difference in utility of air and high speed rail travel broken down into their constituent parts between different zones are shown in Appendix A of this document. These cover a range of origins and destinations with varying levels of accessibility to high speed rail and air and show how the constituent parts of utility varies between origins and destinations and how this impacts on the air-HSR mode split.

The mode choice model assesses the impact of introducing high speed rail through an incremental model following an absolute mode choice with air, or with classic rail where air travel is not a realistic option between a given origin and destination. The default within the model is that the present service levels of other modes remains unchanged from the levels assumed in the base matrices. However, the model structure allows for universal percentage changes in the following aspects of other modes service levels:

- Air: fares and service frequency;
- Classic Rail: fares, service frequency and journey time;
- Bus: fares, service frequency and journey time;
- Car: journey time, fuel cost and toll charges.

The above functionality allows the impact of a competitive response from other modes to be tested (e.g. reduced air fares). Where modes are assessed for incremental changes only full utilities are not calculated but only the incremental change due to the selected scenario. These are based on: base levels of service extracted from NTM5, the model parameters shown in Table 4 and the following formulations:

4.2.2.2. Classic Rail

$$U_{CR} = \beta_c C + Log(\beta_{lc} C) + \beta_t T + \beta_a A + \beta_w W + \beta_u U + \beta_s \frac{1}{S} + \beta_i I + \beta_r + \varepsilon_p$$

Where:

- U_{CR} is the classic rail utility
- C is the total cost of the journey
- β_c is the cost coefficient
- βl_c is the log cost coefficient
- T is the time spent in the train
- β_t is the in-vehicle time cost coefficient for classic rail
- A is the access\egress time from the ultimate origin/destination from/to the rail stations
- β_c is the access\egress time coefficent
- W is the time spent waiting
- β_w is the wait time coefficent
- S is the number of classic rail services in each day
- β_s is the frequency coefficient
- I is the number of interchanges required
- $\beta_i$is the interchange coefficient
- $\beta_r$is the coefficient applied if a return journey can be made within 6 hours

4.2.2.3. Bus

$$U_{Bus} = \beta_c C+Log(\beta_{lc}C)+\beta_t T+\beta_a A+\beta_w W+\beta_u U+\beta_s \frac{1}{S}+\beta_i I+\beta_r+\varepsilon_p$$

Where:

- U_{Bus} is the bus utility
- C is the total cost of the journey
- β_c is the cost coefficient
- βl_c is the log cost coefficient
- T is the time spent in the bus
- β_t is the in-vehicle time cost coefficient for the bus
- A is the access\egress time from the ultimate origin/destination
- β_c is the access\egress time coefficent
- W is the time spent waiting
- β_w is the wait time coefficent
- S is the number of bus services in each day
- β_s is the frequency coefficient
- I is the number of interchanges required
- $\beta_i$is the interchange coefficient
- $\beta_r$is the coefficient applied if a return journey can be made within 6 hours

4.2.2.3.1. Car

$$U_{Car} = \beta_c C+Log(\beta_{lc}C)+\beta_t T$$

Where:

- U_{Car} is the car utility
- C is the total cost of the car journey, accounting for occupancy
- β_c is the cost coefficient
- βl_c is the log cost coefficient
- T is the time spent in the car
- β_t is the in-vehicle time cost coefficient for car travel
- $\beta_r$is the coefficient applied if a return journey can be made within 6 hours

The model considers the level of service (or utility). In the context of mode choice the convention is to reinterpret the utility as a ‘generalised cost’. The method to convert the utility into a generalised cost in minutes is given by dividing the utility by both the nest coefficient θ and the marginal utility of time.

4.2.3. Origin-Destination utility

The spreadsheet model includes an estimation process for the utility for high speed rail and air using the formulas above. Given that the possible high-speed corridors to be assessed limit the number of long-distance routings the model does not include a full network-based routing assignment. The routing is considered within a zone by considering the station access times. The access and egress components of utility have come from a separate access\egress station choice model (for which results are incorporated into the NHSRDM). Access times to\from each zone and any given station have been calculated using a network accessibility model. This has been developed as follows:

- A skeleton highway transport network has been produced within GIS based upon the existing highway infrastructure, as provided by the Client. Using this network a shortest path (uncongested) isochrones layer has been produced for each station (existing and proposed) examining access time in 5 minute intervals.
- This isochrones layer has been overlaid onto population data (available in 1km squares).
- The above has been used to produce the population weighted average access time (and therefore accessibility) between each zone and station location.

Consequently the access\egress times calculated in the model are based upon highway access times. To date base matrices supplied do not allow for segregation into car-available and non-car available passengers, therefore full incorporation of access\egress times by public transport is not possible. The full incorporation of public transport access is likely to have a limited effect on the model as public transport is likely to be used for shorter access trips only.

The access times to\from each zone to any given station\airport have been incorporated into the mode choice model. For alternative station selections this allows the model to select the nearest station from any given zone (in terms of access time). The total utility for each mode and O-D movement is then calculated within the model by summing the utilities associated with both the access\egress and the station to station components of any given journey.

4.2.3.1. High Speed Rail

With regards to high speed rail the model contains an automated procedure to regenerate the utility matrix for a selected high speed scenario. This allows the cost matrices for a high speed scenario to be generated based on selected:

- Corridors;
- Stopping patterns;
- Journey times;
- Headways; and
- Average Fares (based on a % of the existing air fare)

The incorporation of the access model redefines the high speed station catchment areas depending on the full set of stations selected (e.g. passengers will be routed to their nearest high speed station when considering high speed mode share). The take up within this catchment area is modelled using the calculated (dis)utility of travel, therefore where a zone is remote to its nearest high speed station, and closer to alternative modes, the high speed mode share will be restrained by the comparatively larger access time for high speed rail.

- The model contains three options for calculating high speed rail journey times, which are:
- An option to automatically generate journey times using a simplified model based on line speeds and a time penalty incurred per high speed stop;
- An option to manually enter journey times and service frequencies for a single high speed service; and
- A rooftop model which creates a single representative journey time and headway from up to three separate high speed services, each having multiple departure times. This enables demand and revenue to be assessed for combinations of high speed services within the mode choice model which assumes an 18-hour period of operation. The full functioning and purpose of the rooftop model is described in Appendix D Multiple high speed service patterns – the rooftop model.

4.2.3.2. Air

The air (dis)utilities matrix is currently fixed and considers domestic (plus Stockholm\Gothenburg) journeys that can be made directly without interlining. This has captured air demand which is within the scope of the high speed corridors under consideration. The level of direct service between Norway's primary airports has considered movements between:

- Oslo / Gardermoen;
- Bergen / Flesland;
- Stavanger / Sola;
- Trondheim / Værnes;
- Kristiansand / Kjevik;
- Haugesund / Karmøy;
- Sandefjord / Torp;
- Tromsø;
- Bodø;
- Alta;
- Ålesund / Vigra;
- Molde / Årø;
- Kristiansund / Kvernberget;
- Stockholm; and
- Gothenburg.

The primary airports at Harstad, Kirkenes and Bardufoss are within large zones in Northern Norway containing other primary airports. These areas are largely out of scope for the high speed rail corridors considered. These airports are represented by Bodø, Alta and Tromsø airports respectively.

4.2.3.3. Supply

The following sources have been used to provide the absolute level of service (utility) for classic rail, air and high speed rail. Due to the incremental implementation of mode choice the absolute utilities of other modes are not required for the operation of the model. Their relative utilities are reflected in the existing mode share between each origin and destination. Incremental changes are calculated using the model parameters shown in Table 4, and base levels of service extracted from the NTM5.

Table 3. Components of utility

	Classic Rail	Air	HSR
Journey Time	Extracted from NTM5	Extracted on a airport to airport basis from NTM5	Variable by scenario tests (Target journey times are provided in TN6 Scenarios testing note)
Headway\Service Frequency	Extracted from NTM5	Extracted on a airport to airport basis from NTM5	Variable by scenario tests
Average Fare	Extracted from NTM5	Average fares (2009) were provided by Avinor on major movements for business and leisure passengers (fares were interpolated from the above on minor movements using distance as an indicator of air fare)	Variable by scenario tests (set separately as an average fare for business and leisure passengers based on x% of average air fare)
Headway\Service Frequency	Extracted from NTM5	Extracted on a airport to airport basis from NTM5	Variable by scenario tests
Wait Time	Average wait time as stated in the SP surveys	Average wait time as stated in the SP surveys	Average wait time as stated for 'classic rail' in the SP surveys
Parking Charge	Average parking charges are not explicitly modelled and are assumed to be equal between airports and HSR stations		
Station-Station Distance[3]	n/a	Cartesian Distance	Approximate route km from basic GIS mapping
Station Access\Egress Time	Population weighted average access time calculated using a network accessibility model. (Access times of over 120 minutes, the extent covered in the SP surveys, have been weighted by 1.5)		
Station Access\Egress Distance	Derived from the access time above – considering an average access speed of 40kph.		
Station Access\Egress Cost	Fuel cost of 0.27NOK per km[4] adjusted to 2009 prices		

As stated in Table 3 above high speed rail fares are selected as a variable set separately as an average fare for business and leisure passengers based on x% of an average air fare. Although this is true of the model implementation it is a simplification in terms of methodology. The potential scenarios which can be tested for high speed rail alternatives include many alternatives which cannot be made by air and thus have no comparable air fare. Consequently where a movement directly corresponds to an available air movement the fare is set as a percentage of this figure. Where no corresponding air movement is available a formula is applied correlating existing air fares to distance, and this result is then factored by the selected percentage. The relationship is non-linear with shorter distance trips costing more per km than longer trips. The formula representing this relationship is taken such that the fare in NOK equals:

- $-0.00137km^2+2.61107km$ for business trips; and
- $-0.00102km^2+1.74783km$ for leisure trips.

As a general, simplified, rule a fare of approximately 60% of the average existing air fare has been found to roughly correspond to an average existing rail fare. Additionally with regards to HSR fares a rule has been applied to set a minimum fare of 100NOK multiplied by the % of air fare selected (thus if the % air fare is set to 60% the minimum HSR fare will be 60NOK regardless of distance). This assumption is consistent with the fares on the existing rail network.

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[3] Distance is not directly used for mode choice calculations although is used to estimate average air fares by journey purpose where no fare has been provided, and to provide changes in passenger km for appraisal
[4] TØI report 797/2005, Transport Cost-Benefit Analysis:Parameters, Unit Costs and Indices

4.3. Model formulation

Faced with a choice between alternative modes of transport the modelling approach assumes that a passenger would find out the value of each attribute (e.g. cost, in vehicle time, walk time, wait time) and add them so as to calculate the utility for each mode of transport. The passenger would then choose to travel on the mode with lowest (dis)utility[5]. Where more than one passenger is considered it is necessary to consider the mathematical form of the choice model. In the NHSRDM this is implemented through the logit formulations shown in the remainder of this section.

4.3.1. Absolute mode choice

For the bottom nest of the model, where each mode has a full level of service, the split in demand is calculated using the following formula:

$$p_{m|n} = \frac{expV_m}{\sum_{k \in n} expV_k}$$

Where:

- V is the measured utility, which we have for all modes in the nest; and
- k in the summation runs over all the modes in the nest n.

4.3.2. Incremental mode choice

For the subsequent nests, where each mode has an existing demand, an incremental mode choice formulation is used (whether or not a full level of service is available for each mode). Because HSR is nested with other modes at this level we have a non-zero value for p_n^0 in each nest. At this level mode choice is calculated using the following formula:

$$p_n = \frac{p_n^0 exp\theta\Delta V_n}{\sum_h p_h^0 exp\theta\Delta V_h}$$

where

- p_n^0 indicates the base probability of choosing mode or nest n;
- θ is the nest coefficient;
- h in the summation runs over all the modes attached to the root of the tree and
- ΔV is the change in measured utility.

4.3.3. Composite cost

Where modes at one level are nested further up the mode choice hierarchy the formulation of the composite cost is used to reflect the costs faced by travellers given their previous choices lower in the hierarchy. The formulation for composite cost is as follows:

$$\Delta V_n = log(\sum_{k \in n} expV_k) - log(\sum_{k \in n} expV_k^0)$$

Where:

- V_k^0 is the base level of service for each mode

The change in overall utility (needed for appraisal) and trip generation is:

$$\Delta V_{tot} = log(\sum_h p_h^0 exp\theta\Delta V_h).$$

4.3.4. Generated demand

The provision of a HSR service is likely to increase the total traffic between two cities that are served. This increase would arise from an increased frequency of travel by those already travelling between those cities and from the establishment of new work and non-work connections because of the improved accessibility.

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[5] Time and cost are perceived as negative to a passenger

Increased travel frequency can add significantly to the traffic on an improved connection[6]. It is clearly important that this component should be included in a business case for HSR, as the improvement in accessibility can be quite large and the increase in travel correspondingly significant.

Frequency models can be quite simple, predicting an increase in travel as a function of increase in accessibility. An attractive model in this context is the exponential

- $T_{ij} = T_j \exp(\alpha.\Delta A)$

giving the increased trip-making as a function of the increase ΔA in accessibility. In this context, if accessibility is measured by a logsum, as described in section 4.3.3 above, it can be shown that the model has a number of attractive properties consistent with a utility maximisation framework.[7] Moreover, in that framework the parameter α has a specific interpretation, as the ratio of sensitivity of the frequency model to the next 'lower' model in the system, which means that a consistency of values across different studies might be expected. Given the above a default factor of 1/3 is applied to the framework parameter α based on experience in other studies.

As with many models of the type we are constructing the model does not predict explicitly any changes in destination choice that might arise from the provision of HSR. Therefore forecasts will indicate an increase in travel between the city pairs served although will not predict a corresponding decrease in the alternative destinations that are visited less.

4.4. Mode choice parameters

4.4.1. Estimation results

A full description of the SP methodology can be found in 'Contract 5: Market Analysis, Subjects 2 and 3: Expected Revenue and Passenger Choices', with additional analysis conducted during Phase III being contained in Appendix F of this report. This section of the model development report presents the model developed for implementation which itself was simplified from a more complex estimation as described in the above report. The model determines the contributing attributes to utility, and the coefficients, as presented in the formulae for the disutility of travel in section 4.2.2.

[6] See Møller, L., Wätjen, W., Pedersen, K.S., Daly, A.J. (1999) Traffiken på Storebælt (Traffic across the Great Belt, published in Danish), Dansk Vejtidsskrift; (1999) Traffic across the Great Belt, English translation presented to International Road Federation regional conference, Lahti, Finland.
[7] See Daly, A. and Miller, S. (2006) Advances in modelling traffic generation, presented to European Transport Conference, Strasbourg.

Table 4. Estimation results

	Description	Air Available Coefficients		Air Un-available Coefficients	
		Work	Non-Work	Work	Non-Work
Cost (NOK)	HH income below 800,000 NOK	-0.000947	n/a	-0.000611	n/a
	HH income 800,000 - 1,199,999 NOK	-0.000891	n/a	-0.000575	n/a
	HH income more than 1,199,999 NOK	-0.000719	n/a	-0.000464	n/a
	HH income below 200,000 NOK	n/a	-0.0017	n/a	-0.00115
	HH income 200,000 NOK or more	n/a	-0.00114	n/a	-0.00077
Log Cost (NOK)	All respondents	-0.904	-1.51	-0.583	-1.02
In-vehicle time (mins)	Car	-0.00447	-0.0013	-0.00288	-0.000882
	Air (door to door travel time)	-0.00795	-0.00711	-0.00513	-0.0048
	Bus	-0.00812	-0.00616	-0.00523	-0.00417
	Train	-0.01058	-0.00692	-0.00682	-0.00468
	HSR	-0.00905	-0.00548	-0.00584	-0.0037
Access and Egress time (mins)	Bus, Train, Air and HSR	-0.0108	-0.0104	-0.00694	-0.00702
Waiting time (mins)	Bus, Train, Air and HSR	-0.0109	-0.00748	-0.00706	-0.00506
Tunnel perception	(% of HSR time in tunnels)	-0.228	-0.172	-0.147	-0.116
Frequency (services per day)	All PT modes	-1.19	-0.8170	-0.7680	-0.553
Interchanges	All PT modes (number of interchanges)	-0.497	-0.396	-0.321	-0.267
Return in one day	If return journey time < 6 hours	0.339	0.378	0.219	0.256
Alternative specific constants	HSR (compared to car)	n/a	n/a		
	HSR (compared to air)	1.09	0.201	0.113	-0.481
	HSR (compared to bus)	n/a	n/a	n/a	n/a
	HSR (compared to train)	n/a	n/a	n/a	n/a
Implied structural parameters	Bus	1	1	1	1
	Train	1	1	1	1
	Car	1	1	1	1
	Air	0.645	0.676	n/a	n/a

4.4.2. Future year growth in mode choice parameters

To account for real increases in passenger incomes over the appraisal cost coefficients have been adjusted throughout the appraisal period. Business cost coefficients have been adjusted in-line with real income growth with an elasticity of 1.0, whilst leisure cost coefficients have been adjusted in-line with real income growth with an elasticity of 0.8. This is consistent with the economic appraisal and with current Norwegian appraisal guidance. Real incomes have been assumed to grow at a rate of 1.6% per annum.

The impact of the above is to increase values of travel time throughout the appraisal period, increasing the sensitivity of the model to time changes and decreasing the sensitivity to differences in cost. For forecasting purposes the future fares of air and high speed rail have been assumed to remain constant in real terms.

5. Model Validation

5.1. Introduction

This Section of the report presents a number of updated checks which have been undertaken to validate the final model. These checks concentrate on valuation and elasticity including:

- Comparing the inferred values of time from the stated preference to evidence from the published literature.
- Checking that implied elasticities are reasonable and consistent with comparable model systems and published values. Elasticities are used to determine the percent change in demand given a percent change in supply.

5.2. Base matrices validation

Although no comparable flow data is available to allow for independent validation checks on the base matrices, NTM5 matrices for air and classic rail have been adjusted in-line with count data supplied from Avinor and NSB respectively, as described in section 4.1. As a result there is increased confidence in the absolute levels of air and rail travel on corridors within the model. It should be noted that the NTM5 matrices represent the only data received to date between ultimate origins and destinations within Norway, rather than between stations or airports. Consequently the NTM5 matrices continue to play a key role in the Norway HSR modelling and forecasting.

5.3. Valuations

As an initial check on the model parameters the inferred values of time from the stated preference surveys are compared to those from the literature below. Although the value of time from the SP surveys varies with the cost of the journey under consideration, it is possible to make some comparisons with established values by looking at the mean and median VOTs that would be implied from the observed distribution of journey costs within the sample (once the income distribution has been appropriately weighted by mode and purpose to reflect the income distribution for long distance trips within the NTS).

The following tables compare the standard values of time per hour for long-distance private travel in Norway, which are understood to be provided in the 'Handbook 140', in NOK of 2009, with the average values from the current study.

Table 5. Values of time per hour for long-distance private travel in Norway, NOK (2009)

	Air	Car	Rail	Bus
Handbook 140	303	172	94	80

Table 6. Average values of time per hour from current study, NOK (2010)

		Air	Car	Rail	Bus	HSR
Work	Mean	376	135	305	188	325
	Median	387	131	288	143	321
Non-work	Mean	207	29	138	92	119
	Median	206	29	124	63	116

When comparing with the values of time in Handbook 140, we see that the recommended values for air and car are closer to those that we find for trips made for work purposes, whereas those for rail and bus are more in line with the values that this study finds for trips made for non-work purposes. Differences in values are to be expected between studies, and the values for this study are designed to reflect the specific choice of time savings offered by HSR over existing modes rather than improvements in times or fares of those existing modes.

A concern was raised at the end of Phase II relating to the low values of time for car passengers. This has been investigated further during this phase of the study although car value of time. The reasons for this are thought to be:

- partly a function of the fact that as long distance journeys are being considered, passengers using car for these journeys are particularly likely to have low values of time. It tends to be a slower mode over the distances involved so those using it would typically either have a lower value of time to consider it as a viable option or have another particular reason for valuing car use (such as the need for the car at the destination); and
- partly an outcome of the structure of the survey. People were only asked about car journeys if they hadn't taken a Air, Rail or Bus journey on the route in question lately. So this is likely to mean that the respondents are a group who particularly favour car (and therefore may continue to select car whatever options are provided in the survey), re-emphasising the first point. Clear evidence of this appears in the fact that 44% of those surveyed about car-HSR choices were going on holiday.

It should be noted that due to the structure of the model, and the methodology used for appraisal, the car values of time should not undervalue the other values of time/ appraisal/modelling results as:

- the car values of time and cost formulation play no role in the model and benefits calculations for most scenarios. Car costs are only ever considered incrementally and as decongestion benefits aren't being represented, there will not be any changes in car costs between Reference Case and Do-Something scenarios (apart from in possible sensitivity tests looking at fuel cost changes). Therefore the formulation of car cost will not influence the model or appraisal results; and
- the values of time for HSR/Air/Rail – which are the key influences on the modelling/appraisal results are much less affected by the filtering process which influences the car values of time and therefore should provide more representative indications of the values across the full sample.

5.4. Implied elasticities

The validity of the demand model has been assessed by realism tests. The main purpose of the realism tests is to demonstrate that the model parameters replicate elasticities derived from empirical observations and/or best practice.

The elasticities examined in the realism tests are:

- High speed rail in-vehicle time; and
- High speed rail fare.

The demand response parameters have used realism testing for separate 10% increases to high speed rail journey times and fare, using the following formulation:

$$e = (\log(T1)-\log(T0))/(\log(C1)-\log(C0))$$

Where :

- the superscripts 0 and 1 indicate values before and after the change in cost respectively;
- T is the number of trips made; and for
- High speed rail fare elasticity: C represents the fare;
- High speed rail in-vehicle time elasticity: C represents the in-vehicle travel time.

5.4.1. In-vehicle time elasticities

The implied high speed rail journey time elasticities in terms of high speed rail trips to high speed rail journey times are shown below in Table 7. Tests are conducted around 10% increases to in-vehicle times using the target journey times from each corridor as a base. The base journey times are between 2.5-3.0 hours where high speed rail competes strongly with air, therefore the implied elasticities should not be compared to those from classic rail within Norway. The minimum and maximum elasticities shown are the range produced on individual corridors from Oslo to Bergen/Trondheim/Stavanger/Stockholm. The average elasticity is that produced when introducing all of the above corridors as a network.

Table 7. HSR implied in-vehicle time elasticities

HSR Trips w.r.t. HSR in-vehicle time	Corridor Min	Average	Corridor Max
Work Trips	-0.56	-0.82	-1.04
Non-Work Trips	-0.45	-0.62	-0.84
All Trips	-0.52	-0.73	-0.95

Table 7 demonstrates a correct pattern of in-vehicle time elasticities by journey purpose. Work trips, for which passengers will have a higher value-of-time, exhibit higher in-vehicle time elasticities than non-work trips.

The change in in-vehicle times produce implied elasticites which are comparable to those presented in the literature:

- RAVE (2003) reported the average travel time elasticity to be between -0.12 and -0.44 from a survey amongst rail travellers in Portugal.
- Atkins (2002) report IVT elasticities of -0.92 or -1.31 for work trips and -0.78 or -0.88 for non-work trips.
- Román et al. (2010) estimates a demand model for HSR between Madrid-Barcelona. The direct elasticity of demand for train trips -0.38 but is higher, -0.59 for shorter trips.
- Rohr et al. (2010) report -0.4 to -0.9 for a forecasting model of the SAMPERS (Swedish National Forecast Model) type.

5.4.2. High speed rail fare elasticities

Implied high speed rail elasticities have been derived assuming 10% increases to fares from the base case scenario. This assumes high speed rail fares are equal to existing rail fares, with journey times taken from alternatives testing. Implied high speed rail fare elasticities in terms of high speed rail trips to high speed rail journey times are shown below in Table 8. As with journey time elasticities the minimum and maximum elasticities shown are the range produced on individual corridors from Oslo to Bergen/Trondheim/Stavanger/Stockholm on end-end journeys.

Table 8. HSR implied fare elasticities

HSR Trips w.r.t. HSR fares	Corridor Min	Average	Corridor Max
Work Trips	-0.37	-0.42	-0.51
Non-Work Trips	-0.77	-0.87	-0.97
All Trips	-0.54	-0.62	-0.72

Table 8 demonstrates a correct pattern of high speed rail fare elasticities by journey purpose. Work trips, for which passengers will have a higher value-of-time, exhibit lower fare elasticities than non-work trips.

The elasticities shown in Table 8 correspond well to those reported in the literature:

- RAVE (2003) report an average rail fare elasticity of -0.31 to -0.61
- Atkins (2002) reported fare elasticities of -0.48 or -0.62 for work travel and -0.86 or -0.72 for non-work travel.
- Rohr et al (2010) report cost elasticities of -0.5/-0.6.

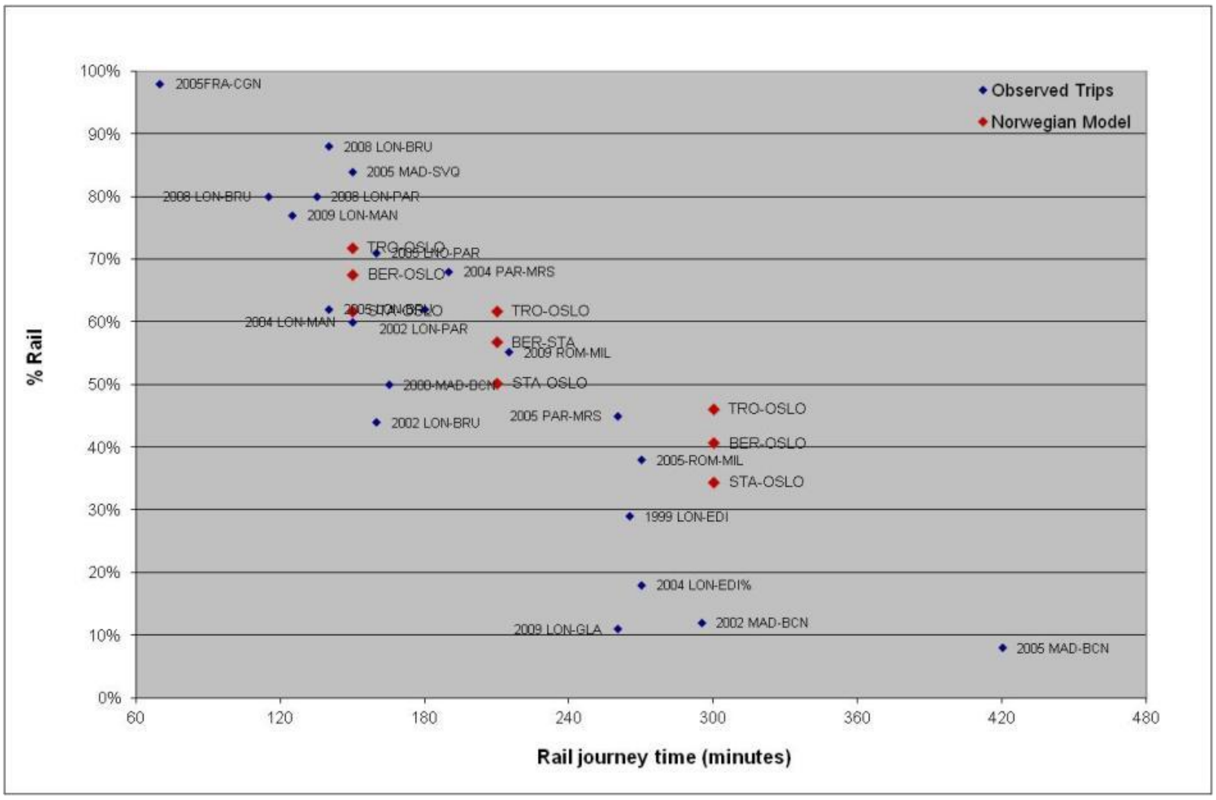
5.5. Comparisons with observed data

5.5.1. Rail-Air mode share

Previous studies have examined the relationship between travel time by train and the rail-air market share. A strong relationship is observed between the two as the majority of travel time by air is not incurred as in-vehicle time.

Figure 4 below shows the relationship as reproduced from Steer Davies Gleave (2006)[8], modelled results from the NHSRDM are overlayed onto this chart.

Figure 4. Rail-Air market share (Steer Davies Gleave, 2006)



From Figure 4 it can be seen that the forecast HSR-Air market share from the NHSRDM fits well with the observed results. Although with lower journey times the HSR market share is at the upper levels of the observed results, the inferred in-vehicle journey time elasticities from the model, at the top of the curve, have been shown to be similar to those presented in other studies.

It is noted that although the above relationship is observed there still exists a significant variation even when rail journey times are similar. On market shares rail/air Steer Davies Gleave (2006) writes, *"the rail journey time was the single most important factor determining market share, but nonetheless there could be*

[8] Steer Davies Gleave (2006), Air and Rail Competition and Complimentarity

significant variation even where the journey times were similar: for example, routes with rail journey times of about 2 hours 30 minutes had rail shares varying from 44% to 85%. This variation arose because:

- *Other factors related to the schedule offered or the effective journey time, such as the frequencies offered by each mode and average access times, influence market share;*
- *Other factors not related to the schedule, including price and service quality, also influence market share; and*
- *Definitions of the markets varied between routes, and were sometimes different for air and rail on the same route."*

Whilst only journey time is changed in the test results above from the NHSRDM it is noted that other factors may vary more significantly along with rail journey time on the observed corridors (for instance slower journey times may correlate to longer trips and increased fares or reduced service quality). This may result in the modelled mode rail mode shares being higher than those on observed corridors.

5.5.2. Generated demand

Preston (2009[9]) presents evidence on the amount of traffic generated by new high speed rail services. The levels of induced journeys are typically shown to be between 10-30%. Madrid-Seville is shown to be an exception where generation is cited as 50% of all HSR trips; however it is suggested that some of this may be due to external growth on the line. The levels of generated traffic from the NHSRDM generally sit within the range of 30%-35% of total high speed rail demand. The proportion of generated trips will vary for different high speed corridors as the changes to the total accessibility brought about by the introduction of high speed rail are a function of both the new service provided and the existing alternative services for making a given journey.

[9] Preston (2009) The Case for High Speed Rail: A review of recent evidence, RAC Foundation

6. Gravity Model

6.1. Introduction

As described in Section 2.4, as the base matrices in the mode choice model come from the NTM5, the mode choice model contains only journeys above 100 kilometres. Originally this was not an issue, although the increasing emphasis on intermediate stations as the study has progressed left gaps in the mode choice model forecasts. In order to forecast the number of trips of less than 100km made by high speed rail a separate gravity model has been developed. This forecasts demand directly based on the population served by each station and the generalised journey time between stations under different alternatives. The model is also used in a number of other circumstances where the mode choice model either does not forecast, or under forecasts, high speed rail demand. This occurs where there is little existing air or rail flows between zones causing the mode choice model to break down. The remainder of this section describes the development, and use, of the gravity model.

The gravity model is the most commonly used method of deriving trips where no matrix exists. It is named from the gravity analogy in that the number of trips between two zones is directionally proportional to their mass (e.g. population\employment) and indirectly proportion to the cost of travel between them.

The decay factor is central to the gravity model and represents the decrease in trip-making associated with increased travel cost.

6.2. Model Development

The following sections describe the development and structure of the gravity model.

6.2.1. Formulation

The gravity model uses the formula

$$T_{ij} = K.P_i^{\alpha}.P_j^{\beta}.G^{\lambda}$$

where

- Tij = number of trips between regions i and j
- K = empiric constant factor
- α = population elasticity for region i
- β = population elasticity for region j
- G = cost of travel (GJT) of movement from i to j
- λ = distance decay factor
- Pi = mass factor (population) of region i
- Pj = mass factor (population) of region j

And

- GJT = IVT + Headway + Access\Egress Time

6.2.2. Model development

The population elasticities and distance decay factor above have been calibrated with relation to NTM5 costs and trip levels. The methodology for this is outlined below:

The NTM5 inputs with relation to classic rail demand for the NHSRDM were extracted on an origin-destination basis. This gave over 11000 rows of data containing values for the:

- Origin zone population;
- Destination zone population;
- Existing rail in-vehicle time;

- Existing rail headway (time between trains);
- Existing access\egress time; and
- The existing number of rail trips.

The components relating to rail in-vehicle time, rail headway and rail access times were combined to give a single value for rail generalised journey time. Each component was weighted relative to the in-vehicle time using the average business\leisure weighting form the main mode choice parameters given in Table 4 above. Thus the final variable in the formula above (generalised journey time) could be calculated where:

GJT = IVT + 15%Headway + 150%Access\Egress Time

This data provided all the inputs to perform a regression where the single dependant variable (trips) is affected by the multiple independent variables (origin population, destination population and GJT).

As the zones in the mode choice mode do not have a wide range of populations the urban zones (e.g. the cities of Oslo, Bergen, Stavanger, Trondheim and Kristiansand) within the mode choice model were amalgamated and regression concentrated on trips to\from these zones between and to\from all other zones within the model.

Multiple regression was performed using the ‘Data Analysis’ addin in Excel. As this performs a least squared linear regression. As the original equation is a power function the natural log of both sides was taken such that:

$$\text{Log}\,(T_{ij}) = K + \alpha\,\text{Log}\,(P_i) + \beta\,\text{Log}\,(P_{i)} + \lambda\,\text{Log}(G)$$

This log transformation allowed the linear regression to be performed. Removing the natural log from both sides of the equation following regression provided the original formula such that :

$$T_{ij} = e^{K}.P_i^{\alpha}.P_j^{\beta}.G^{\lambda}$$

The derived parameters within the model are:

- K (empiric constant factor) = 0.73
- α (population elasticity for region i) =1.02
- β (population elasticity for region j) = 1.03
- λ (distance decay factor) = -2.71

Thus increasing the population of either the origin or destination of a zone by 10% roughly increases the number of trips by 10% whist increasing the GJT between zones by 1% roughly decreases the number of trips between them by 2.7%.

6.3. Components of utility

6.3.1.1. Zones\Populations

The gravity model treats each potential high speed station as an individual entity with the population being taken as that of the urban population as given by Statistics Norway. This limits trips made between two stations to the urban populations they serve, which is appropriate for short distance trips. The exception to this has been for trips to\from the metropolitan areas of; Oslo, Stavanger, Bergen and Trondheim where the metropolitan population has been found to be a better indicator of the levels of attraction from more minor stations.

6.3.1.2. Access Times

As with the main mode choice mode access times have been calculated using the network accessibility model. For use in the gravity mode drive time isochrones have been created around each station, with the population within each isochrones being calculated from population provided per square km by Statistics Norway. The population isochrones have then been used to create a population weighted average access time to each station from the population served.

6.3.1.3. High speed service specification

As with the main mode choice model the high speed rail journeys time and the frequency of the high speed service are variable and are set for each scenario.

6.4. Model calibration\validation

Figure 5 below shows the forecast flows from the gravity model against the flows used to calibrate the gravity model.

Figure 5. Calibration of gravity model using NTM5 data

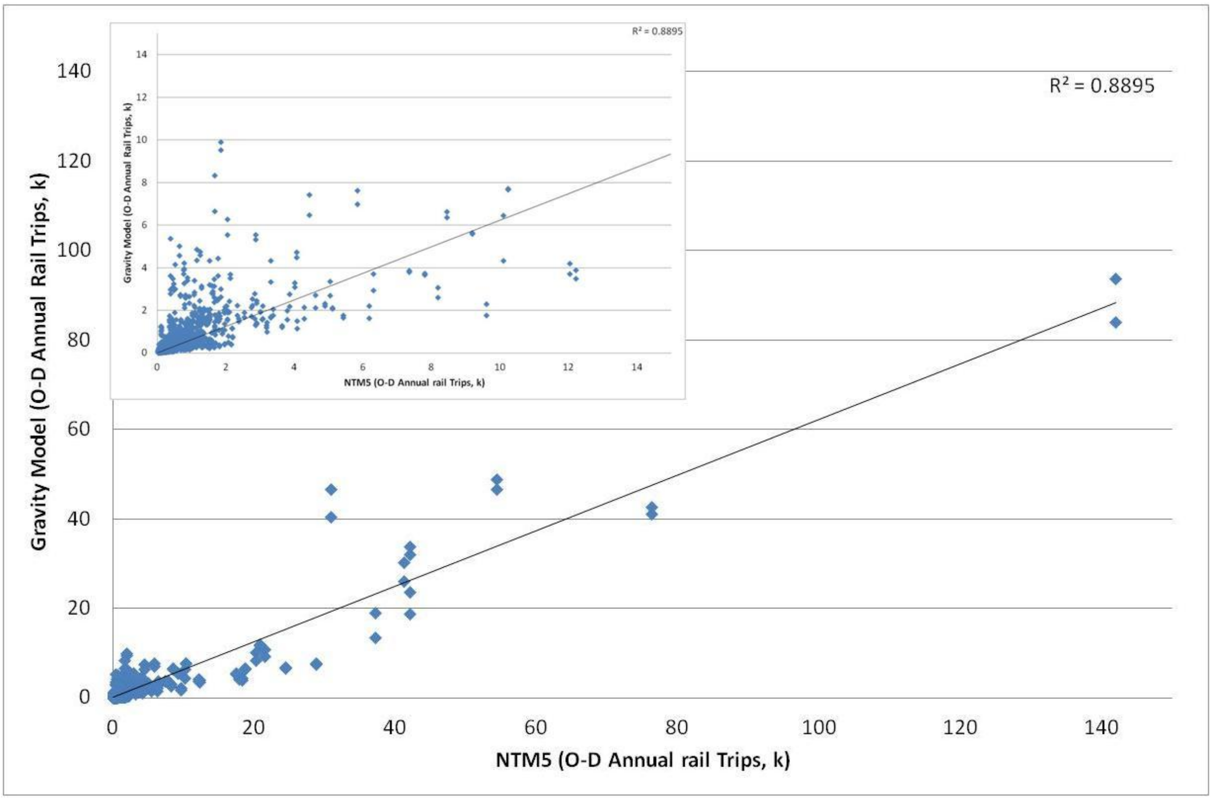
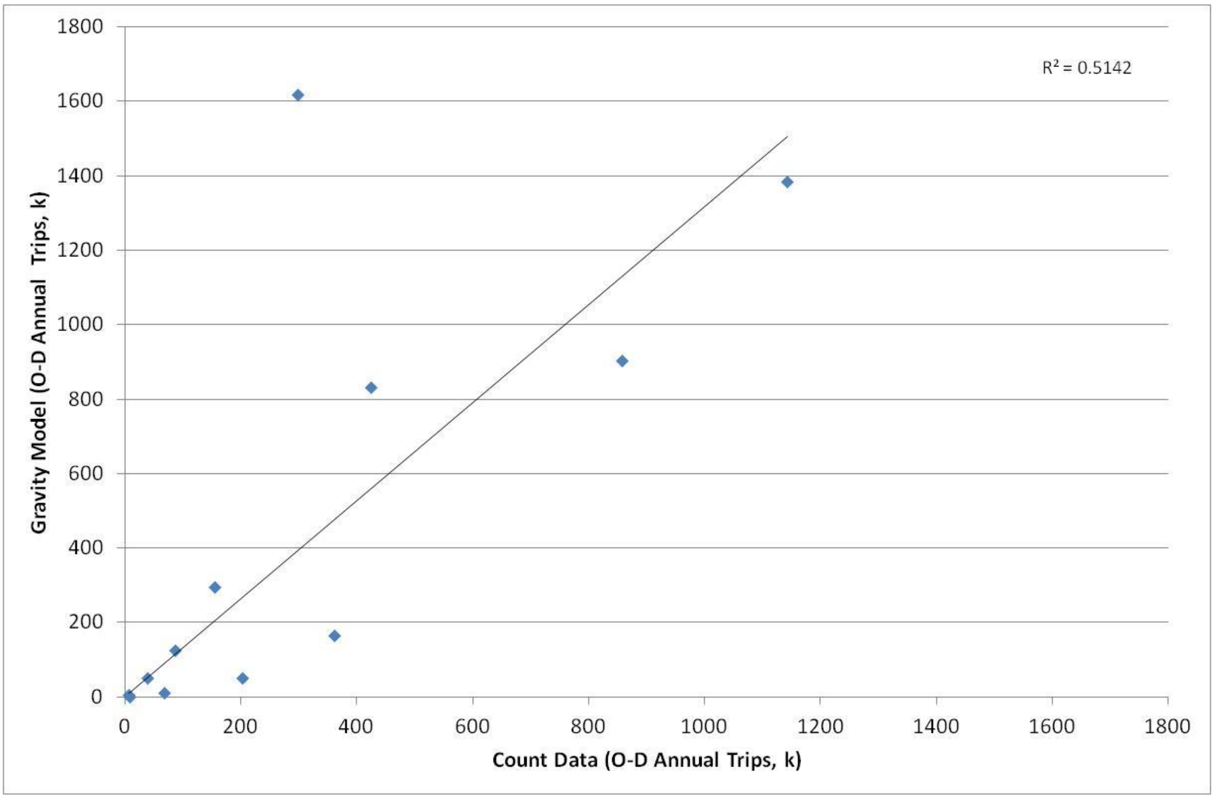


Figure 5 above shows the best fit between the forecast rail trips and rail trips as contained in NTM5 using the formula above. Although variation between the two can be seen, the r-squared valuation (0.89) indicates that the gravity model is explaining a significant proportion of the variation in the number of rail trips made between two zones.

Figure 6 below shows gravity model forecasts against actual flows within the Oslo intercity area. This comparison is provided as is gives an independent check that the gravity model is suitable to forecast trips between origins and destinations outside the data used for calibration. This is especially important as the model is calibrated from NTM5 data using rail trips of over 100km but will largely be applied to trips of under 100km. The figure below is intended to ensure that the decay factor derived applies to reduced generalised journey times associated with shorter journeys.

Figure 6. Gravity model forecasts of NSB flows within the Oslo Intercity area



It can be seen from Figure 6 above that although the model does not forecast demand as accurately from the observed inter-city flows, as for on the calibrated NTM5 flows, it still accounts for over half of the variance on the flows examined. This suggests that the model is suitable to estimating the short distance intermediate demand for the high speed corridors, which is generally of secondary importance when considering the demand on the high speed corridors as a whole.

6.5. Model limitations

Although the gravity model is the most commonly used method of deriving trips where no existing matrix is available it is not without limitations. With regards to gravity model results and validation is should be noted that:

- The gravity model takes into account the levels of attraction between two stations, as a result of the relative size of the two areas of population and the rail service provided between them, it does not account for the impact of competing modes. Obviously if two otherwise identical origins and destinations have a good highway link, as opposed to a poor highway link, car would compete more significantly with rail and the number of rail trips would be reduced. The differing levels of competition from other modes are likely to account for a significant proportion of the variation between observed and forecast flows in both the figures above.
- The gravity model as estimated above does not include any information on high speed rail fares. As the model is calibrated against existing rail fares the forecast will assume fares equivalent to the existing rail service. However, this means that the gravity model is not suitable for undertaking sensitivity tests around high speed fare levels.
- As a direct demand model the forecasts give no information on where high speed rail trips would come from in terms of modes of origin or trip generation. As a result assumptions have to be made with regards to these factors in the scheme appraisal.

6.6. Model application

Although the NHSRDM and the gravity model forecast different areas of demand for the same high speed scenarios they are essentially two separate models. For scenario tests results are collated using the assumptions below

- The main mode choice model is the default source of demand and revenue.
- Results are taken from the gravity model where:
  - HSR journeys are less than 100km. Generally these trips are not included in the mode choice model however, the mode choice model does generate high speed rail trips of under 100km where the total distance, including access and egress is greater than 100km. On inspection is felt that the model is over representing the number of these trips, as it relies very heavily on the access component and is still treating the short HSR journey as a new mode. Consequently the gravity model is used to forecast all high speed rail journeys of under 100km; and
  - Where the origin-destination trip is less than 200km and the gravity model forecasts demand of more than double the demand from the mode choice model. The gravity model has been used in these scenarios as; on some movements of up to 200km the mode choice model under forecasts demand. This is a rare occurrence within the modelling results and generally happens for one of two reasons either; O-D pairs are not well served by either existing air or rail services and so the mode choice model structure is not well placed to forecast demand, or the amalgamation from smaller zones excludes trips of under 100km where zone centroids are further than 100km apart.
- In instances where high speed stations are less than 20km apart the gravity model is not considered reliable and demand is excluded from the analysis. Demand is also excluded within the Oslo inter-city area where trips are not considered to be part of the high speed rail market.

For each alternative tested the origin model of demand between each origin-destination pair is shown alongside analysis of results. This is shown in the:

Norway High Speed Rail Study: Phase III, Market, Demand and Revenue Analysis, Final Report.

As fares are not directly included in the gravity model the impact on revenue of the trips taken from the gravity model has been assumed to be proportional to the change in high speed passenger km brought about as a result of these trips.

7. NTM5

7.1. Introduction

As part of the Norwegian high speed rail study, Atkins received a version of the Norwegian Transport Model (NTM5). As previously described the NTM5 matrices have been used as an input to the Norwegian High Speed Rail Demand Forecasting Model, built by Atkins. The NTM5 model has also been used directly for a comparison of Scenario A (Do-Minimum), and Scenario B. The remainder of this Section describes the use of the existing NTM5B model for the analysis of scenarios A and B.

7.2. Suitability for assessing HSR

NTM5B is widely used in Norway for demand forecasting, supporting the development of National Transport Plans. NTM5, version B, was received by Atkins from Per Jorulf Overvik at Jernbaneverket in November 2010. This is a national model, which contains trips of over 100 kilometres. The demand forecasting stage of NTM5B uses a bespoke executable model, which receives as input the generalised times and costs of travel, referred to as “Level of Service” (LoS) data and derived from an EMME based network model. There is no standardised procedure for assigning that demand onto the network to identify passenger loadings, such as station to station flows.

Scenarios A and B represent relatively small improvements to the base-case rail network. NTM5B therefore provides a suitable basis for forecasting the demand impacts for each scenario. Additional data would be required to assess the demand response for international travel in the Goteborg and Stockholm corridors. However, NTM5B is considered suitable to assess the domestic demand response in these corridors.

Atkins has developed EMME macros to facilitate the standardised assignment of the forecast demand to the available transport networks, using conventional EMME assignment procedures which are consistent with those used in determining the LoS data.

In addition, Atkins has developed a methodology for the use of NTM5B such that the demand and travel time data can be retained within the EMME data repository, so that the standard EMME matrix manipulation software can be utilised to prepare data for economic assessment purposes.

7.3. Representation of Scenarios A and B

Atkins was supplied with the NTM5B network specifications and associated socio-economic data, as used for the recent National Transport Plan work in Norway. The networks were identical for the two forecast years under scrutiny (2024 and 2043).

The broad specification, in terms of target journey times and frequencies, for these Scenarios is provided in “TN6 Scenario Testing”. In summary, Scenario A anticipates an increase in train frequency (or reduction in service headway), whilst Scenario B anticipates an improvement in train speed and hence reduction in journey time.

Atkins calculated the change, from the “Fastest 2010” in the Scenario Testing Note, for each corridor, as shown in Table 9.

Table 9. Representation of changes in supply in NTM5B

Corridor	Scenario A: Headway Factor	Scenario B: Journey Time Factor
Oslo-Bergen	0.5	0.85
Oslo - Kristiansand -Stavanger	0.5	0.83
Oslo-Trondheim	0.33	0.85
Oslo-Stockholm	0.5	0.92
Oslo-Göteborg	0.33	0.90

To implement these Scenarios in NTM5B, these corridor specific adjustments were applied to the relevant services. The factors are multiplicative, and were applied within the EMME data repository.

As a result, the changes modelled in these NTM5B tests do not represent a change in stopping pattern or variation in speed change along the corridor, merely an improvement in headway or journey time at the strategic level. This will be adequate for end to end travel, but may not identify more local demand responses to supply changes at a local level.

It should be noted that these changes were applied to both "Day Trains" and "Night Trains", as both are specified in NTM5B, and equally contribute to supply and are available for assignment, as the model is based on aggregate daily demand and supply levels.

In the case of Scenario A, a single NTM5B test was undertaken, with the train frequencies improved in all five corridors.

In the case of Scenario B, a similar initial test was undertaken, with the train journey times improved in all five corridors, mainly to give assurance that the model would respond appropriately to a more marked improvement in the supply side. This was followed by testing one corridor at a time, as proposed in the Scenario Testing Note; the latter results are those reported in the appended technical note: 'Use of existing NTM5 model'.

7.4. Phase III Work

For the purposes of the Phase III work, Scenario B was conceptually defined by JBV as:

'***Delivery of a uniform 20% reduction in travel time, maintaining the current stopping pattern and remaining single track outside of the Inter-City (IC) area'***

In order to undertake an analysis of the performance of Scenario B a clear specification of what this would involve was required. JBV's alignment design teams each examined possible options for delivery of Scenario B and high level specifications were provided to Atkins and F+G, covering each route per corridor, and reflecting the sections of route where the journey time improvement would be secured. This is summarised in Table 10 below:

Table 10. Scenario B Summary of Specification

Corridor	Route	Section(s) of route where journey time improvement is secured	% Journey Time Assumption
North	Oslo-Trondheim	Gardermoen-Oppdal	20% reduction in total end-to-end time
West	Oslo-Bergen	Hønefoss-Bergen	
South	Oslo - Kristiansand -Stavanger	Drammen-Sandnes	
East	Oslo - Stockholm	Lillestrøm-Kongsvinger	20% reduction in Olso-Charlottenburg time: equates to a 5% reduction in Oslo-Stockholm time

The exceptional Scenario B alternative is clearly the East corridor alternative between Oslo and Stockholm where the specification aims only to achieve a 20% reduction in journey time between Oslo and Charlottenburg. Norconsult, the alignment consultants for this corridor advised that insufficient information was available to determine a specification for Scenario B improvements on Swedish sections of route and consequently specification only aimed to deliver the reduction in journey time within Norway.

Therefore, it has been assumed that there is no journey time improvement within Sweden. In addition there has been no improvement in service frequency assumed. Testing has been carried out on four corridors:

- Oslo-Trondheim;
- Oslo-Bergen;
- Oslo-Kristiansand-Stavanger; and
- Oslo-Charlottenburg (Stockholm).

Atkins calculated the overall change in journey time based on the current fastest timetabled journey times for each route, and the alignment data for Scenario B provided by the alignment teams was used to determine where the journey time reductions are applied along each corridor.

To implement these Scenarios in NTM5, corridor specific adjustments were applied to the relevant services on the relevant links. The factors are multiplicative, and were applied within the EMME data repository. The derivation of these factors is based on the current journey times contained within NTM5.

These factors have been applied to the sections of each route, based on where the line upgrades have been specified in the alignment data. The time saving required from the current NTM5 times to achieve the Scenario B times was calculated, and a reduction factor was then derived to apply to the journey time of the section where the Scenario B improvements have been made. This working is shown in Table 11 below. Note that the journey time was calculated separately for each direction, labelled as “from Oslo” and “to Oslo” in the table.

Table 11. NTM5 Journey Time Factor

Corridor	Current NTM5 Time (Reference Case)		Time Saving Required		NTM5 JT over Upgraded Section		Journey Time Reduction Factor Applied to Section	
	From Oslo	To Oslo	From	To	From	To	From	To
Oslo-Trondheim	6:22	6:22	1:06	1:06	4:25	4:21	0.75	0.75
Oslo-Bergen	6:12	6:24	1:02	1:14	4:43	5:00	0.78	0.75
Oslo - Kristiansand – Stavanger	6:49	6:39	0:40	0:30	6:13	6:02	0.89	0.92
Oslo-Charlottenburg	1:44	1:48	0:22	0:26	1:01	0:57	0.64	0.54

As a result, the changes modelled in these NTM5 tests represent an improvement in journey time on sections of track where the upgrades are to be implemented, with the end-to-end journey time representing a 20% reduction to the current rail service. This will enable more local demand responses to supply changes at specific locations to be identified.

It should be noted that these changes were applied to long distance services on each corridor, including “Night Trains”, as well as Oslo-Kristiansand and Kristiansand-Stavanger regional services. Each corridor has been tested individually, with Scenario B improvements applied to one corridor for each test, in order to identify the relative effect on demand of Scenario B to each corridor.

Revenue calculations have been made based on the forecast demand in NTM5 and the fare assumptions stored within the NTM5 model.

8. Conclusions

In order to investigate the impact of an incremental development of the Norwegian railway network, beyond the National Transport Plan covering the period 2010-2019, a dual forecasting approach has been developed. This approach uses a bespoke model developed to asses full ‘high speed’ rail implementation whilst the NTM5 model is used to assess the impacts of small scale incremental changes to the conventional rail network. This mixed methodology has been adopted because of reservations about using the NTM5 for modelling large step-change improvements in rail levels of service.

Although not being used for high speed the NTM5 is an established model which has been audited and accepted as broadly fit-for-purpose, therefore it has been retained for the assessment of relatively minor timetable improvements which represent much smaller improvements in the existing long-distance rail services.

A new bespoke framework of tools has been developed from stated preference analysis for the testing of high speed alternatives and gives the best representation of high speed demand within Norway. The model is designed to test the introduction of new high speed services.

Matrices of base demand, base utilities, and incremental changes to utilities are the key inputs to the model. The model has been developed to allow for different high speed corridors to be tested including:

- Full mode choice between high speed rail, car, rail and coach for strategic flows across Norway on the basis of the overall utility in the cost of travel by high speed rail;
- Annual demand forecasting (for the years 2018, 2024, 2043 and 2060);
- High Speed Rail annual revenue forecasting (for the years 2018, 2024, 2043 and 2060);
- High speed station choice based on an incorporated accessibility model;
- Different demand responses based on travel for work and non-work purposes; and
- Responses to changes in high speed; journey times, average fares, headways, accessibility and % of time in tunnels.

Developments undertaken in Phase III allow for the incorporation of full mode choice based on incremental changes in the utilities of other modes. This includes options to change:

- Air fares and service frequency;
- Classic rail service frequency, fares and journey times;
- Bus service frequency, fares and journey times; and
- Highway fuel costs, toll charges and journey times

At the end of Phase II it was also identified that further model development was desirable. This largely related to the increasing emphasis that has been placed on intermediate trips as the study had developed. The Phase II model had been developed using the NTM5 matrices and consequently only forecast trips of over 100km. In addition there were further gaps in the forecasts due to the modelling structure; for instance where air was not an existing option for travel, HSR forecasts were significantly under-estimated.

Phase III developments have filled in these forecasting gaps as described below. As a result of these modelling improvements the Phase III demand forecasts represent a more complete picture of HSR demand, and correspondingly have increased relative to the previous phase. The improvements include:

- The incorporation of improved data on baseline passenger movements on the Swedish corridors. At the end of Phase II the data incorporated into the base matrices for international trips made by highway or rail was sourced from the TransTools model. Taking the granularity of this model into consideration this data was considered to be less accurate than that incorporated for the domestic Norwegian corridors. During this phase further data from additional sources was incorporated into the mode choice model. This has primarily been in the form of existing Sampers matrices provided from KTH.
- The implementation of a dual nesting structure. During the course of this study the emphasis has evolved from concentrating largely on long-distance end-to-end trips (e.g. Bergen-Oslo) to providing a parallel consideration for intermediate movements (e.g. Bergen-Kongsberg, Kongsberg-Oslo). Having

been developed with the longer distance trips in mind this left the Phase II model with weaknesses when forecasting the later type of 'intermediate' movement. In essence the model had been calibrated to provide the best mode choice representation for long distance trips where air travel is available. On a number of intermediate movements, where air was not a feasible option, this was resulting in high speed rail movements being underestimated. During this phase a duel modelling structure was investigated, and incorporated into the model. This continues to provide an initial mode choice against air on long distance trips however, where air is not a feasible option a second nest is applied providing an initial mode choice against the current rail service; and

- The development of a separate gravity model to fill in missing areas of high speed demand. This forecasts high speed demand directly as a factor of the population around two stations and the separation between them in terms of high speed rail accessibility. The model parameters have been estimated by a regression of existing rail trips from the NTM5 against populations and existing rail; journey times, headways and access\egress times. This is generally used to forecast high speed trips where station-station movements are less than 100km. Additionally it is also used to fill in demand where the mode choice model under forecasts trip levels; this usually relates to origin-destination pairs where there is little existing air or rail demand causing the mode share model to break down.

Our assessment of the final inferred model elasticiities, and cross-checking of demand model outputs against observed international HSR mode shares, suggest that the forecasting model provides a robust basis for decision-making at this stage of scheme development. However, it is also important to note that there are some limits to forecasting, especially related to estimation of individual HSR station usage, and the potential for new rail markets – particularly commuting into Oslo – to be developed by introduction of HSR services.

Appendix A. **Levels of service**

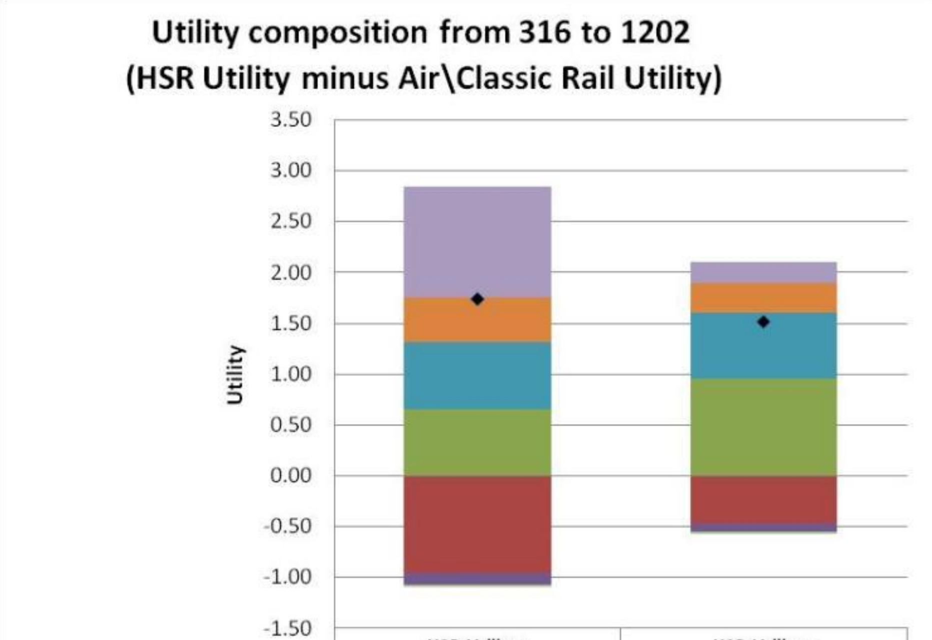
For given O-D movements, and work and non-work journeys, the following graphs show:

- Composition of HSR and Air Utilities by travel attribute (stacked column)
- Net utility (scatter plot point); and
- HSR:Air mode split on the movement.

It should be noted that the values are variable and change depending on the high speed scenario under consideration. The graphs however do give an indication of where the differences in perceived costs of travel between modes originate from on different movements.

The corresponding figures show the zones under consideration. Plots show how the elements of each O-D journey combine to give a disutility for travel. A range of O-D movements are selected to show the varying levels of accessibility by HSR and air from different areas, and the reasons for these variations. The resulting split in Air vs HSR mode share is also examined separately for work and non-work journeys.

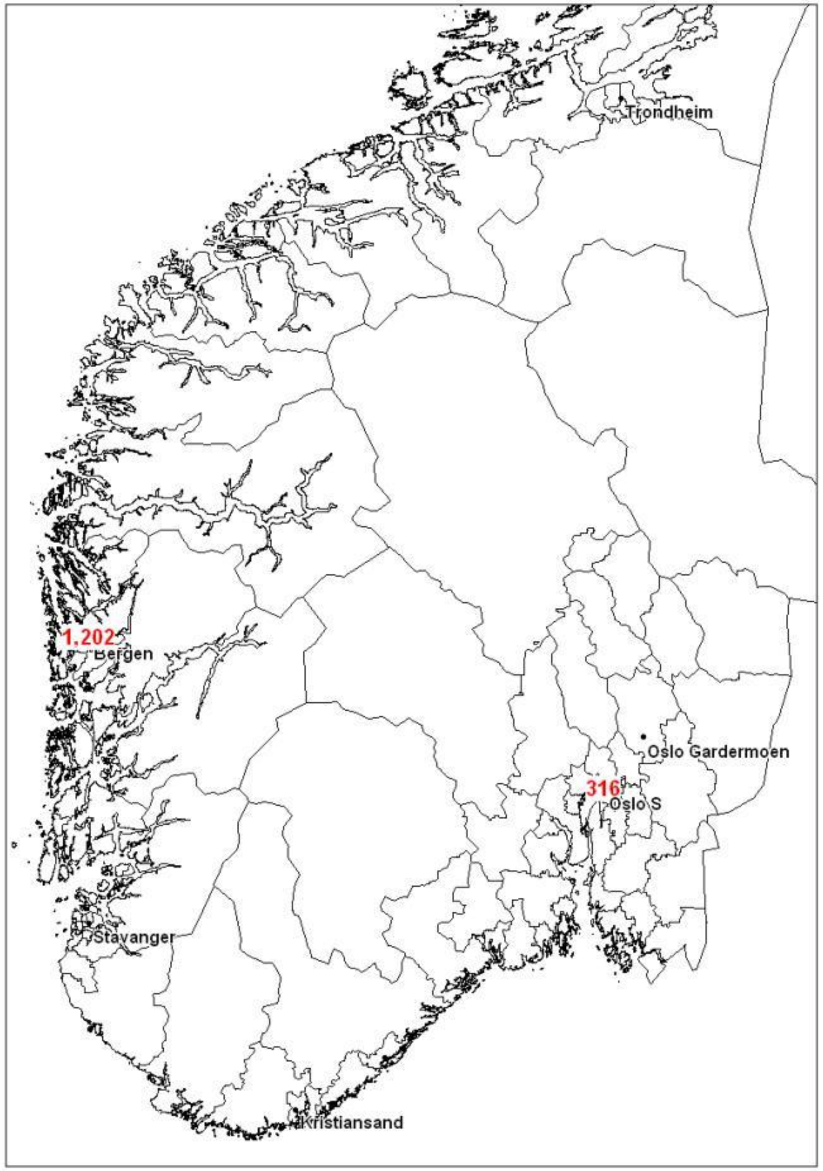
Oslo to other City Centres: Oslo Sentrum (zone 316) to Bergenhus (zone 1202);



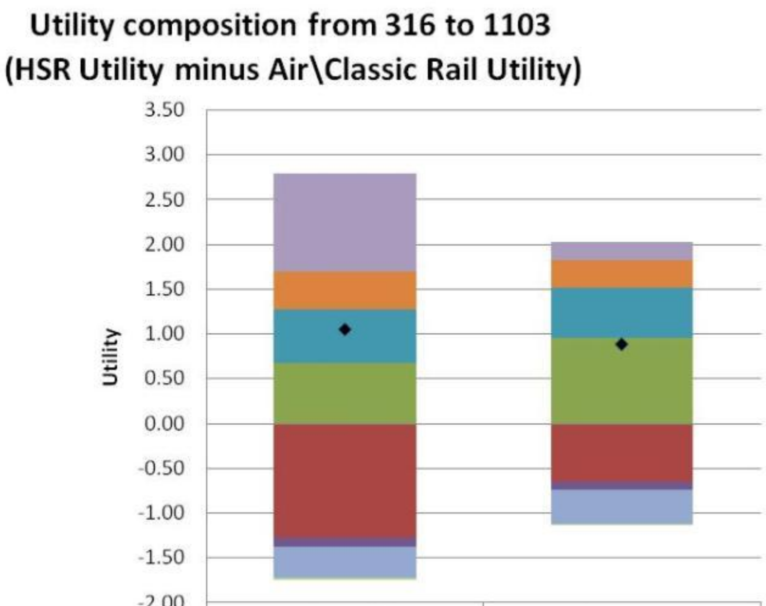
	HSR Utility - Air Utility WORK	HSR Utility - Air Utility LEISURE
ASC	1.09	0.20
Daily Services	-0.03	-0.02
Interchange Penalty	0.00	0.00
Return in 1 day	0.00	0.00
Wait Time	0.43	0.30
Access\Egress Time (minutes)	0.67	0.64
% Time in Tunnels	-0.11	-0.09
HSR Fare (NOK)	0.65	0.96
In-Vehicle Time	-0.95	-0.47
◆ Utility	1.74	1.52

HSR Fare	60%

HSR:Air		HSR:Air	
85.1%	14.9%	82.1%	17.9%



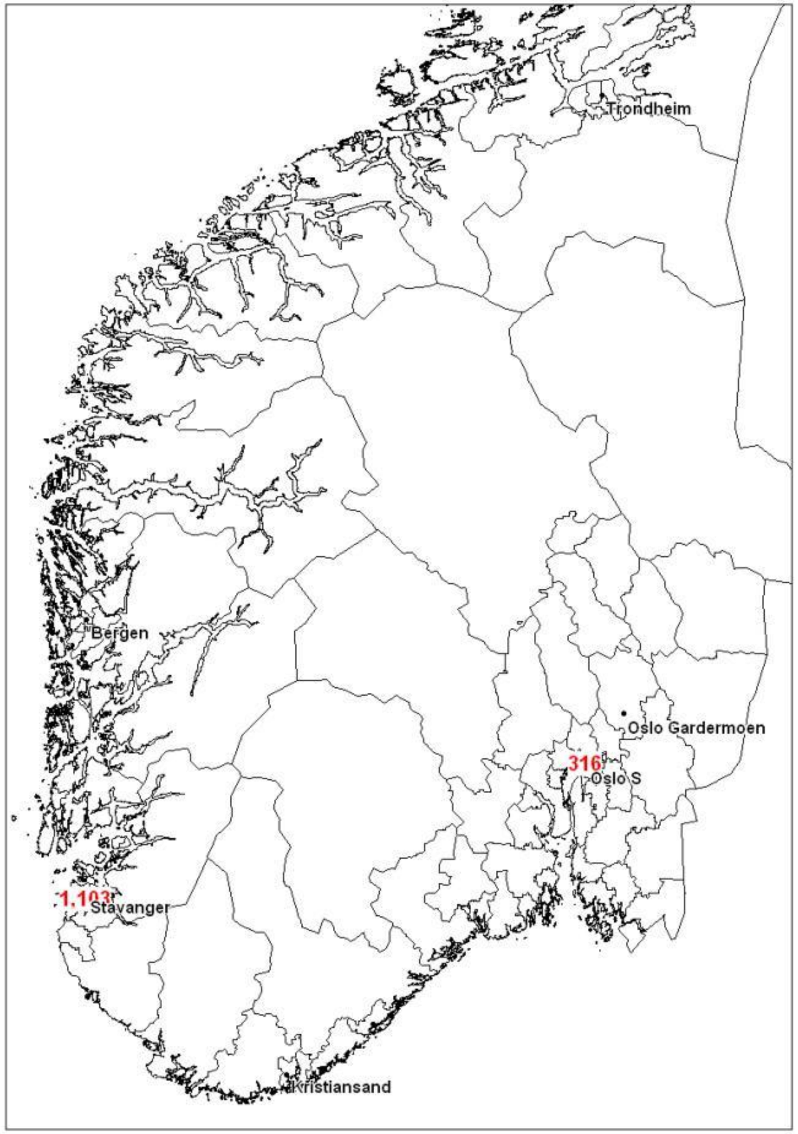
Oslo to other City Centres: Oslo Sentrum (zone 316) to Eiganes (zone 1103, within Stavanger)



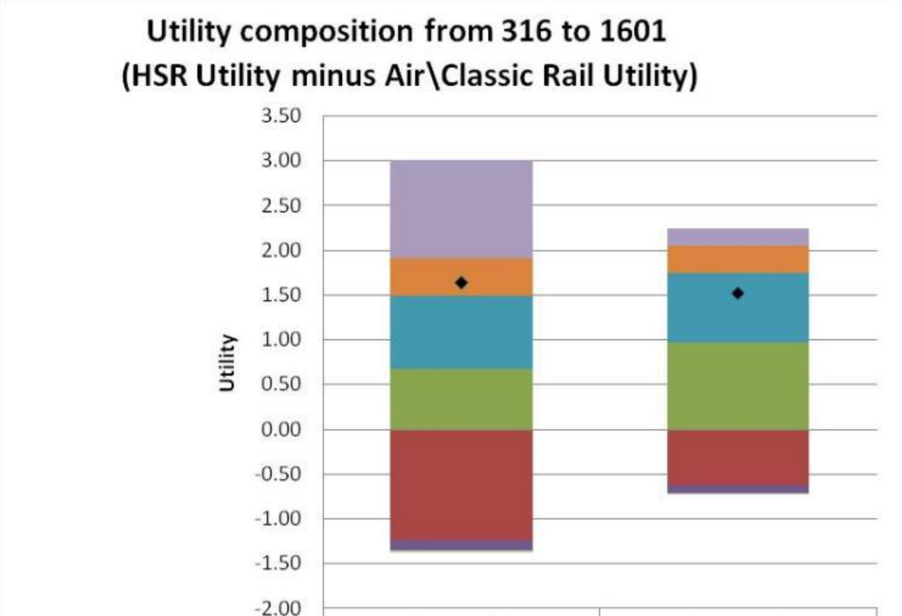
	HSR Utility - Air Utility WORK	HSR Utility - Air Utility LEISURE
ASC	1.09	0.20
Daily Services	-0.02	-0.01
Interchange Penalty	0.00	0.00
Return in 1 day	-0.34	-0.38
Wait Time	0.43	0.30
Access\Egress Time (minutes)	0.59	0.57
% Time in Tunnels	-0.11	-0.09
HSR Fare (NOK)	0.67	0.95
In-Vehicle Time	-1.27	-0.65
◆ Utility	1.05	0.89

HSR Fare	60%

HSR:Air		HSR:Air	
74.1%	25.9%	70.9%	29.1%



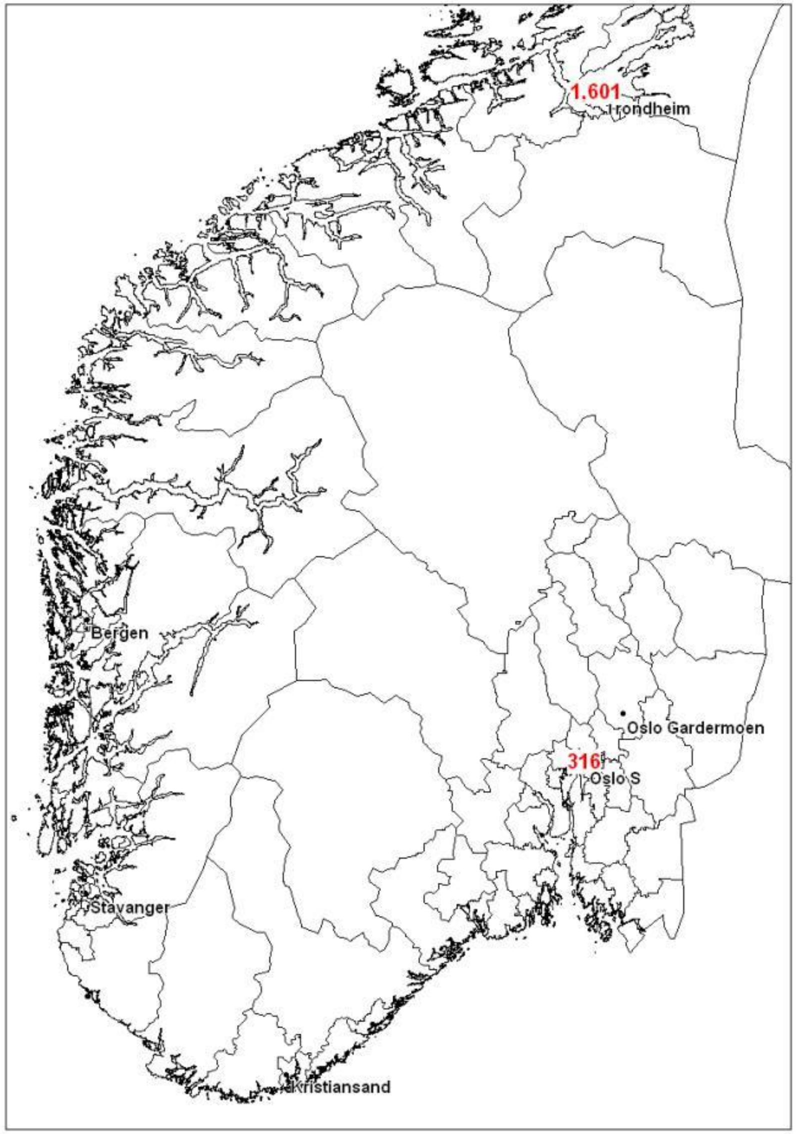
Oslo to other City Centres: Oslo Sentrum (zone 316) to Midtbyen (zone 1601, within Trondheim)



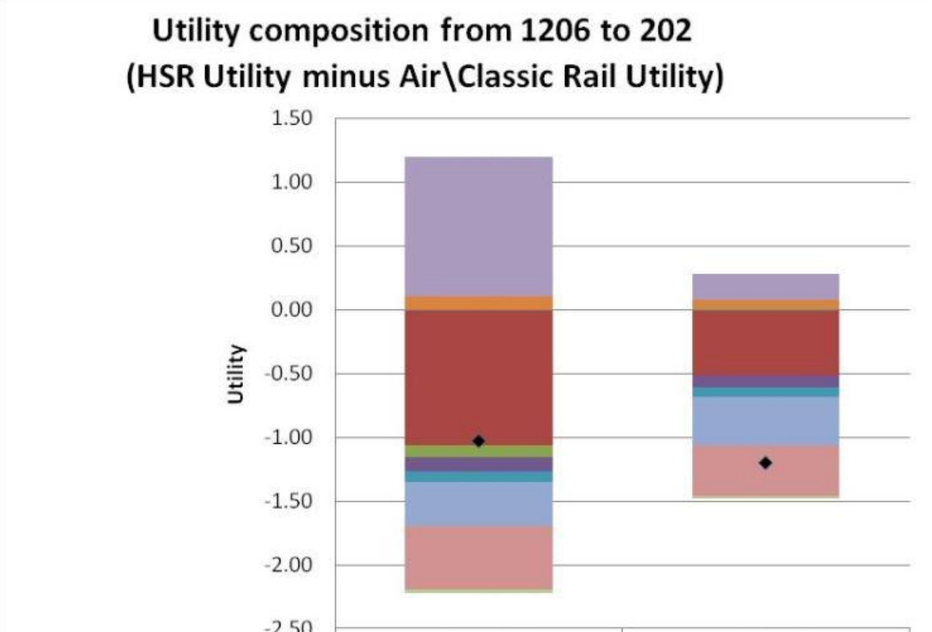
	HSR Utility - Air Utility WORK	HSR Utility - Air Utility LEISURE
ASC	1.09	0.20
Daily Services	-0.02	-0.02
Interchange Penalty	0.00	0.00
Return in 1 day	0.00	0.00
Wait Time	0.43	0.30
Access\Egress Time (minutes)	0.81	0.78
% Time in Tunnels	-0.11	-0.09
HSR Fare (NOK)	0.68	0.97
In-Vehicle Time	-1.24	-0.63
◆ Utility	1.63	1.52

HSR Fare	60%

HSR:Air		HSR:Air	
83.7%	16.3%	82.0%	18.0%



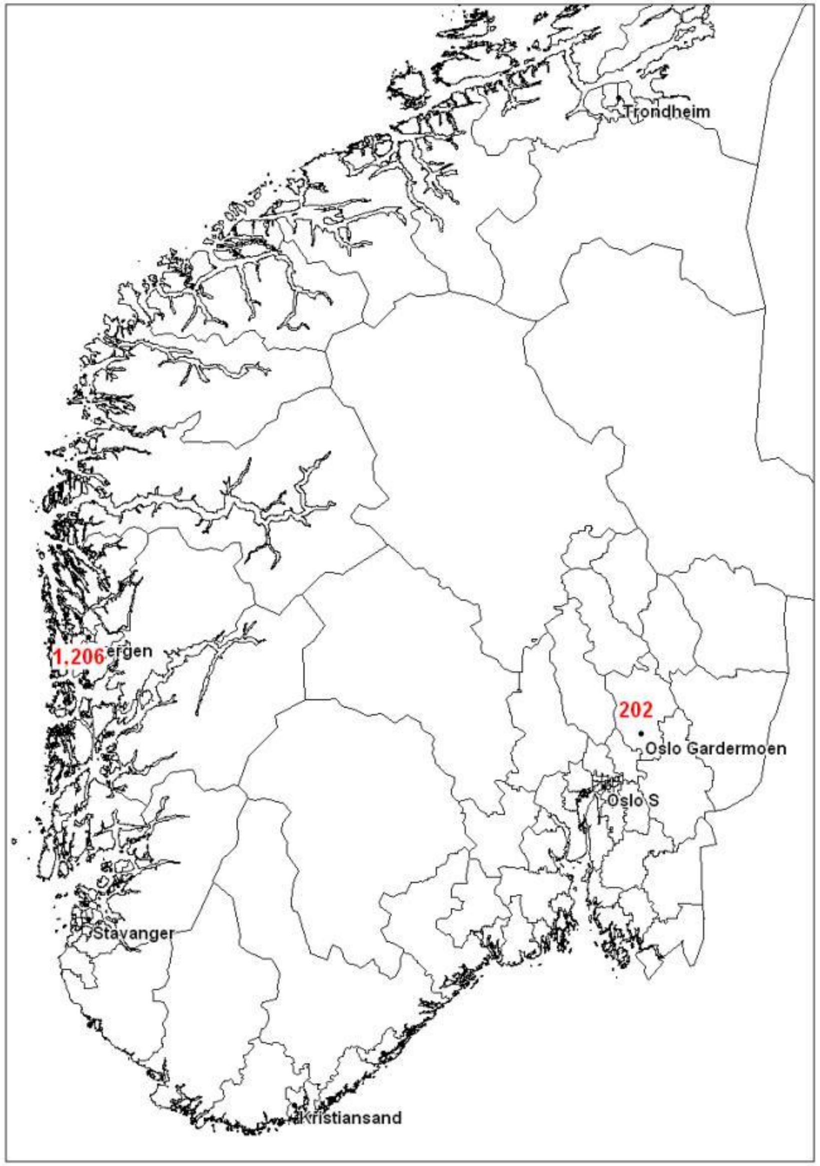
Relatively easy airport access: Gardermoen (zone 202) to Ytrebygda (zone 1206, within Bergen)



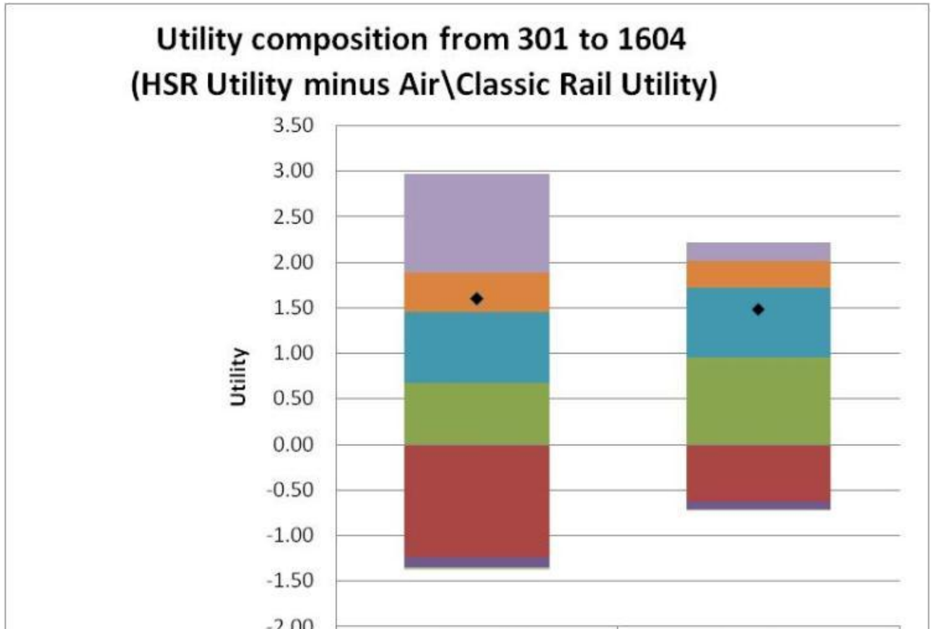
	HSR Utility - Air Utility WORK	HSR Utility - Air Utility LEISURE
ASC	1.09	0.20
Daily Services	-0.03	-0.02
Interchange Penalty	-0.50	-0.40
Return in 1 day	-0.34	-0.38
Wait Time	0.10	0.07
Access\Egress Time (minutes)	-0.08	-0.08
% Time in Tunnels	-0.11	-0.09
HSR Fare (NOK)	-0.09	0.01
In-Vehicle Time	-1.07	-0.52
◆ Utility	-1.03	-1.20

HSR Fare	60%

HSR:Air		HSR:Air	
26.3%	73.7%	23.1%	76.9%



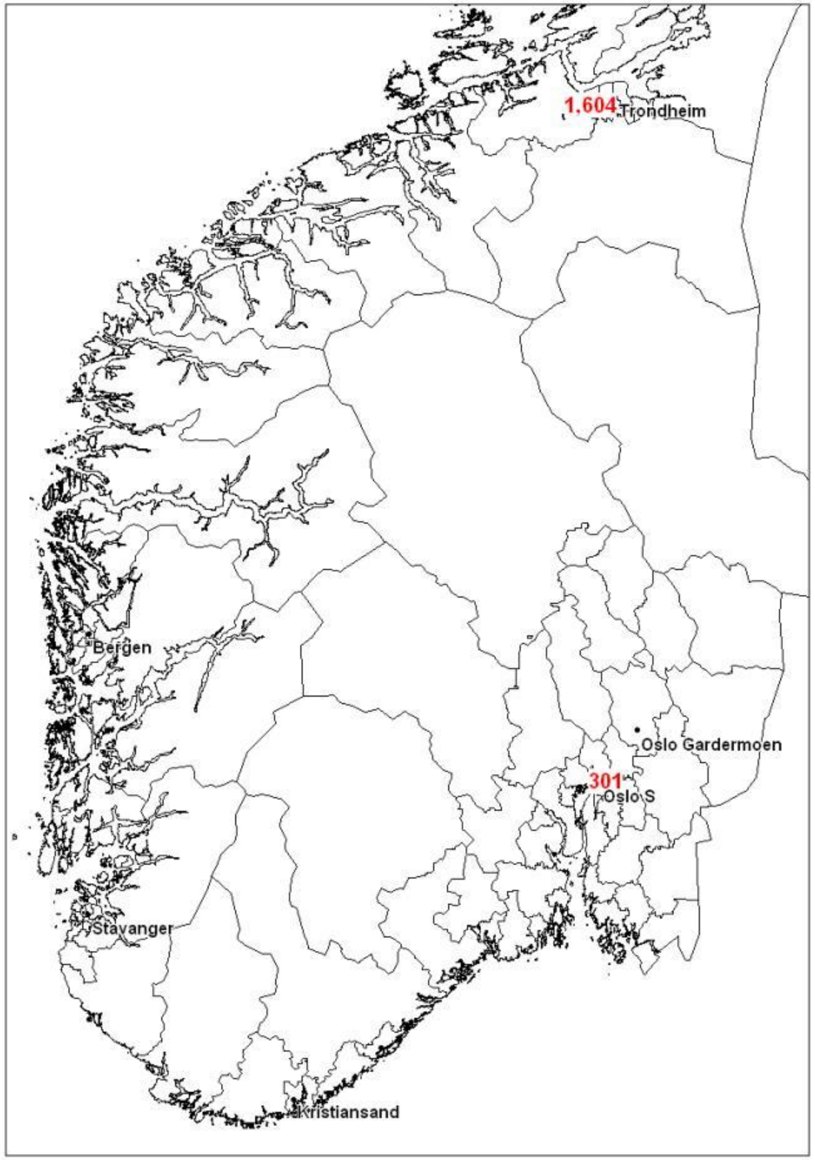
Relatively poor airport access: Gamle Oslo (zone 301) to Heimdal (zone 1604, within Trondheim);



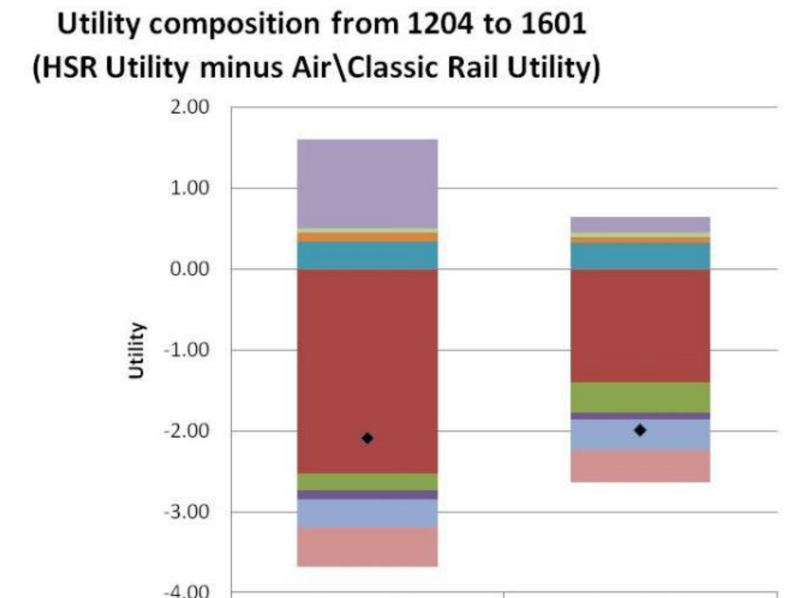
	HSR Utility - Air Utility WORK	HSR Utility - Air Utility LEISURE
ASC	1.09	0.20
Daily Services	-0.02	-0.02
Interchange Penalty	0.00	0.00
Return in 1 day	0.00	0.00
Wait Time	0.43	0.30
Access\Egress Time (minutes)	0.78	0.75
% Time in Tunnels	-0.11	-0.09
HSR Fare (NOK)	0.67	0.96
In-Vehicle Time	-1.24	-0.63
◆ Utility	1.60	1.48

HSR Fare	60%

HSR:Air		HSR:Air	
83.2%	16.8%	81.5%	18.5%



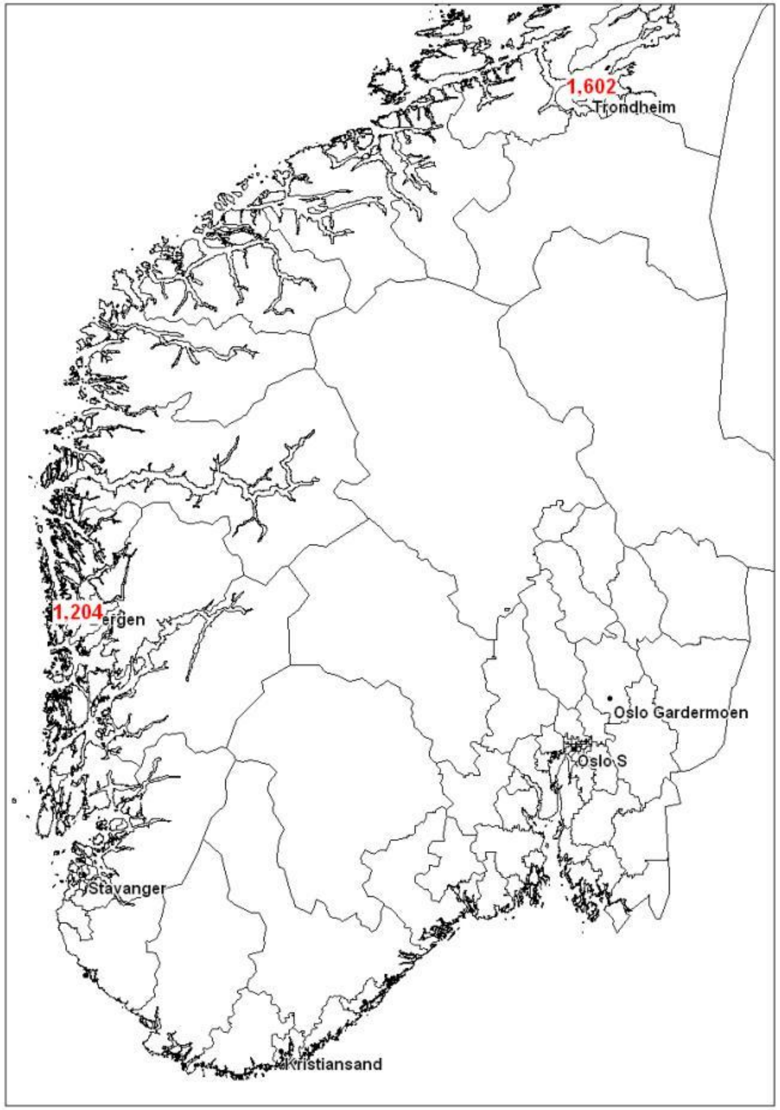
Direct flight and HSR interchange: Fyllingsdalen (zone 1204, within Bergen) to Østbyen (zone 1602, within Trondheim) via Oslo



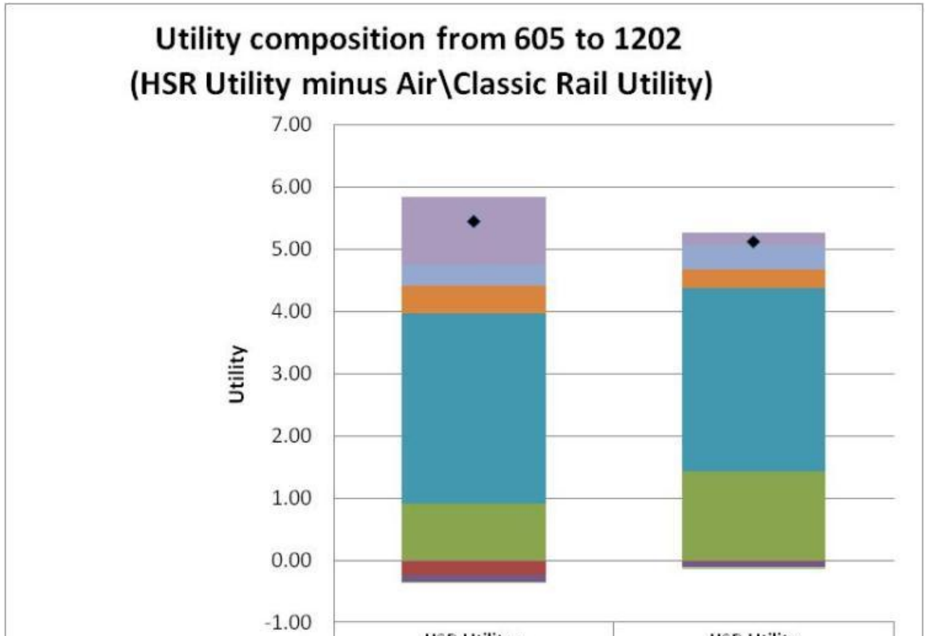
	HSR Utility - Air Utility WORK	HSR Utility - Air Utility LEISURE
ASC	1.09	0.20
Daily Services	0.07	0.05
Interchange Penalty	-0.50	-0.40
Return in 1 day	-0.34	-0.38
Wait Time	0.10	0.07
Access\Egress Time (minutes)	0.34	0.32
% Time in Tunnels	-0.11	-0.09
HSR Fare (NOK)	-0.21	-0.38
In-Vehicle Time	-2.53	-1.40
◆ Utility	-2.09	-1.99

HSR Fare	60%

HSR:Air		HSR:Air	
11.0%	89.0%	12.0%	88.0%



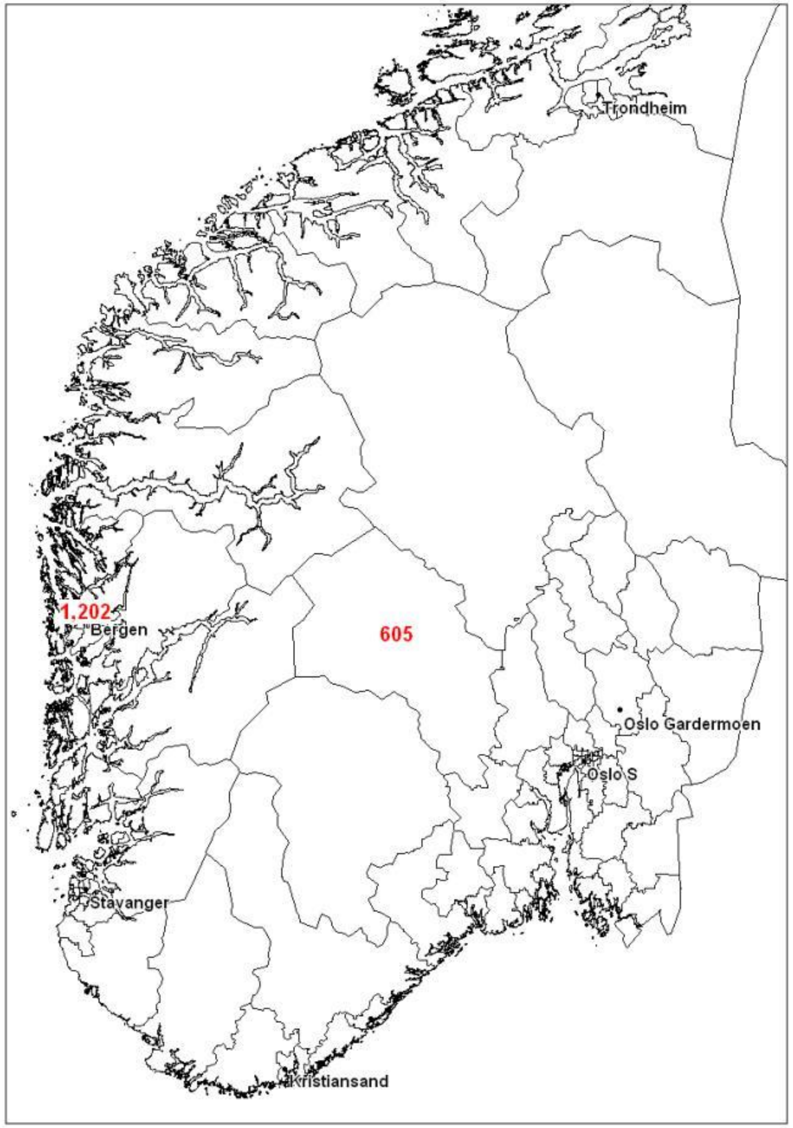
Zone served by intermediate HSR station to non-Oslo major city centre – no interchange: Rollary (zone 605) to Bergenhus (zone 1202)



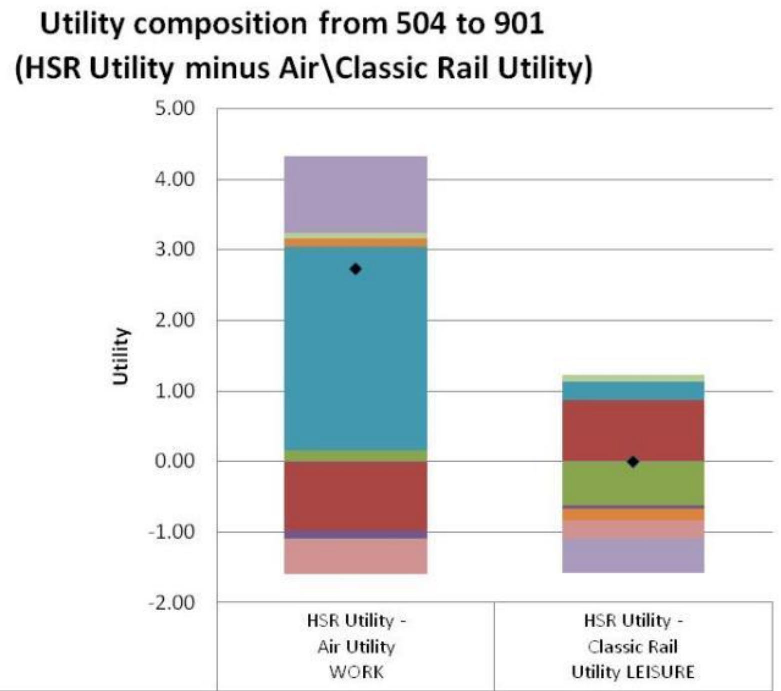
	HSR Utility - Air Utility WORK	HSR Utility - Air Utility LEISURE
ASC	1.09	0.20
Daily Services	-0.03	-0.02
Interchange Penalty	0.00	0.00
Return in 1 day	0.34	0.38
Wait Time	0.43	0.30
Access\Egress Time (minutes)	3.07	2.95
% Time in Tunnels	-0.11	-0.09
HSR Fare (NOK)	0.91	1.43
In-Vehicle Time	-0.23	-0.03
◆ Utility	5.45	5.12

HSR Fare	60%

HSR:Air		HSR:Air	
99.6%	0.4%	99.4%	0.6%

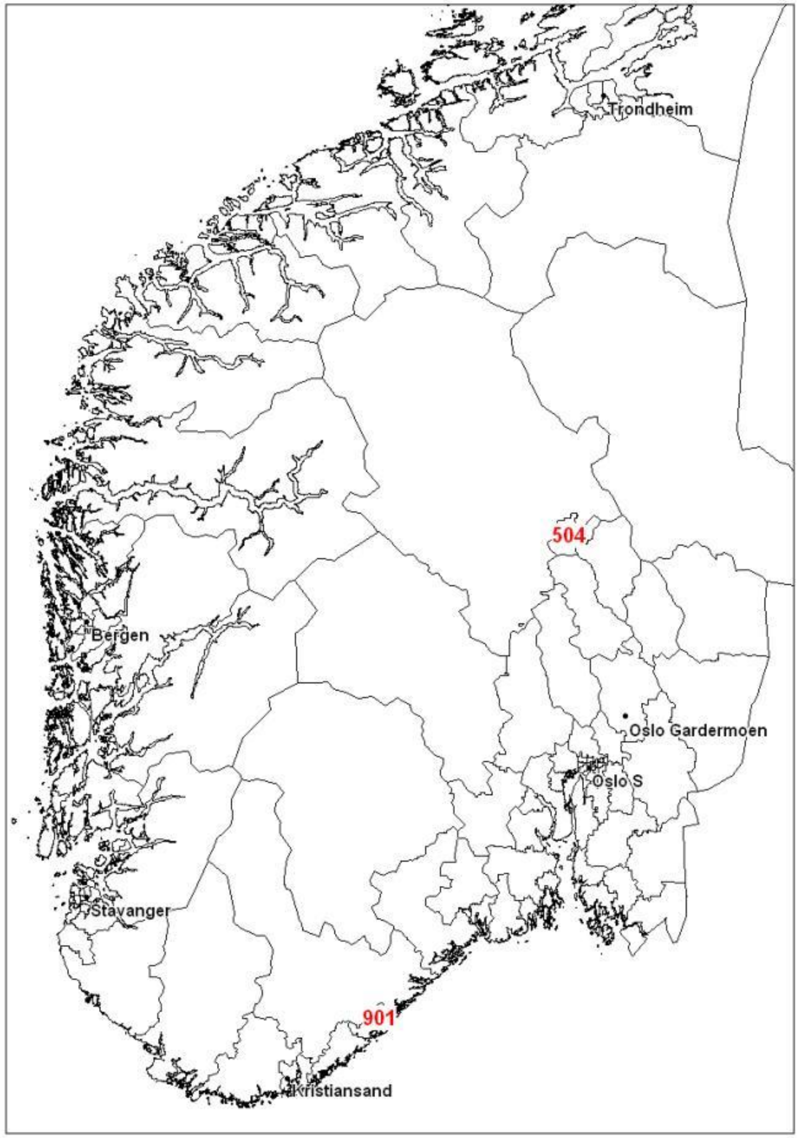


Zones served by intermediate HSR station to intermediate HSR station – with Olso interchange: Lillehammer (zone 504) to Arendal (zone 901)



	HSR Utility - Air Utility WORK	HSR Utility - Classic Rail Utility LEISURE
ASC	1.09	-0.48
Daily Services	0.08	0.10
Interchange Penalty	-0.50	-0.27
Return in 1 day	0.00	0.00
Wait Time	0.10	-0.15
Access\Egress Time (minutes)	2.88	0.25
% Time in Tunnels	-0.11	-0.06
HSR Fare (NOK)	0.16	-0.62
In-Vehicle Time	-0.98	0.87
◆ Utility	2.74	-0.01

HSR Fare	60%



Appendix B. **Use of existing NTM5B model**

B.1. Introduction

For the assessment of Norway High Speed Rail (HSR), Contract 6 Subject 4 economic analysis requires different models to assess different the HSR scenarios.

The HSR scenarios to be considered using the models are:

- A – relatively small (already planned) improvements, to be used as a reference case;
- B – more significant improvements, involving double tracking;
- C – introducing the HSR concept, with infrastructure works along existing lines; and
- D – full HSR with separate new lines.

This note describes the use of the key Norwegian NTM5B model for the assessment of HSR scenarios A and B.

B.2. NTM5B

NTM5B is widely used in Norway for demand forecasting, supporting the development of National Transport Plans. NTM5, version B, was received by Atkins from Per Jorulf Overvik at Jernbaneverket in November 2010. This is a national model, which contains trips of over 100 kilometres. The demand forecasting stage of NTM5B uses a bespoke executable model, which receives as input the generalised times and costs of travel, referred to as "Level of Service" (LoS) data and derived from an EMME based network model. There is no standardised procedure for assigning that demand onto the network to identify passenger loadings, such as station to station flows.

To form a sound basis for socio-economic assessment of transport schemes, a model like this should typically have:

- Differentiated trip numbers and journey costs for a large number of demand segments;
- Demand segments differentiated by characteristics that influence travel costs and choices, including mode and purpose;
- Detailed representation of the transport system in terms of available network including points of origin and destination;
- Travel costs and demand determined based on the above detailed representation;
- Travel choice functions, to forecast choices such as whether to travel or not and between different modes available to establish the demand and forecast realistic responses to changes in travel conditions, such as mode improvements.

B.2.1. NTM5B contents and characteristics

The review of NTM5B suggested that the model is a nested multinomial logit-model estimating destination, mode choice and frequency of travel for the four journey purposes (business/work, leisure, visits and other). This structure fulfils the requirement outlined above for travel choice functions to reflect responses to changes in travel conditions.

The review also suggested that the model contains the majority of the other important characteristics identified above. In particular:

- A set of networks and matrices – including base year 2006 and future years of 2010, 2014, 2018, 2024, 2030, 2043 and 2060 (matrices received by Atkins);
- Adequate zoning – a network of 13,875 zones for demand assignment, which are aggregated to 1,428 zones for reporting purposes;
- Sufficient transit lines to represent rail routes and services– as observed in the text input files as well as via Geographic Information System (GIS);
- Adequate segmentation by journey purpose – P0 work or business, P1 leisure, P2 visits, P3 other;
- A comprehensive list of modes – air, train, bus, boat and car;
- An adequate number of auxiliary transit modes – walk, train, air, boat;

- Disaggregate matrices – matrices are split by purpose and mode. Car matrices are reported in terms of passenger trips and vehicle trips. All matrices are in terms of daily trips. TØI identified that the annual level of demand can be derived using a factor of 365; and
- Useful outputs:
  - Non-car modes: matrices available are Mf21 - in-vehicle time, Mf22 -auxiliary time, Mf23 - total wait time, Mf24 - first wait time, Mf25 - average number of boardings (1 minus the number of interchanges), Mf26 - number of ferry trips, Mf27 - fare, Mf28 - ferry cost;

  - Car: matrices available are Mf20/25 - in-vehicle time (including on-road connecting ferries), Mf21/26 - distances (including distances travelled on ferries), Mf22/27 toll and ferry cost for car and driver, Mf23/28 - toll and ferry cost for car passengers, and Mf24/29 number of ferry trips;

  - Time matrices are output in terms of minutes, distance matrices in terms of kilometres and cost/charge matrices in terms of NKr.

Sample information extracted from the matrices, including rail and air fares between Oslo and key cities, appears reasonable (with rail fare being approximately 50% of air fares, and within the ranges found through internet research).

B.2.2. Weaknesses of NTM5B

Following the initial review, the following shortcomings have been identified with NTM5B:

- There is no interaction between demand and travel time, i.e. no recognition that any mode is likely to become congested with increasing demand, and hence less attractive; and
- There is no representation of international travel. This is particularly relevant for the assessment of the Goteborg and Stockholm corridors.

The development of NTM5B to address these shortcomings is beyond the scope of the current phase of this project.

B.2.3. Use of available information for HSR assessment

Atkins has established model zones appropriate for HSR demand forecasting. These zones can be mapped to the zones in the NTM5B model, enabling the use of NTM5B data as input to Atkins' bespoke demand forecasting model. In addition, we will be able to represent results from NTM5B for Scenarios A and B on a similar basis as that used for Scenarios C and D.

It is noted that the model does not currently include economic calculations as an automatic part of each model run so additional macros will need to be developed to produce the outputs required. The outputs will also need to be manipulated in matrix software or Access as they contain 2.5 million rows.

B.2.4. Suitability for assessing HSR

Scenarios A and B represent relatively small improvements to the base-case rail network. NTM5B therefore provides a suitable basis for forecasting the demand impacts for each scenario.

Additional data will be required to assess the demand response for international travel in the Goteborg and Stockholm corridors. However, NTM5B is considered suitable to assess the domestic demand response in these corridors.

Atkins has developed EMME macros to facilitate the standardised assignment of the forecast demand to the available transport networks, using conventional EMME assignment procedures which are consistent with those used in determining the LoS data.

In addition, Atkins has developed a methodology for the use of NTM5B such that the demand and travel time data can be retained within the EMME data repository, so that the standard EMME matrix manipulation software can be utilised to prepare data for economic assessment purposes.

Appendix C. **Zoning system**

C.1. Introduction

This appendix describes the formation of a zoning system for the Norway High Speed Rail project for Jernbaneverket. It details the approach taken and methodology used in creating the zoning system for the purpose of client review.

C.2. Requirements

It was important that a zoning system was created for the purpose of modelling the movements of passengers under a series of scenarios for potential high speed rail routes. The zoning system would be required to show more detail near to the proposed high speed corridors:

- Oslo – Gothenburg;
- Oslo – Stockholm;
- Oslo – Stavanger;
- Stavanger – Bergen;
- Oslo – Bergen; and
- Oslo – Trondheim.

There would need to be a high level of detail within the main Norwegian cities served by high speed rail in order to model access and egress times, and a good level of detail around areas of higher population density, mainly in the south of the country. In areas of low population density and areas not bisected by the high speed rail corridors, a lower level of detail is required. A final requirement of the zoning system was that the number of zones would be around 100.

A further review of the zoning requirements will be undertaken once the pilot survey for the stated preference research has been completed. If required, this may result in minor amendments to the zoning system proposed below.

C.3. Methodology

C.3.1. Zone Development

The creation of zones was carried out in four stages:

- Divided up into administrative areas;
- Grouping of municipalities to form approximately 100 larger zones;
- Further refining of the zones by checking population is evenly spread; and
- Addition of “point” zones to represent locations without population.

It was decided to base the zoning system on administrative regions in order to ensure that sensible borders are used and to effectively display demographical data, such as population and employment, which is usually grouped by administrative areas. The administrative areas in Norway fall under the following categories:

- Fylker (counties) – 19
- Kommuner (municipalities) – 433
- Bydeler (urban districts) – 36 (including Oslo Centre and Oslo Forest) – within the following cities:
  - Oslo;
  - Bergen;

- Trondheim; and
- Stavanger.

The external dependencies of Svalbard and Jan Mayen have not been included in our zoning system.

For the first stage we decided that the zones should be much smaller close to the main stations considered in the high speed study. For this reason the urban districts have all been considered as separate zones. For North Norway, i.e. north of Trondheim, where demand for high speed rail is likely to be lower, counties have been considered as single zones. In south Norway outside of the large cities, this left the municipalities.

Stage two involved grouping together municipalities outside of the main cities in Southern Norway, which was carried out on a county-by-county basis. Zones were grouped based on their approximate population density, so that in some cases several municipalities of low population density were all grouped together to form a single zone, and in other instances a single municipality has been considered as a zone by itself as it contains a large population, such as Kristiansand. This process left us with 96 zones in total.

The third process was to calculate the population of each of the new zones to check that there were no zones with either extremely high or extremely low populations. During this process a net total of 8 additional zones were created after dividing some zones into two smaller ones and in one case joining two zones together. There were now 104 zones in total. Excluding zones in Northern Norway, the zone with the largest population is Bærum with 108,753 residents. The zone with the smallest population, excluding the four main urban areas, is Rakkestad with 22,035 residents.

For the final stage it was decided that we add “point” zones for Gardermoen Airport, Stockholm and Gothenburg. The airport zone was added as a node with zero population, separate from the zone within which it sits. This is due to its status as a vital international gateway, and HSR could abstract significant volumes of domestic air journeys for passengers currently transferring to (long distance) international flights. Nodes representing Gothenburg and Stockholm were added in order to model cross-border trips into Sweden.

C.3.2. Numbering System

It was decided that the zone numbering system should contain the county number at the beginning to give an indication of the approximate location of the zone within Norway. The second half of the zone number gives the number of the zone within the county, approximately numbered from South to North. For example, Halden is numbered “01” to indicate its location within Østfold county, followed by “01”, as it is the southernmost zone within the county of Østfold.

Zones which represent urban areas within the cities of Oslo, Bergen, Trondheim and Stavanger are numbered according to their urban district number. For example, Gamle Oslo, which has the urban district code of “030101” is designated the zone number of “0301” to match with the rest of the zoning system.

C.4. List of Zones

The final list of zones is presented in Table 4.1, which shows the zone number, population, area, the county the zone is located within and the municipalities incorporated within the zone.

Zone List

Halden	0101	30145	981	Østfold	Aremark, Halden
Rakkestad	0102	22035	1,267	Østfold	Rømskog, Marker, Rakkestad, Eidsberg
Sarpsborg	0103	51678	427	Østfold	Sarpsborg
Fredrikstad	0104	78179	1,078	Østfold	Hvaler, Fredrikstad
Moss	0105	50938	411	Østfold	Råde, Rygge, Moss
Askim	0106	38295	914	Østfold	Skiptvet, Våler, Hobøl, Spydeberg, Trøgstad, Askim
Sørum	0201	57582	1,982	Akershus	Fet, Aurskog-Høland, Sørum, Nes
Eidsvoll	0202	63268	1,335	Akershus	Hurdal, Nannestad, Eidsvoll, Ullensaker
Nittedal	0203	78268	346	Akershus	Gjerdrum, Nittedal, Skedsmo
Lørenskog	0204	58860	375	Akershus	Rælingen, Lørenskog, Enebakk
Ski	0205	55251	211	Akershus	Ski, Oppegård
Ås	0206	62215	488	Akershus	Vestby, Frogn, Ås, Nesodden
Asker	0207	55812	131	Akershus	Asker
Bærum	0208	108753	217	Akershus	Bærum
Gardermoen Flyplass*	0209	0	0	Akershus	
Gamle Oslo	0301	45159	8	Oslo	
Grünerløkka	0302	32563	5	Oslo	
Sagene	0303	25444	3	Oslo	
St.Hanshaugen	0304	55308	4	Oslo	
Frogner	0305	42310	8	Oslo	
Ullern	0306	29829	9	Oslo	
Vestre Aker	0307	41190	17	Oslo	
Nordre Aker	0308	46204	14	Oslo	
Bjerke	0309	24548	8	Oslo	

Grorud	0310	17345	7	Oslo	
Stovner	0311	32854	8	Oslo	
Alna	0312	34685	14	Oslo	
Østensjø	0313	42659	12	Oslo	
Nordstrand	0314	45674	17	Oslo	
Søndre Nordstrand	0315	32612	18	Oslo	
Sentrum	0316	1179	2	Oslo	
Marka	0317	30858	301	Oslo	
Kongsvinger	0401	41564	3,539	Hedmark	Grue, Nord-Odal, Eidskog, Sør-Odal, Kongsvinger
Ringsaker	0402	31656	1,280	Hedmark	Ringsaker
Hamar	0403	55562	1,445	Hedmark	Løten, Stange, Hamar
Elverum	0404	31275	2,975	Hedmark	Våler, Åsnes, Elverum
Tynset	0405	30421	18,159	Hedmark	Engerdal, Tolga, Folldal, Rendalen, Os, Alvdal, Stor-Elvdal, Åmot, Tynset, Trysil
Gran	0501	34011	2,003	Oppland	Jevnaker, Lunner, Gran, Søndre Land
Gjøvik	0502	56049	1,484	Oppland	Vestre Toten, Østre Toten, Gjøvik
Sel	0503	68505	21,227	Oppland	Nord-Aurdal, Nordre Land, Etnedal, Sør-Aurdal, Vang, Lesja, Skjåk, Vestre Slidre, Lom, Dovre, Øystre Slidre, Sør-Fron, Vågå, Ringebu, Øyer, Nord-Fron, Sel, Gausdal
Lillehammer	0504	26423	478	Oppland	Lillehammer
Røyken	0601	52329	711	Buskerud	Hurum, Røyken, Lier
Drammen	0602	62312	146	Buskerud	Drammen
Kongsberg	0603	63895	1,372	Buskerud	Øvre Eiker, Nedre Eiker, Kongsberg
Ringerike	0604	47530	2,265	Buskerud	Modum, Ringerike, Hole
Rollag	0605	32057	10,560	Buskerud	Hol, Flå, Rollag, Krødsherad, Hemsedal, Nore og Uvdal, Flesberg, Nes, Sigdal, Gol, Ål
Sandefjord	0701	47945	951	Vestfold	Tjøme, Sandefjord
Larvik	0702	42279	1,282	Vestfold	Larvik

Tønsberg	0703	70960	488	Vestfold	Nøtterøy, Tønsberg, Stokke
Horten	0704	41915	863	Vestfold	Lardal, Andebu, Re, Horten
Holmestrand	0705	27897	535	Vestfold	Hof, Svelvik, Sande, Holmestrand
Drangedal	0801	39479	3,244	Telemark	Kragerø, Bamble, Drangedal, Sauherad, Nome
Porsgrunn	0802	33726	199	Telemark	Porsgrunn
Skien	0803	54890	997	Telemark	Siljan, Skien
Notodden	0804	39735	11,718	Telemark	Fyresdal, Nissedal, Hjartdal, Tokke, Kviteseid, Seljord, Vinje, Bø, Tinn, Notodden
Arendal	0901	41316	919	Aust-Agder	Arendal
Grimstad	0902	30083	1,793	Aust-Agder	Lillesand, Grimstad
Bygland	0903	36786	9,177	Aust-Agder	Bykle, Bygland, Valle, Iveland, Åmli, Vegårshei, Gjerstad, Evje og Hornnes, Birkenes, Froland
Kristiansand	1001	81167	776	Vest-Agder	Kristiansand
Mandal	1002	50945	3,442	Vest-Agder	Marnardal, Lindesnes, Songdalen, Søgne, Vennesla, Mandal
Hægebostad	1003	37687	6,866	Vest-Agder	Åseral, Hægebostad, Audnedal, Sirdal, Kvinesdal, Lyngdal, Flekkefjord, Farsund
Hundvåg	1101	13239	6	Rogaland	
Tasta	1102	14365	11	Rogaland	
Eiganes og Vålan	1103	24183	8	Rogaland	
Madla	1104	21068	15	Rogaland	
Storhaug	1105	12646	7	Rogaland	
Hillevåg	1106	17408	8	Rogaland	
Hinna	1107	20655	15	Rogaland	
Eigersund	1108	49939	4,675	Rogaland	Bjerkreim, Lund, Sokndal, Gjesdal, Eigersund, Hå
Time	1109	33009	730	Rogaland	Time, Klepp
Sandnes	1110	63902	355	Rogaland	Sandnes

Sola	1111	33084	656	Rogaland	Randaberg, Sola
Karmøy	1112	39420	2,207	Rogaland	Utsira, Karmøy
Strand	1113	23550	4,848	Rogaland	Forsand, Hjelmeland, Suldal, Sauda, Strand
Vindafjord	1114	26468	2,556	Rogaland	Kvitsøy, Bokn, Finnøy, Rennesøy, Vindafjord, Tysvær
Haugesund	1115	34249	366	Rogaland	Haugesund
Arna	1201	12619	102	Hordaland	
Bergenhus	1202	39703	27	Hordaland	
Fana	1203	40663	160	Hordaland	
Fyllingsdalen	1204	28772	19	Hordaland	
Laksevåg	1205	37026	32	Hordaland	
Ytrebygda	1206	24175	39	Hordaland	
Årstad	1207	33955	8	Hordaland	
Åsane	1208	39086	71	Hordaland	
Stord	1209	44000	3,927	Hordaland	Tysnes, Fitjar, Austevoll, Sveio, Bømlo, Stord
Kvinnherad	1210	30576	8,074	Hordaland	Eidfjord, Jondal, Ulvik, Ullensvang, Etne, Odda, Kvinnherad
Fjell	1211	32066	2,320	Hordaland	Øygarden, Sund, Fjell
Voss	1212	58024	5,329	Hordaland	Granvin, Samnanger, Fusa, Vaksdal, Osterøy, Kvam, Voss, Os, Modalen
Askøy	1213	55509	2,467	Hordaland	Fedje, Masfjorden, Austrheim, Radøy, Meland, Lindås, Askøy
Balestrand	1401	57119	16,815	Sogn og Fjordane	Solund, Balestrand, Hyllestad, Aurland, Leikanger, Lærdal, Gulen, Fjaler, Vik, Gaular, Askvoll, Høyanger, Luster, Årdal, Sogndal, Førde
Naustdal	1402	49376	10,295	Sogn og Fjordane	Hornindal, Naustdal, Selje, Jølster, Bremanger, Gloppen, Eid, Vågsøy, Stryn, Flora
Ørsta	1501	62531	6,886	Møre og Romsdal	Stordal, Norddal, Ørskog, Sande, Vanylven, Stranda, Hareid, Ulstein, Sykkylven, Herøy, Volda, Ørsta
Alesund	1502	70509	2,446	Møre og	Skodje, Giske, Sula, Haram, Ålesund

				Romsdal	
Molde	1503	63430	7,602	Møre og Romsdal	Sandøy, Midsund, Gjemnes, Nesset, Aukra, Eide, Vestnes, Rauma, Fræna, Molde
Kristiansund	1504	54279	9,363	Møre og Romsdal	Halsa, Rindal, Smøla, Tingvoll, Aure, Averøy, Surnadal, Sunndal, Kristiansund
Midtbyen	1601	43238	53	Sør-Trøndelag	
Østbyen	1602	45677	74	Sør-Trøndelag	
Lerkendal	1603	53037	76	Sør-Trøndelag	
Heimdal	1604	28933	139	Sør-Trøndelag	
Røros	1605	64507	15,897	Sør-Trøndelag	Tydal, Holtålen, Rennebu, Meldal, Selbu, Røros, Klæbu, Midtre Gauldal, Oppdal, Malvik, Melhus
Orkdal	1606	54637	12,542	Sør-Trøndelag	Roan, Snillfjord, Osen, Agdenes, Åfjord, Hemne, Hitra, Frøya, Bjugn, Ørland, Rissa, Skaun, Orkdal
Nord-Trøndelag	17	131440	29,688	Nord-Trøndelag	Steinkjer, Namsos, Meråker, Stjørdal, Frosta, Leksvik, Levanger, Verdal, Mosvik, Verran, Namdalseid, Inderøy, Snåsa, Lierne, Røyrvik, Namsskogan, Grong, Høylandet, Overhalla, Fosnes, Flatanger, Vikna, Nærøy, Leka
Nordland	18	234483	81,003	Nordland	Bodø, Narvik, Bindal, Sømna, Brønnøy, Vega, Vevelstad, Herøy, Alstahaug, Leirfjord, Vefsn, Grane, Hattfjelldal, Dønna, Nesna, Hemnes, Rana, Lurøy, Træna, Rødøy, Meløy, Gildeskål, Beiarn, Saltdal, Fauske, Sørfold, Steigen, Hamarøy, Tysfjord, Lødingen, Tjeldsund, Evenes, Ballangen, Røst, Flakstad, Vestvågøy, Hadsel, Bø, Øksnes, Sortland, Andøy, Moskenes
Troms Romsa	19	155434	41,133	Troms Romsa	Harstad, Tromsø, Kvæfjord, Skånland, Bjarkøy, Ibestad, Gratangen, Lavangen, Bardu, Salangen, Målselv, Sørreisa, Dyrøy, Tranøy, Torsken, Berg, Lenvik, Balsfjord, Karlsøy, Lyngen, Storfjord, Kåfjord, Skjervøy, Nordreisa, Kvænangen
Finnmark	20	72753	74,294	Finnmark	Vardø, Vadsø, Hammerfest, Kautokeino, Alta, Loppa, Hasvik,

Finnmàrku				Finnmàrku	Kvalsund, Måsøy, Nordkapp, Porsanger, Karasjok, Lebesby, Gamvik, Berlevåg, Tana, Nesseby, Båtsfjord, Sør-Varanger
Stockholm*	21	0	0		
Gothenburg*	22	0	0		

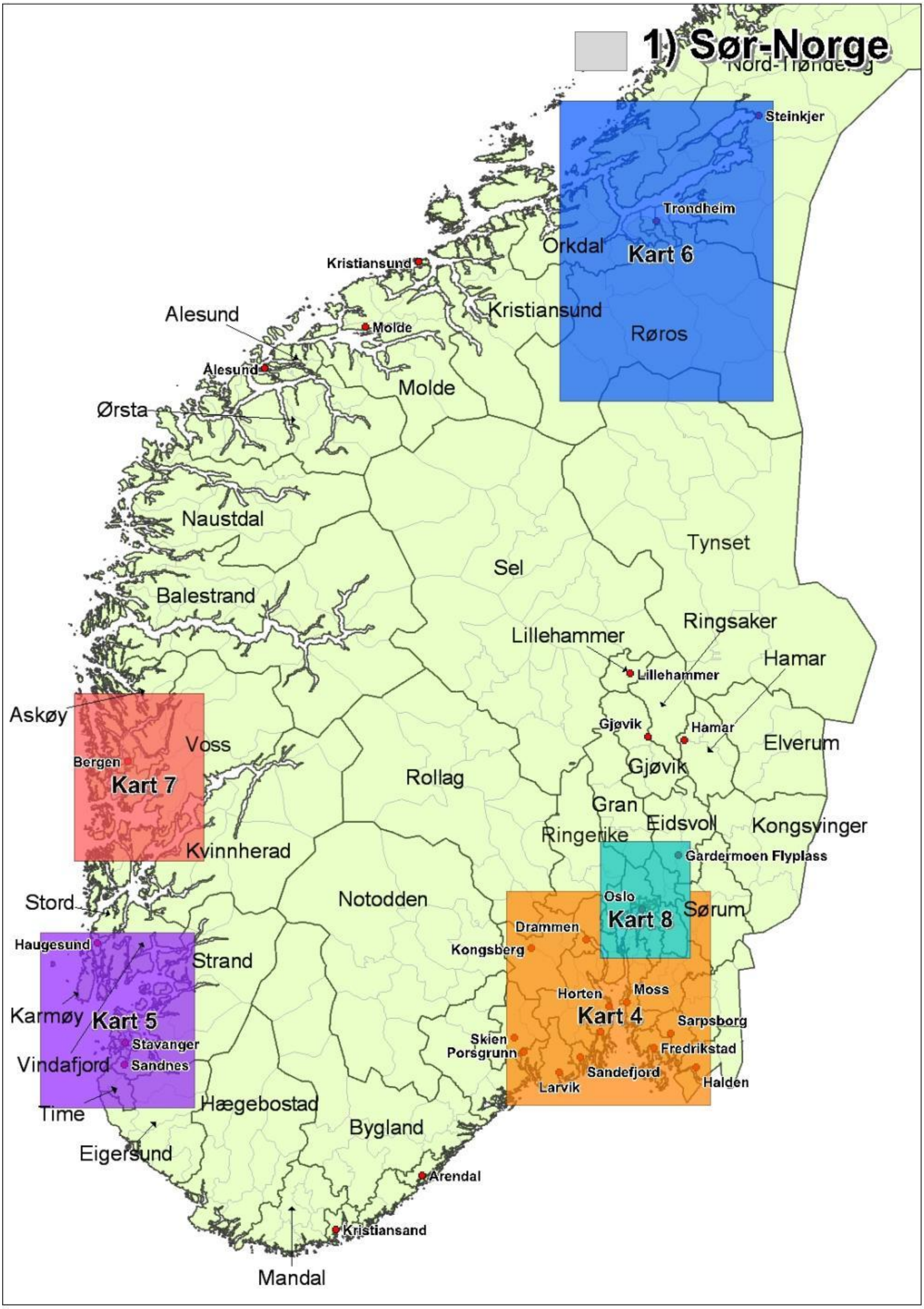
*These zones are treated as points and represent no area or population

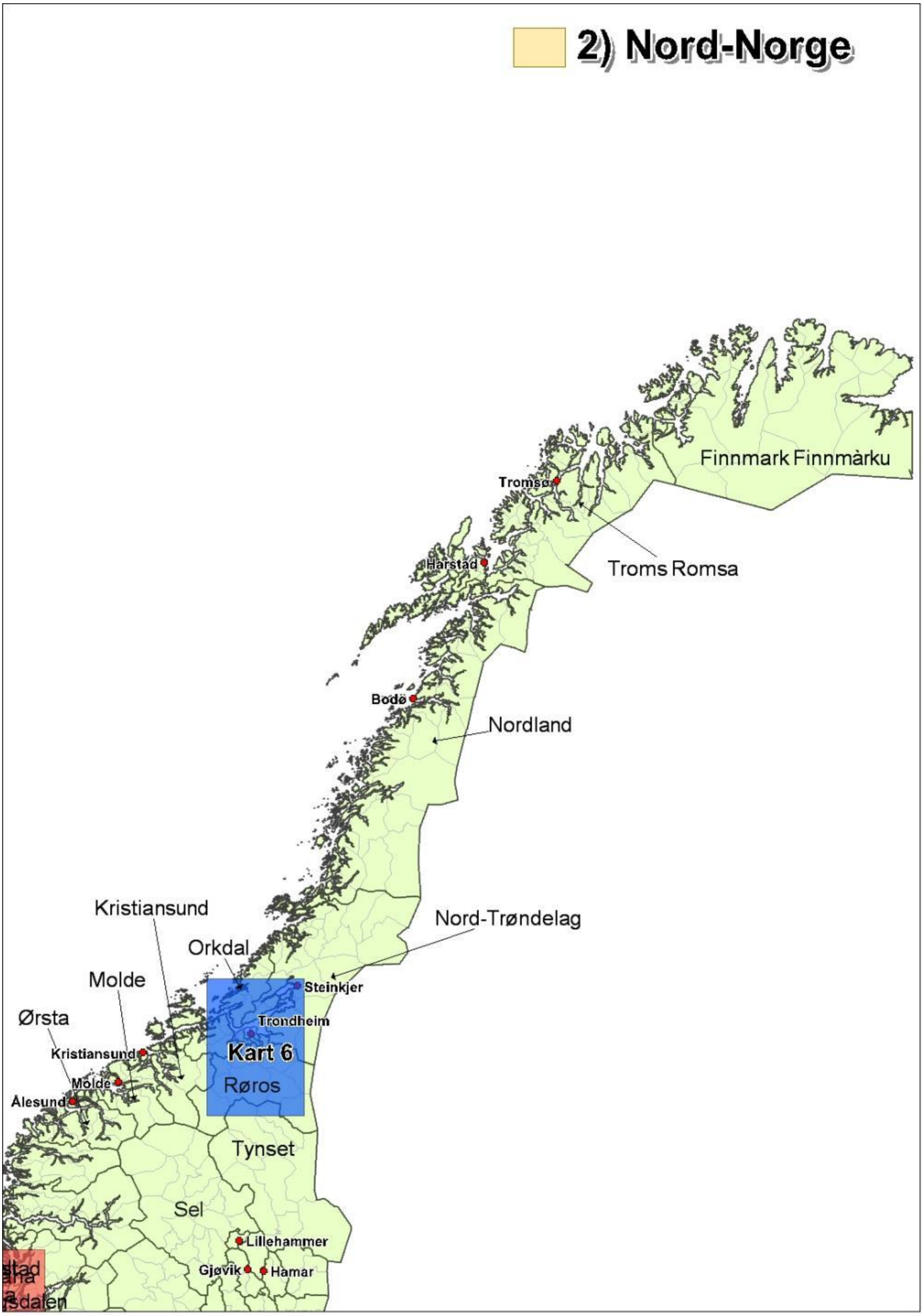
**Area includes territorial waters

C.5. Map of Zones

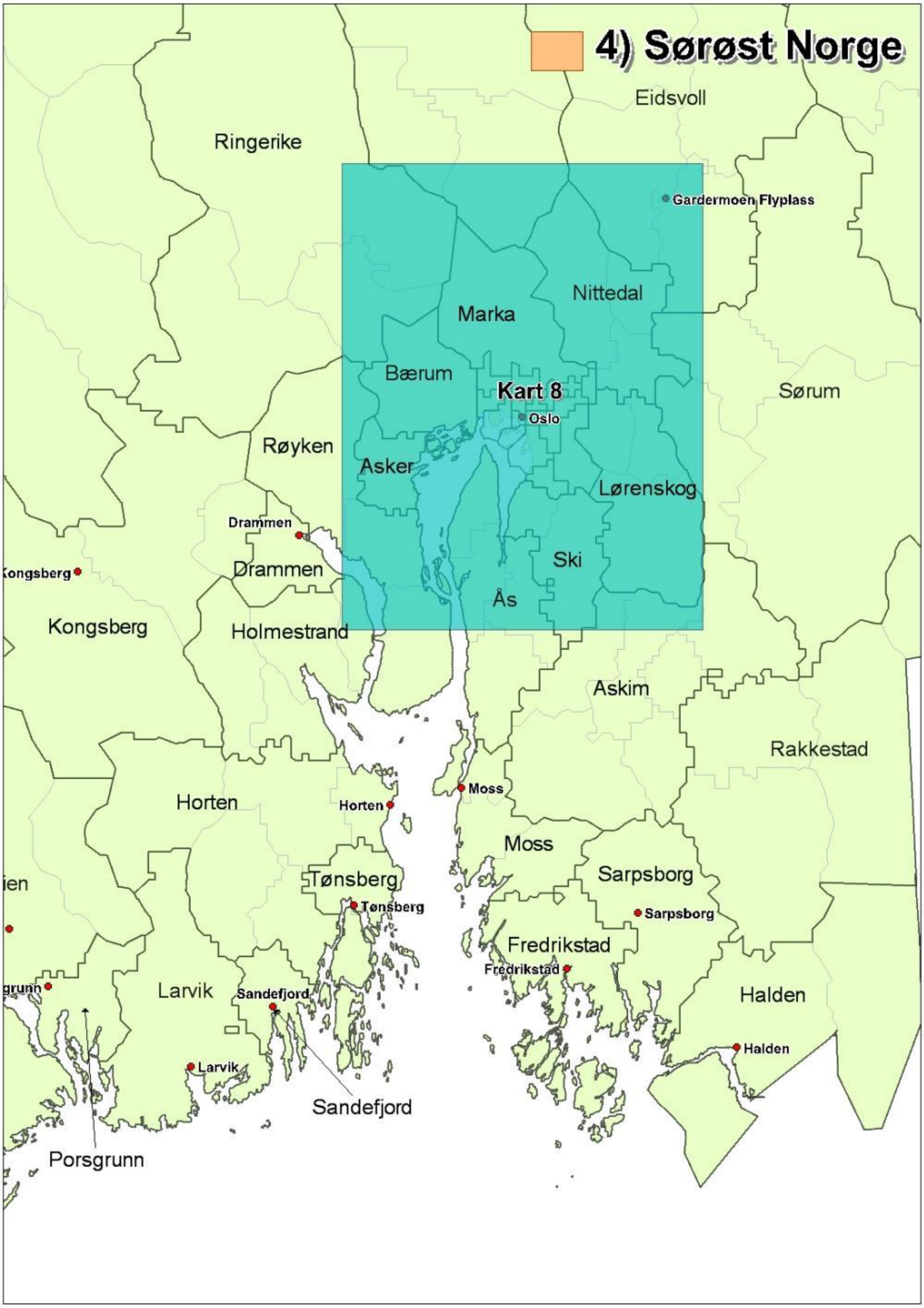
The following maps give an indication of the location of the zones.

- Sør-Norge – gives an overview of Southern Norway;
- Nord-Norge – gives an overview of Northern Norway;
- Sørvest Norge – gives a more detailed view of South-West Norway;
- Sørøst Norge – gives a more detailed view of South-East Norway;
- Stavanger og Haugesund – shows the Stavanger urban area, including Haugesund;
- Trondheim – shows the Trondheim urban area;
- Bergen – shows the Bergen urban area; and
- Oslo-området – shows Oslo and the surrounding areas.


1) Sør-Norge
Steinkjer
Trondheim
Orkdal
Kart 6
Kristiansund
Kristiansund
Røros
Molde
Molde
Alesund
Ålesund
Ørsta
Naustdal
Tynset
Sel
Balestrand
Ringsaker
Lillehammer
Lillehammer
Hamar
Askøy
Gjøvik
Hamar
Elverum
Voss
Bergen
Kart 7
Gjøvik
Rollag
Gran
Eidsvoll
Kongsvinger
Ringerike
Gardermoen Flyplass
Kvinnherad
Stord
Notodden
Oslo
Kart 8
Sørum
Drammen
Kongsberg
Haugesund
Strand
Horten
Moss
Karmøy
Kart 5
Kart 4
Sarpsborg
Stavanger
Skien
Porsgrunn
Fredrikstad
Vindafjord
Sandnes
Sandefjord
Halden
Larvik
Time
Hægebostad
Bygland
Eigersund
Arendal
Kristiansand
Mandal

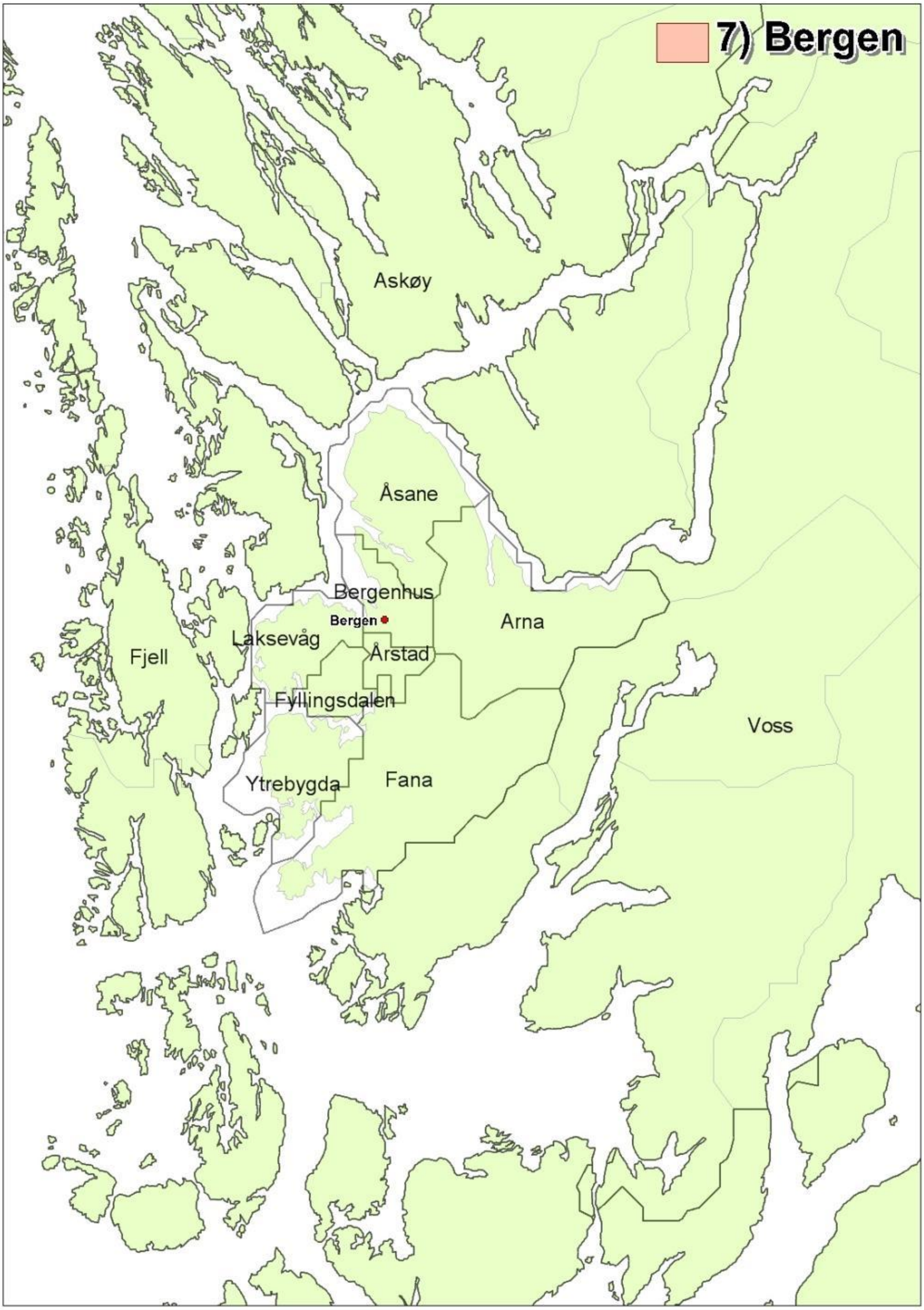

2) Nord-Norge
Finnmark Finnmàrku
Tromsø
Troms Romsa
Harstad
Bodø
Nordland
Kristiansund
Orkdal
Nord-Trøndelag
Molde
Steinkjer
Ørsta
Trondheim
Kristiansund
Kart 6
Molde
Røros
Ålesund
Tynset
Sel
Lillehammer
Gjøvik
Hamar

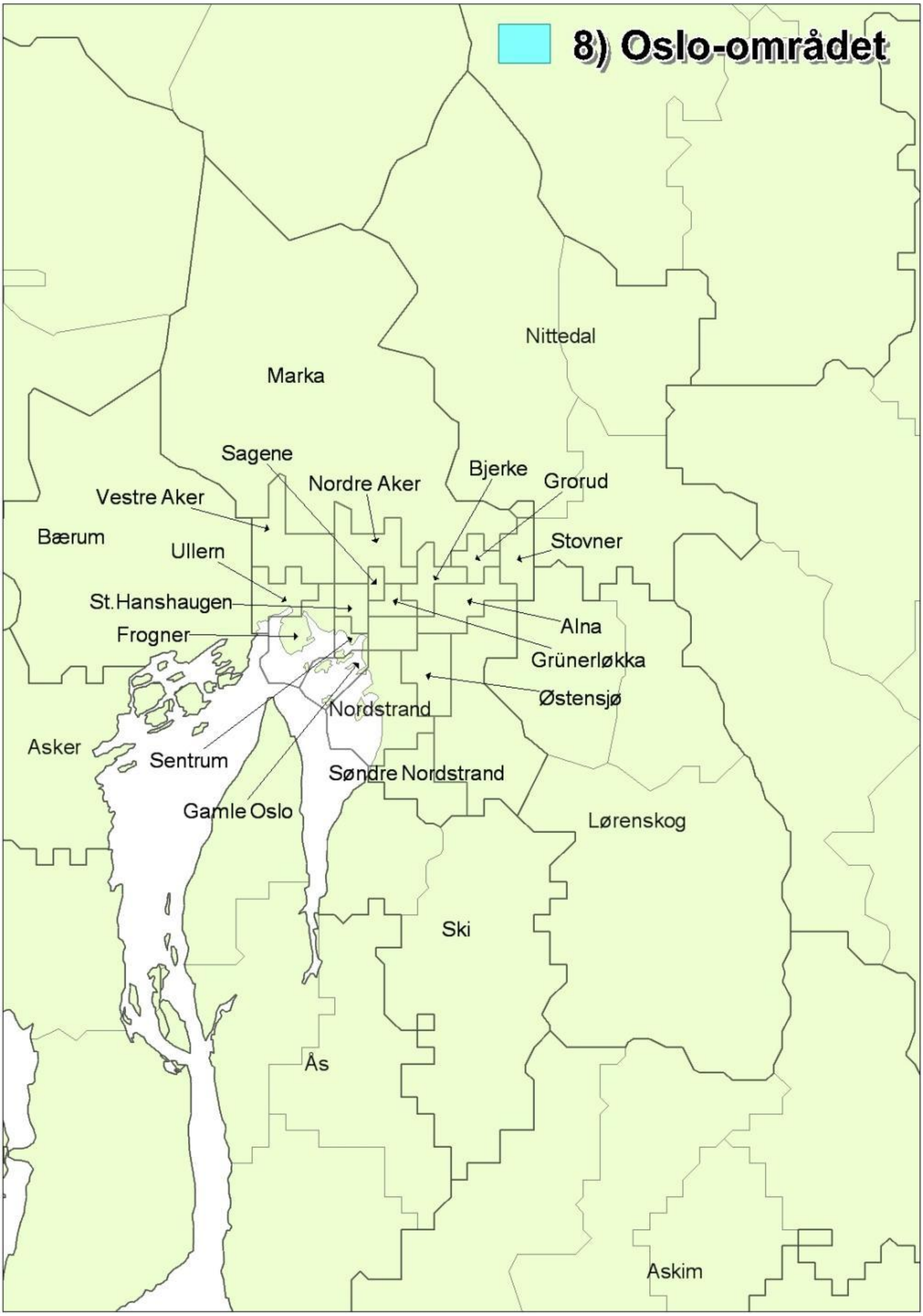

3) Sørvest Norge
Voss
Rollag
Ringerike
Kvinnherad
Bærum
Røyken
Asker
Drammen
Kongsberg
Notodden
Holmestrand
Kongsberg
Strand
Horten
Horten
Skien
Drangedal
Tønsberg
Skien
Porsgrunn
Larvik
Sandefjord
Bygland
Larvik
Porsgrunn
Hægebostad
Arendal
Arendal
Mandal
Grimstad
Kristiansand
Kristiansand


4) Sørøst Norge
Eidsvoll
Ringerike
Gardermoen Flyplass
Nittedal
Marka
Bærum
Kart 8
Oslo
Sørum
Røyken
Asker
Lørenskog
Drammen
Ski
Kongsberg
Drammen
Ås
Kongsberg
Holmestrand
Askim
Rakkestad
Moss
Horten
Horten
Moss
Sarpsborg
Tønsberg
Tønsberg
Sarpsborg
Fredrikstad
Fredrikstad
Larvik
Sandefjord
Halden
Halden
Larvik
Sandefjord
Porsgrunn


5) Stavanger og Haugesund
Haugesund
Haugesund
Vindafjord
Karmøy
Eiganes og Vålan
Tasta
Hundvåg
Strand
Storhaug
Sola
Stavanger
Madla
Hinna
Hillevåg
Sandnes
Sandnes
Time
Eigersund


6) Trondheim
Midtbyen
Trondheim
Orkdal
Heimdal
Nord-Trøndelag
Østbyen
Lerkendal
Kristiansund
Røros


7) Bergen
Askøy
Åsane
Bergenhus
Bergen
Arna
Laksevåg
Årstad
Fjell
Fyllingsdalen
Voss
Ytrebygda
Fana


8) Oslo-området
Nittedal
Marka
Sagene
Nordre Aker
Bjerke
Grorud
Vestre Aker
Bærum
Ullern
Stovner
St.Hanshaugen
Frogner
Alna
Grünerløkka
Østensjø
Nordstrand
Asker
Sentrum
Søndre Nordstrand
Gamle Oslo
Lørenskog
Ski
Ås
Askim

Appendix D. **Multiple high speed service patterns – the rooftop model**

D.1. Introduction

This appendix describes the representation of service patterns within the mode choice model for Phase III of the Norwegian High Speed Rail (HSR) assessment. Reflecting its strategic purpose, the mode choice model assumes an 18-hour period of operation for air and rail services. This technical note describes the rooftop model used to derive the impact of a proposed services journey time and frequency on the utility of travel. This enables alternatives to be tested running dual HSR services with separate journey times and frequencies.

D.2. The Rooftop Model

D.2.1. Theory

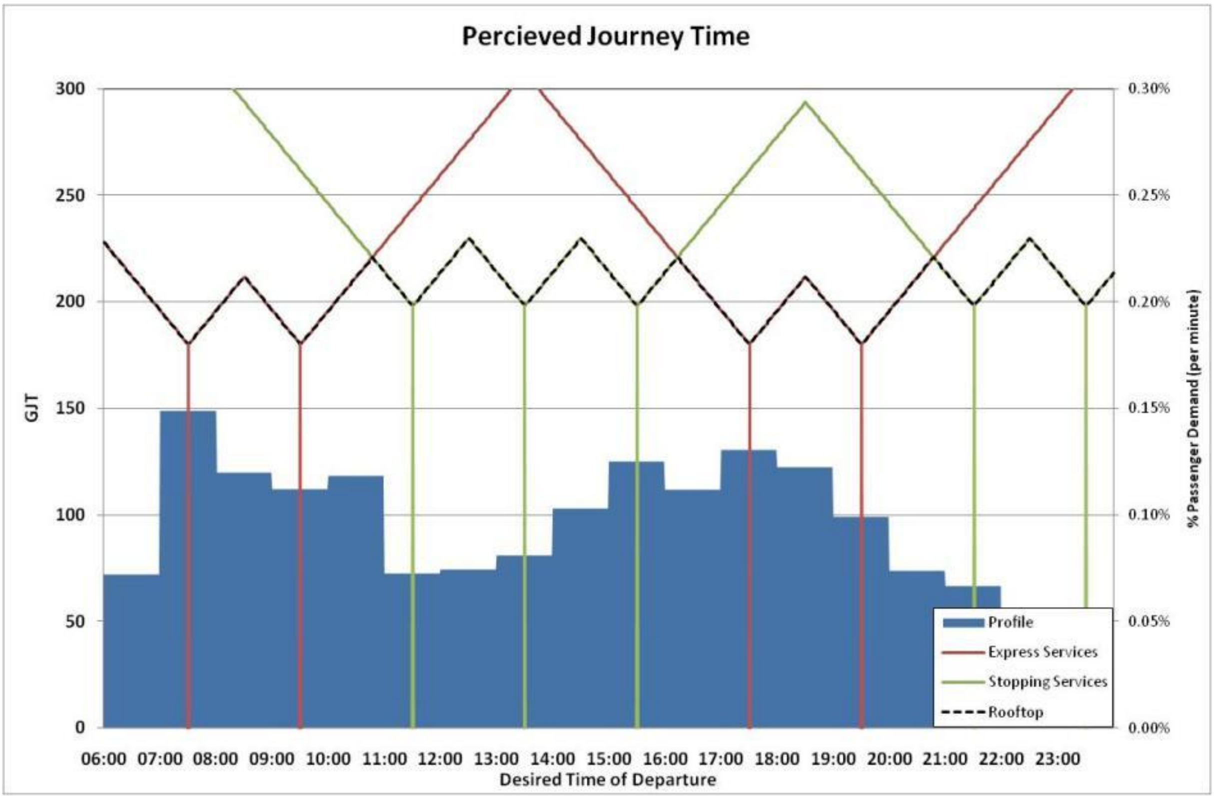
Where journey time is constant and frequency is perfectly regular the impact of these two variables on the utility of travel are easy to calculate. Where services include both faster and slower services, or do not operate to a clock-faced timetable the impact on utility is not so straightforward. To enable the impact of running stopping services alongside express services the rooftop model is used.

The rooftop model estimates the perceived journey time of a rail service between two stations with an example shown in **Error! Reference source not found.** below (this could be extended to include the other aspects of utility such as access time or interchange penalties although in the Norwegian High Speed study these are consistent between services).

Within **Error! Reference source not found.** the y-axis represents GJT (in minutes) whilst the x-axis represents both train departure times and the desired departure times of passengers wishing to travel. In the example below two services are represented; a ‘red’ express train taking 180 minutes (departing at 07:30, 09:30, 17:30 and 19:30), and a ‘green’ stopping service taking 198 minutes (departing at 11:30, 13:30, 15:30, 21:30 and 23:30). The vertical lines show the departure time of each service and the in-vehicle time for each departure.

It is assumed that passengers can have a desired departure time anywhere along the x-axis and also have the same aversion to travelling earlier or later. The extent of the aversion is reflected in the gradients of the diagonal line. Therefore for any desired departure time, the rooftop model defines which train a passenger will catch, and the perceived journey time. The perceived journey time of the rail service is the average height of the rooftop, weighted by the percentage of people desiring to depart at each time. The PDFH recommends that a demand profile be applied, when weighting journey times, if headways of over 3-hours are considered otherwise a flat profile can be used. (The model is not appropriate for assessing headways of less than 3 hours as they are outside of the extent of data collected by the stated preference surveys.)

Rooftop Model



D.2.2. Application

The rooftop model for the Norwegian High Speed rail study is calculated in excel and is based on the results of the SP survey. The rooftop model calculates the utility of travel as a result of journey time and headway for both business and leisure passengers, who have different valuations of headway with respect to in-vehicle time. The additional components of utility (e.g. access time, wait time) are the same for each service and are considered at a later stage within the mode choice model.

For the purposes of application in the mode choice model the rooftop model then splits the utility back out into valuations by journey time and headway. This serves the purposes of providing a format suitable for input into the mode choice model and for economic analysis.

Using the model derived from the SP surveys, the contribution of headway to the total utility of travel by HSR is calculated using the following formula:

$$\beta_s \frac{1}{S}$$

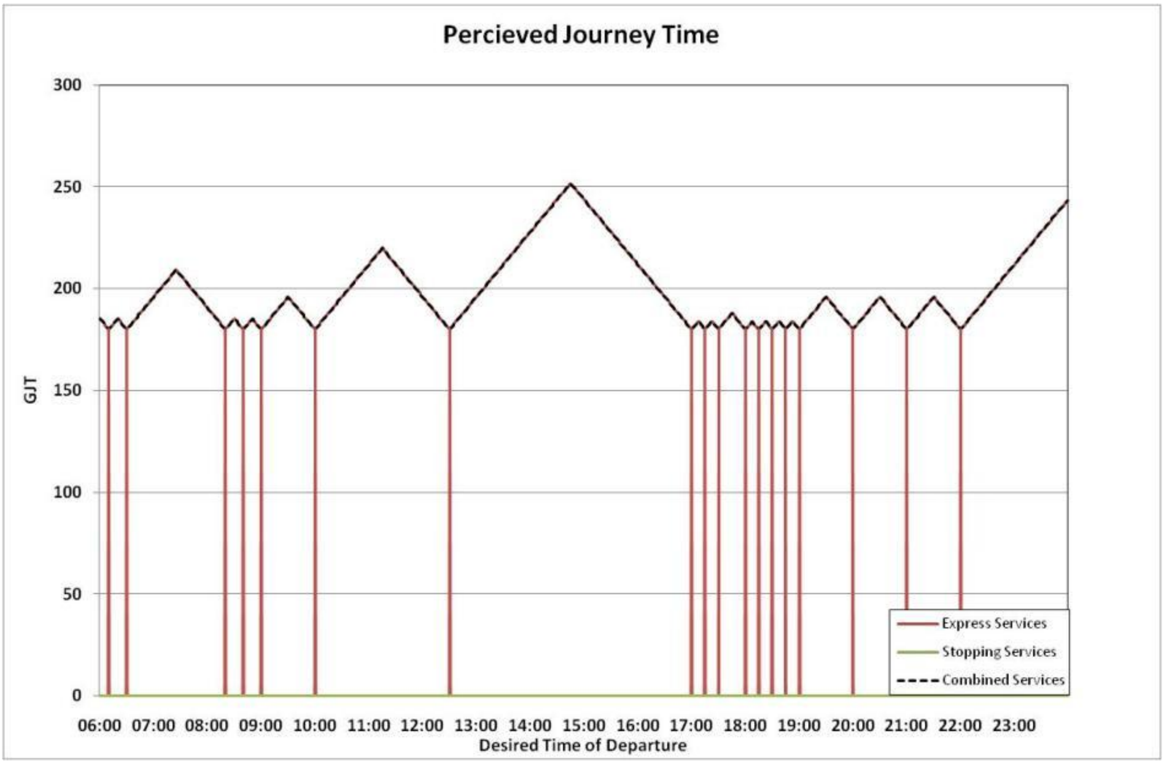
- Where:
- S is the number of high speed services in each day
- β_s is the frequency coefficient

The assumption using the formula above is that services are evenly distributed throughout the day. When splitting the utility calculated in the rooftop model back into the individual components of journey time and headway it is assumed that the headway is equal to the number minutes in a day divided by the number of services in a day (regardless of the time of departure). The average journey time then taken as that time required to give the utility calculated. As a result, due to uneven headways, the perceived average journey time can be different to the actual in-vehicle time.

As an example **Error! Reference source not found.** shows a service operating 18 trains a day with journey time of 180 minutes and a regular service pattern, here the perceived journey time is the same as the in-vehicle time; 180 minutes. Although **Error! Reference source not found.** also shows a service also operating 18 trains a day with journey time of 180 minutes in this example the uneven service pattern results in a perceived average journey time of 191 minutes. This is due to the disparity between passengers desired departure times and the departure times available.

Clock-Faced Timetable

Non Clock Faced Timetable



In conjunction with the mode choice model the rooftop model allows tests to be undertaken investigating the impact upon demand and revenue of;

- irregular service for a single service
- Three different high speed rail services (e.g. an express service, a core service, and a stopping service) running with separate stopping patterns and journey times.
- An irregular service pattern between the above (e.g. express services in the peak, stopping services in the inter-peak).

Appendix E. Key model outputs

E.1. Description of Summary Tables

This appendix contains a single summary sheet containing an example of the key mode share model outputs:

Firstly the sheets contains a schematic of the corridor under consideration and a table giving stations and journey times\train frequencies as entered into the mode choice model following an incorporation into the roof top model (as described in Appendix D).

The remaining tables\figures contain results for each corridor and include:

E.1.1. Summary of demand and revenue

The table gives daily and annual figures of:

- Demand in terms of passenger numbers on HSR (including a breakdown by business and leisure travellers);
- Demand in terms of passenger km of HSR. In many respects this is a better figure of demand than passenger numbers which does not differentiate between short intermediate trips and end-end trips;
- HSR train km. The number of HSR train km assumed to be operated within the scenario;
- Average train occupancy, assumed to be passenger km divided by train km: actual loading figures will vary across the length of the route and time of day; and
- Total revenue split by business and leisure passengers, in 2009 values.

E.2. Mode share by HSR journey length

Mode share is shown for all trips of a given length where passengers have a total HSR access egress time of less than two hours. The access time limitation is to ensure a defined catchment is set for mode share – which can suffer from wide ranges in definition when compared across different markets. For instance some passengers may travel a large distance to access\egress high speed stations, including these zones within the below analysis would not contain many more HSR trips in the analysis, and would show an increased mode share of car. The figure contains results from the mode choice model only as by definition the mode share cannot be derived from the gravity model.

The figures demonstrate the relative competitiveness of HSR by journey length. Generally it would be expected that the HSR mode share will increase with distance over the corridors assessed. It would be anticipated that car would dominate over shorter distances as it is better served to meet ultimate origins\destination and is faster than total rail time over shorter distances. Over longer distances we would expect the air mode share would be expected to increase and obtain a larger share of demand than high speed rail. This output both provides analysis for results and corridor comparison and a sense check of model results (i.e. large air mode shares shown over short distances would highlight an issue with modelling results.)

E.2.1. Summary of high speed demand by originating mode

This figure contains two pie charts showing the proportion of high speed rail demand as forecast from the mode choice model who originally would have:

- Made their journey by air;
- Made their journey by the existing rail network;
- Made their journey by coach;
- Made their journey by car;
- Made their journey by ferry; or
- Would not have travelled without the HSR service

Of the two pie charts the pie on the left hand side shows the originating mode by HSR trips whilst the one on the right shows the originating mode by HSR km.

E.2.2. High speed rail mode share by airport catchments

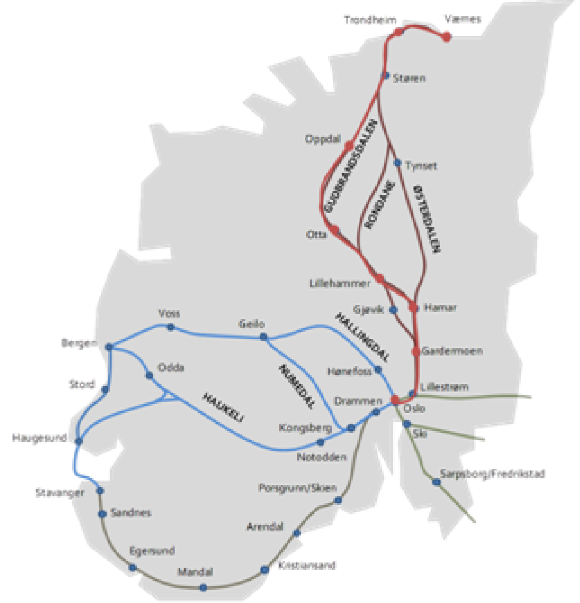
This figure shows the proportion of demand between two airport catchments (as defined by the mode choice model) that would travel by high speed rail under the scenario in question. For example where Bergen Airport and Gardermoen Airport intersect the figure is the percentage of all traffic between the catchments around these two airports that would travel by HSR as opposed to by air, car, coach, rail or ferry.

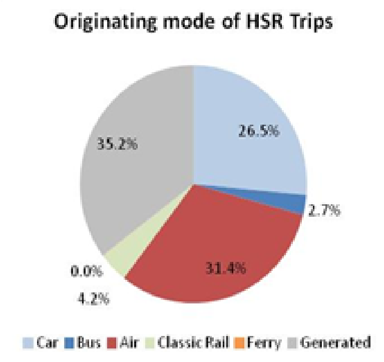
E.2.3. Indicative station-station demand

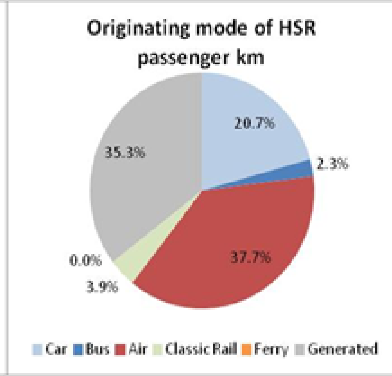
The final table contains an estimate of daily demand matrix between high speed stations. Demand is labelled as estimated as individual station usage is limited by the zone system and representation of the road and rail network access. This can result in demand being incorrectly allocated between neighbouring stations when one occupies a significantly larger zone than the other.

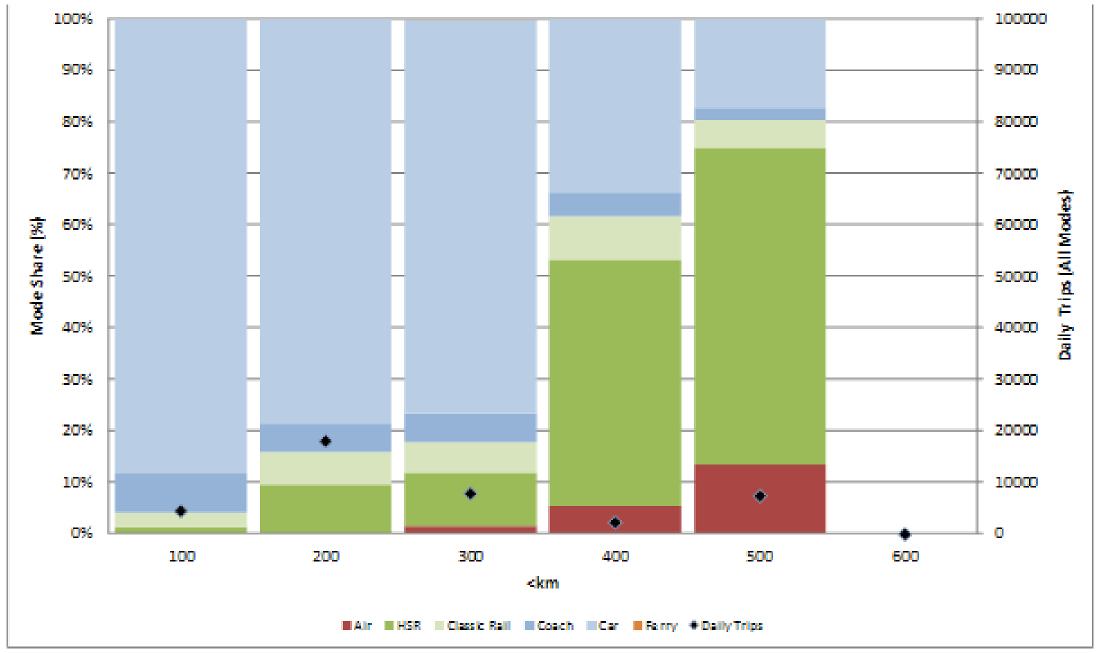
Route / alignment description	Ref	Alt.
Oslo – Trondheim (Hamar & Gudbrandsdalen)	G3Y	250

Station	Peak Fast JT	Peak Fast Hway	Core JT	Core Hway
Oslo S	0	135	0	60
Gardermoen	31	135	22	60
Hamar	56	135	47	60
Lillehammer	73	135	64	60
Otta		0	90	60
Oppdal		0	124	60
Trondheim	153	135	155	60
Værnes		0	168	60









2024	TOTAL	
Demand	**Annual [k]**	**Per day [k]**
Total HSR Passengers	**4424**	**12.12**
HSR Business Passengers	1873	5.13
HSR Leisure Passengers	2551	6.99
HSR passenger km [million]	**1607**	**4.40**
Revenue NOK [p.a.]	**Annual [million]**	**Average yield**
HSR Total revenue	**1475**	**308**
HSR revenue from Business travel	820	404
HSR revenue from Leisure travel	655	237
HSR Train km	**Annual [k]**	**Per day [k]**
Total HSR Train km	**9971**	**27.3**
Average Train Occupancy	**163.5**	

Station	Oslo Distance (km)	HSR Daily Trips: Oslo S	Hamar	Gardermoen	Lillehammer	Otta	Oppdal	Trondheim	Værnes	Total
Oslo S	0	0	679	0	173	500	554	1665	509	4079
Hamar	117	713	0	24	48	21	33	88	23	949
Gardermoen	48	0	24	0	9	83	117	585	233	1052
Lillehammer	182	185	48	10	0	17	32	73	19	384
Otta	273	516	21	85	17	0	90	229	72	1030
Oppdal	390	571	33	119	32	101	0	76	33	966
Trondheim	496	1693	88	592	74	231	84	0	0	2763
Værnes	525	514	23	235	19	72	36	0	0	899
Total		4192	917	1067	372	1024	946	2715	888	12120

High Speed Rail: Mode Share

Airport Catchments	Gardermoen Airport	Sandefjord (Torp) Airport	Trondheim Airport	Bergen Airport	Stavanger Airport	Kristiansand Airport	Stockholm	Gothenburg	Bodø lufthavn	Trømsø lufthavn	Huegesund	Ålesund lufthavn, Vigra	Kristiansund, Kvernberget	Alta lufthavn	Molde lufthavn, Årø
Gardermoen Airport	5%	0%	41%	3%	0%	0%	0%	0%	0%	0%	0%	5%	33%	0%	15%
Sandefjord (Torp) Airport	0%	0%	25%	0%	0%	0%	0%	0%	7%	0%	0%	0%	0%	0%	0%
Trondheim Airport	41%	25%	2%	5%	1%	3%	0%	0%	0%	0%	0%	4%	5%	0%	5%
Bergen Airport	3%	0%	5%	0%	0%	0%	0%	0%	3%	0%	0%	0%	1%	0%	0%
Stavanger Airport	0%	0%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Kristiansand Airport	0%	0%	3%	0%	0%	0%	0%	0%	2%	0%	0%	0%	0%	0%	0%
Stockholm	0%	0%	0%	0%	0%	0%	0%		0%	0%	0%	0%	0%	0%	0%
Gothenburg	0%	0%	0%	0%	0%	0%		0%	0%	0%	0%	0%	0%	0%	0%
Bodø lufthavn	0%	7%	0%	2%	0%	2%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Trømsø lufthavn	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Huegesund	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Ålesund lufthavn, Vigra	5%	0%	4%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Kristiansund, Kvernberget	33%	0%	3%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Alta lufthavn	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Molde lufthavn, Årø	16%	0%	5%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

Appendix F. **Model Estimation**

This brief appendix covers the developments in model estimation that have led to changes in the model structure and parameters shown in Table 4 of this report relative to those from Phase II.

The model parameters provided in Section 4 of this report are a result of models estimated from SP data the methodology of which can be sound in ‘Contract 5: Market Analysis, Subjects 2 and 3: Expected Revenue and Passenger Choices’. During Phase III additional analysis was carried out, this additional analysis was compatible with the requirements described under Section 2.4 above. A brief description of the additional analysis undertaken during this phase, and the impact this has had on the main model parameters is provided below:

During this phase significant work has been conducted in cleaning the dataset used for model estimation. This has helped to remove outliers that had the potential of biasing results and has allowed a better representation of the air-HSR trade-offs. This has improved the fit of the models and has allowed for a better estimate of separate travel time components for air.

In order to develop parameters for the dual nesting structure SP data was additionally segmented from the previous phase according to whether the trip under consideration was from an origin-destination pair that had air available as a feasible alternative. The model was set up to include different scales to capture the potential differences in error variance between the data from these respondents, and to allow different scales on each of the mode combinations under consideration. This structure allowed consistent estimates of the sensitivity to journey time, cost, and other service attributes between those who were making trips where air was or was not an available alternative, but allowed the development of separate mode nesting structures for these cases.

As a result of the above the final model differs from the Phase II model in the following aspects:

- Separate models have been estimated for instances where; air is a current option for travel, and where air is not an existing option for travel.
- The primary mode choice model where air is available now has a significant lower nest for HSR-air. Previously no significant nest had been found for the non-work model which was essential multinomial in structure applied with by pairing HSR with air and implemented with an artificial nest using a scale parameter of 1.0.
- In the original model a single parameter was provided for air door-to-door time. The updated model estimation has found separate terms for IVT, access/egress and waiting time making the valuation of air more consistent with other public transport modes.

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