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FINDING THE OPTIMAL SEAT CAPACITY FOR TRAIN-SERVICES USING TRANSPORT MODELS

DEPARTMENT OF TRANSPORT

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ABSTRACT

This master thesis project aims to estimate the optimal capacity for the rush period in the Jæren line, particularly in the service between Stavanger and Egersund. The study is based on the modelled demands using the part-area-model DOM_Jæren of the Norwegian Regional Transport Model.

The general idea and methodology behind the transport models is described in this report, as well as, a deeper analysis on the Norwegian Transport Models, especially the Regional Transport Model.

The transport model used is validated and calibrated with respect to observed train passengers' counts. Potential sources of errors in modelling the train demand are identified and understood in order to update the model, and hence improving the simulation.

Society is nowadays demanding more comfortable means of transport. Therefore, in the decision process of a possible public transport user new variables might be involved. A review of different comfort variables is encompassed in this project.

Including crowding in the demand model is proposed and developed. The perception of travel time on board of a crowded carriage could be perceived as longer for some users. In this report, different crowding factors are suggested in order to use them as travel time multipliers. A possible methodology for implementing crowding in the model is also described. In addition, potential passengers' reactions towards highly occupied carriages are analysed.

After obtaining an updated and crowding dependent load profile for the line Stavanger - Egersund, the optimal capacity in the rush period is estimated. On one hand, based on an economic approach using the marginal utility and cost of an extra vehicle or carriage. On the other, a method based on the demand profile and frequencies.

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1. INTRODUCTION

The Norwegian National Transport Plan assumes that all growth is absorbed by public transport, cycling and walk (Meld.St.26, 2013). Nevertheless, the increase in population joined to higher salaries enhance the desire towards owning a car, so it is unlikely to experience a reduction in car ownership. Several policies towards greener transports have been made without outstanding results, as from 2011 to 2012 there was an increment in car ownership of 2,8% (Statistics Norway, 2013).

Transport projects and policies are surrounded by many uncertainties. Transport analysis contributes in the decision process by quantifying transport impacts from the alternative strategies through transport models.

Traditionally, the general idea behind transport models is that they simulate a basis scenario, generally the actual situation, and different scenarios which entails exogenous changes by varying endogenous variables (measures to assess) (De Jong, et al., 2007). They are built according to the four-step model, trip generation, trip distribution, mode choice and route assignment.

Transport models in Norway are done in collaboration between different parties. These are the Ministry of Transport and Communications, Norwegian Public Roads Administration, Norwegian National Rail Administration, Norwegian National Coastal Administration and Avinor.

There are three main transport models, Freight Transport Model (for goods transportation), National Transport Model (journeys longer than 100 km), and Regional Transport Model (RTM) (trips shorter than 100 km), which this project is focused on.

Several variables are included into the model; the larger number the better approximation to reality but the more complexity into the model. Once the model is built it can be validated and calibrated with observed data to assess its performance. Conversely, the real behaviour is not correctly simulated in some situations.

The initial aim of this project is to evaluate if more variables should be included into the model and how they should be implemented in order to obtain closer results to reality. In particular, the variable of the study is comfort which is not included in the actual transport models but it might affect the attractiveness of the public transport service. There are several components describing comfort factors including seating, crowding and delays, which could be affected by the lack of capacity.

Crowding is studied in more detail, in particular in the Jæren line (Stavanger – Egersund) which is starting to suffer crowding problems at rush periods (Rogalandsavis, 2014). In this project, the response towards a loss in comfort of the train passengers is analysed. The Rogaland region is experiencing the fastest growth in the country, consequently, larger occupancies on board are expected to grow in the near future (Skarpen, 2014).

Figure 1: Bryne station (Jæren line) at morning peak (Source: retrieved from (Skarpen, 2014), photo: Refvem, F.)

One of the consequences of crowding is the loss of privacy experienced in the public transport. This enhances a shift towards private transport (Evans & Wener, 2007). Therefore a better understanding of crowding and hence passengers' behaviour could support the definition and implementation of more attractive public transport policies.

Once the new parameters are implemented in the transport model, the final purpose is to estimate the optimal seat capacity in the Jæren line for the rush periods (morning and afternoon). Two methods are discussed in this project, the economic, regarding the marginal cost and utility, and the load-profile, based on the demand's distribution.

1.1 STRUCTURE OF THE PROJECT

This project is structured in 10 sections, including introduction and appendix.

In section 2, possible comfort variables to be included in the transport model are described. Two features are discussed more in detail, these are crowding and capacity. The former gathers a background regarding what are the effects of crowding on board and how differently they are perceived. Moreover, the ways to measure it and values in the transport models are also mentioned.

In section 3, a definition of transport models is followed by the description of the Norwegian Transport Models, including the National Transport Model, the Regional Transport Model, and the part-area-model DOM- Jæren.

In section 4, the Jæren line is additionally commented. Socio-demographic features of the cities and towns where the most important stations within the line are described as well as some train policies and types. The different services using the line and their schedules are also mentioned.

In section 5, the part-area-model DOM-Jæren is validated and calibrated. Moreover, the crowding factors are defined and the methodology for implementing those factors into the demand model in the DOM-Jæren is explained.

In section 6, the simulated scenarios using the updated model are defined and observed. Comments about capacity constraints on the road and train service are included. Moreover, the results regarding passengers' behaviour when crowding is taking part in the decision process are analysed and discussed. Finally, a sensitivity analysis of the passengers' reactions towards different levels of crowding on board is conducted.

In section 7, based on the demand profile from the previous section, two methods are used in order to estimate the optimal seat capacity, economic and load profile approaches. The methods and results are described and discussed.

In sections 8 and 9, the discussion and conclusion take place. Some of the matters are the uncertainties of the model, the implementation of crowding on board in the model, the passengers reactions towards crowding and the estimation of the optimal seat capacity.

2. COMFORT VARIABLES

According to (Oxford, 2014), comfort is the *“easing or alleviation of a person’s feelings of grief or distress”*. It can be noted the mention to person, meaning that the feeling differs for each individual, thus the estimation is rather complex.

In transport models, mode choice for public transport is basically related to travel time (walking time, waiting time and on board time), cost, frequency and transfers.

The study of correlation among passengers and delays in the rail line Dovrebane between Oslo and Lillihamer (Veiseth, Indbryn, Olsson, & Sætermo, 2003) shows that the impacts in rush hours are higher, suggesting there are more aspects affecting the demand than the ones treated. Nowadays, demand could be more associated to quality and comfort features since users’ income are higher (Tirachini, Hensher, & Rose, 2013). Furthermore, new rail systems include reduction of crowding as important factor in the design (Henser, Rose, & Collins, 2011), often comparable to travel time savings (Li & Hensher, 2011).

2.1 CROWDING

Comfort on public transport can be partially measured through crowding, which refers to the amount of people in the vehicle. In general terms, both variables have an indirect relation, i.e. the higher the crowding is the lower the comfort becomes.

Effects of crowding

Some of the effects of crowding on board are mentioned henceforth. Invasion of space can lead to safety problems and perception of risk (Cox, Houdmont, & Griffiths, 2006); increased psychological stress (Middlemist, Knowles, & Matter, 1976); likelihood to arrive late on commute trips (Mohd Mahudin, Cox, & Griffiths, 2011); decreasing rate of production for passengers working on-board (Gripsrud & Hjorthol, 2012).

Dwell times are affected when the occupancy (ratio between the number of passengers and the number of seats) is over 60%, increasing the overall travel time (Fletcher & El-Geneidy, 2013), (Rail Operational Research, 1996). Nonetheless, this time increment varies depending on the passengers´ position. This is greater if users are standing close to doors (Katz & Garrow, 2012).

Not only crowding inside vehicles affects the travel time but also the occupancy at stations. Those with lower capacity might cause larger dwell times due to the difficulties associated to users for reaching the door or for leaving the vehicle (Lin & Wilson, 1992). In the case of Norwegian trains, these extra times at stations cause 13% of the delays according to the database TIOS (Tørset, 2014).

Perception of crowding

Through real observations it has been demonstrated that the stress on board is not related to the car occupancy but to the number of people sitting close to the passenger (Evans & Wener, 2007), confirming previous studies such as (Altman, 1975) or (Evans G. , 2001). In fact, some people prefer to stand up rather than occupy a seat next to one non-available (Fried & DeFazio, 1974). Middle seats are very aversive for passengers according to the study (Mc Geeham, 2005).

In addition, rail passenger stress levels might be related to the number of people in the entrance, since passengers need to cross it and the friction among them could be higher (Singer, Lundberg, & Frankenhauser, 1978).

On the other hand, vehicles almost empty might also trigger stress due to safety concerns, as well as, less active passengers given the quiet atmosphere. Talking to people leads to a higher satisfaction during the travel (Ettema , Friman, Gärling, Olsson, & Fujii, 2012).

Few papers in the literature on the effects of crowding on public transport demand accounts for subjectivity in the perception of crowdedness by the different users. This would lead to a better representation of the willingness to pay in order to reduce crowding (Whelan & Crockett, 2009).

The study (Mohd Mahudin, Cox, & Griffiths, 2012) proves that the reaction to the crowded situation depends on the evaluation of the physiological aspects (dense, chaotic…), ambient environment (noisy, smelly…) and passenger density. According to (Sudstom, 1978) the perception might also vary depending on aspects such us culture, individual factors (personality, sex, experience of crowds…), and modifiers (duration, activity…).

Concerning travel times, passengers are less sensitive to the crowding when the travel time on board is shorter (Lam, Cheung, & Lam, 1999), or in commute trips rather than in leisure ones (Wardman & Whelan, 2011).

A study of comfort perception in the line Oslo-Akershus showed that few passengers consider it important to have an available seat due to the short journey (Ruud, Ellis , & Norheim, 2010). However, there is a desirable maximum time of standing of approximately fifteen minutes on a crowded carriage based on an Australian survey (Thompson, Hirsch, Muller, & Rainbird, 2012).

Measurement of crowding

There is not a fixed standard to set the benchmark of comfort regarding crowding in trains since they are different in every country or region (Li & Hensher, 2013). Despite that, different methods to measure objective crowding have arisen in literature.

Occupancy or load factor (Whelan & Crockett, 2009), which can be estimated among seated or standing. Density of the standing passengers per square meter (Wardman & Whelan, 2011). Seat density, which is the number of people sitting in the same row as a passenger divided by the number of total seats in the row (Evans & Wener, 2007). Probability of getting a seat (Polydoropoulou & Ben-Akiva, 2001). Probability of occurrence (seated or standing) and length of time (Lu, Fowkes, & Wardman, 2008).

In addition to the objective crowding, different ways to measure the subjectivity of the crowding have been also studied in the literature. For example, how crowded people perceive the carriage, how they feel, and how they find the rest of physical environment (Mohd Mahudin, Cox, & Griffiths, 2012) . In the report (Zheng & Hensher, 2011) two different aspects are mentioned: how crowded people feel and how people rate sitting.

Crowding in transport models

Crowding can be added to the model as time multiplier (seventeen studies are reviewed in (Wardman & Whelan, 2011) and one in (Zheng & Hensher, 2011)); monetary value per minute (five studies are recorded in (Zheng & Hensher, 2011)); or hour or monetary value per trip (three studies are summarized in (Zheng & Hensher, 2011) and one in (Prud'homme , Koning, Lenormand, & Fehr, 2012)).

The Norwegian Rail Administration (Jernbaneverket) has developed a simplified model based on elasticities, denominated Trenklin. The demand elasticity for the actual generalized costs is estimated by using the RTM. The methodology behind the model is explained henceforward. The annual observed number of trips between stations for each line are split in three purposes: work, business and leisure. These annual values are adjusted to a weekday figures and distributed evenly among both directions. Posteriorly, these trips are assigned to hourly periods based on observed demand distributions. The new generalized costs including crowdedness factor as time multiplier are estimated by using a set of equations and algorithms. Including the elasticity in the Trenklin model and using the new GC it is possible to know the new demand for the line (Aarhaug, et al., 2013).

The effect of crowding should be considered from the earlier stages of appraisal of public transport projects, given that passengers may change their departure times, mode choice or route choice depending on the availability of seats (Tirachini, Hensher, & Rose, 2013). Improvements in the service towards a reduction of crowdedness could involve changes in frequency, services or in the design of the carriage itself.

Value of crowding

Despite there have not been previous studies about the value of crowding in Norway, some related information can be extracted from the National Travel Survey. The monetary value of getting a seat specific time along the trip in the public transport is shown in Table 1.

Table 1: Value of having a seat on short trips, base case: having to stand the whole trip. NOK/trip (Source: (Johansen & et al., 2010))

	Public transport
Seat on a quarter of the trip	5.00
Seat on half of the trip	14.30
Seat on most of the trip	24.00
Seat on the whole trip	27.50

From these data, it can be stated that passengers value more being seated in a trip, however, it is not possible to relate it to the trip length or occupancy in the carriage. It is highly recommended to conduct a local survey in crowding areas such as Oslo or Rogaland, in order to come up with national values. The design of the stated[1] preferences survey should be carefully planned since travellers perceive closely related reliability, overcrowding and frequency. Even though, the time span for this project is not enough to carry out this survey.

The train service operator NSB conducts a Customer Satisfaction Survey twice per year. Unfortunately for this project, the questions are not specific regarding passengers' feelings in crowding situations at peak periods and they cannot be related to passenger counts. Therefore, the results are not used for building a new analytical model (Tørset, 2014).

The previously mentioned Trenklin model makes some assumptions in order to obtain the crowding factor. Up to 60% of occupancy rate the crowding factor is 1, in accordance with the literature. Between 60% and 100% the crowding factor increases linearly. Finally, for levels of occupancies higher than 100%, the crowding factor has steeper increase and it is divided between travel time standing or seated, as crowding would not be affected in the same way standing and seated passengers. These crowding factor values are based on the study review (Wardman & Whelan, 2011).

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[1] SP (stated preference survey), users choose transport alternatives in hypothetic situations.
RP (revealed preference survey), passenger behaviour is based on observed choices.

2.2 CAPACITY

Capacity refers, among others, to the maximum number of passengers that can be transported in a vehicle. Unlike crowdedness, it does not account for different users´ perceptions since it is a rather objective feature, capacity reached or not. However, cultural differences may incur as in the study (Connor, 2011) mentioned acceptable values of 4-5 passenger/m^2 in EU countries, whilst 8/m^2 in Asian countries. The London Underground accepts 8 passengers/m^2 in doorways and 6/m^2 elsewhere.

High occupancy rates can be problematic when the capacity of the vehicle is not enough to hold all the passengers waiting at stations. In some cases it could lead to vehicle bunching (Abkowitz & Tozzi, 1987). Some users have to wait for next vehicle to come, which also trigger an increase on on-board time since more passengers board in the vehicle. Therefore, it might be delayed and the reliability of the transport could be negatively affected. Following trains need to reduce the speed, henceforth they are also delayed (Douglas Economics, 2012).

The Regional Transport Model does not account for capacity constraints for passengers in public transport modes, i.e. a modelled vehicle can carry excess of users over the real capacity. In favour of the model is that the train service operator NSB reports that there are no cases in which the train capacity is lower than the demand, for that reason all passengers manage to board on the train, although it could be crowded (Tørset, 2014).

In spite of that, models are used to simulate future demands and according to (Statistics Norway, 2012) population will increase even considering a pessimistic approach, moreover the demand for rail service will grow as well (Madslien, Steinsland, & Maqsod, 2011). Therefore, models should be ready to properly simulate the behavior and accommodate forthcoming passengers' demand.

Capacity constraints in the transport model

The first model that included capacity constraints on board public transports was TRANSEPT. In particular bus services, where waiting times depend on link flows and the frequency is effective, i.e. the inverse of the waiting time. However, it is only valid for radial networks (Last & Leak, 1976).

Posterior models for assigning passengers to the transport network are built based on either schedule or frequency based. In general terms, the former is common for lower frequencies; it considers dynamic effects and allows tracking the time passengers spend between nodes.

The schedule based model in the study (Poon, Wong, & Tong, 2004) uses a time-increment simulation. The available capacity is automatically updated and the demand distribution is based on minimizing the generalized costs. A fee for line change is included in the model.

The study (Hamdouch & Lawphongpanich, 2008) represents the waiting time due to capacity constraints by boarding some passengers randomly instead of FCFS (first comes first serves). The model allows passengers to decide the departure time in order to minimize their waiting time.

The study (Nuzzolo, Crisalli, & Rosati, 2012) assumes that passengers are flexible in times, being able to choose between waiting for next vehicle in the same stop, changing stop or departure time in order to avoid crowdedness. Passengers are allocated according to user´s choices and capacity constraints in a dynamic approach.

The frequency-based models are more used for high frequencies, requiring less detailed information but, in general, do not account for capacity problems (Schmocker, Bell, & Kurauchi, 2008).

The method of the successive average is used in the study (Cepeda, Cominetti, & Florian, 2006) in addition to a given probability to board for passengers. It updates the travel times and frequencies in each iteration as the average between the current and the previous one.

Another dynamic approach in (Schmocker, Bell, & Kurauchi, 2008)is that the time is divided in fifteen minutes intervals in which passengers that have not boarded (there is a probability of not to) are allowed to change destination.

2.3 ADDITIONAL COMFORT VARIABLES

Many others features can be considered as comfort variables as for example noise, temperature or ride quality, although they are included in the perception of crowdedness (Cox, Houdmont, & Griffiths, 2006). Additionally, air conditioning and flow or behaviour of close passengers also affect the perception of crowding on-board (Hirsch & Thompson, 2011).

Different comfort variables are associated to the weather itself, for example in winter a warm carriage and a proper shelter in the waiting area could make more attractive one transport mode against other. In the Regional Transport Model, season variable is included in the trip purpose as dummy variable for winter season. A possible discussion could be regarding the possibility of including this variable in the transport mode as it is perceived differently whether travelling by bike or car.

3. NORWEGIAN TRANSPORT MODELS

Transport models are tools for the evaluation and assessment of strategic projects and policies in all transport sectors through estimating the transport demand. They are built based on the network, the public transport system, zone and demographic data and trip patterns.

Regarding the network, the modelled area is divided into a number of zones, each of them has one centroid which represents the attraction/generation centre of trips in the zone. Centroids are joined into the real network through connectors. The existing network is represented by links, as roads, and nodes which join the links, as shown in Figure 2.

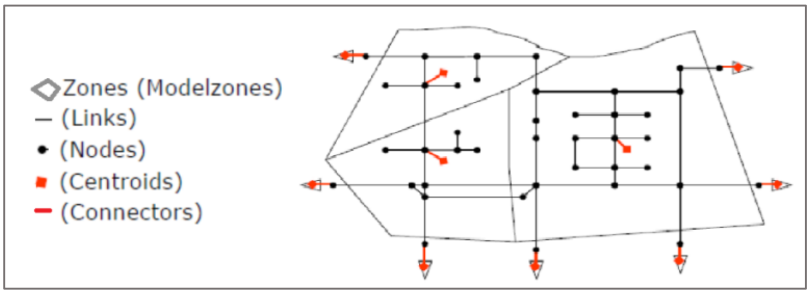

Figure 2: Network (Source: modified after (Anderson, 2013))

The public transport system encompasses the transit routes, mode, headway, stops and travel time between them.

In Norwegian Transport Models, the zone and demographic data are based on the information provided by Statistics Norway, administratively under the Ministry of Finance but operating independently (Statistics Norway, 2014).

The users´ behaviour is based on the National Travel Survey (RVU), carried out approximately every four years in Norway. Citizens, older than thirteen years and from different locations, are asked through a telephone interview about their trips in a normal day (revealed preferences) such as: purpose, from-to, time, transport mode, cost and travel time. Moreover, they provide some socioeconomic details such as income, sex, age, family members and cars at home among others. The last version of the RTM is based on the survey RVU2001 (Norwegian National Travel Survey, 2011).

The classical approach of transport models is based on the four step method. The steps with the input and output data are described in Table 2.

Table 2: Four step method

Step	Input	Output
Trip generation	Zonal data (people, jobs, schools…) Travel survey	Number of trips (frequency)
Trip distribution	Number of trips Generalized costs (GC)	Origin-Destination (OD) matrixes
Mode choice	OD matrixes Level of Service (LoS) Explanatory variables	OD matrixes by mode
Route assignment	OD matrixes Number of trips Generalized costs (GC)	Traffic loads

Trip generation determines the frequency of origins or destinations in each zone. Trip distribution establishes origin-destination flows. Mode choice computes the proportion of trips between each zone pair. Route assignment allocates trips between each OD pair.

The applications of the Norwegian Transport Models are run and supported by the software CUBE from Citilabs. This is the software used in this project referring to the demand simulation.

3.1 NATIONAL TRANSPORT MODEL (NTM)

The National Transport Model version 5 (NTM5), based on the NTM4, divides the country in 1428 zones in order to simulate the travel behaviour for long distance activities (more than 100 km) with origin and destination in Norway by the following modes (Rekdal, 2006):

- Car (driver and passenger)
- Train
- Bus
- Boat
- Airplane

The model consists of sub-models by travel purpose (work related, private visits, leisure, and other purposes) for which the travel frequency, destination and mode choice are calculated independently by using logit models. Afterwards, the route choice model is applied. The variables involved in the model can be seen in Table 3.

The output is the demand for long trips, which can be visualized on every link for each purpose and transport mode.

Table 3: Variables in NTM5 (Source: (Hamre, 2002))

Car transport	Public transport	Passenger	Zone / Destination
Journey "door to door"	Travel time on-board	Gender and age	Population
Gasoline consumption	Distance	Income	Workplaces per industry
Costs of tolls and ferry	Waiting time	Occupation	Hotels
Driving license and car ownership	Transfers	Type of household	Cabins and holiday homes
	Fare	Zone / Geography	Transportation services

3.2 REGIONAL TRANSPORT MODEL (RTM)

Models are used to analyse how different measures affect the demand in the basis year and in the future. RTM forecasts data for the years 2010, 2014, 2018, 2024, 2025, 2030, 2040, 2043, 2050 and 2060, based on data provided by Statistics Norway (up to 2030) and the National Transport Plan (Rekdal, Larsen, Løkketangen, & Hamre, 2013).

The Regional Transport Model in Norway divides the country in 14.000 zones, with five main areas of simulation, these can be seen in Figure 3.

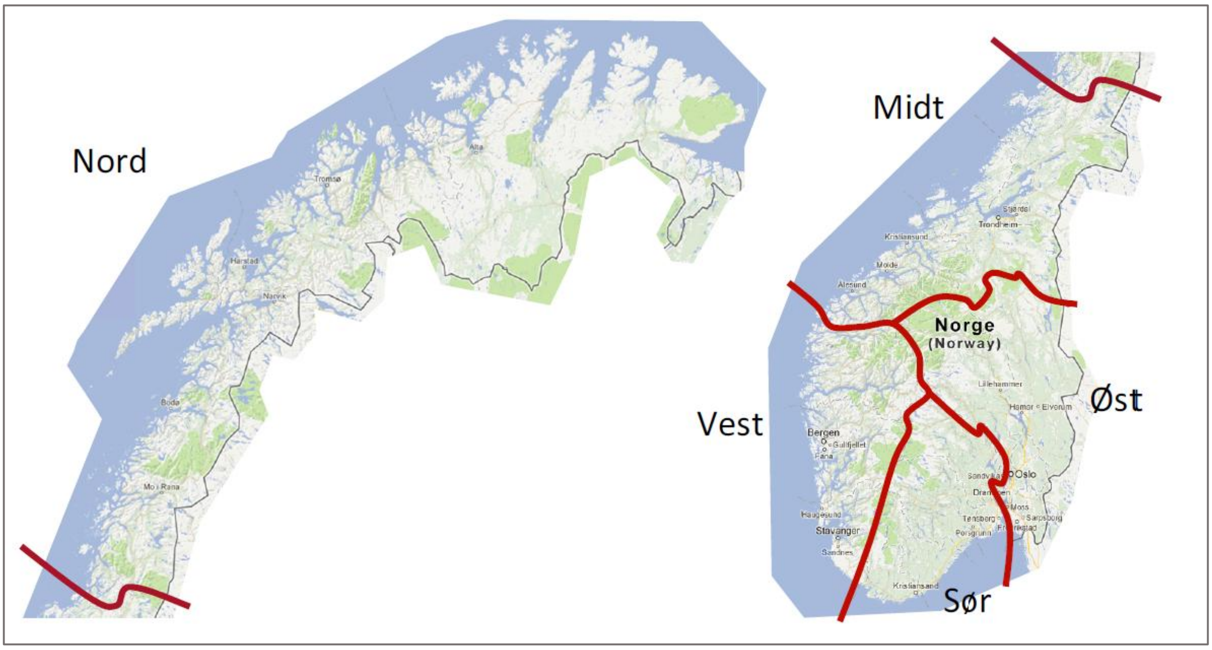

Figure 3: Areas in the RTM (Source: (Tørset, Malmin, Bang, & Bertelsen, 2013))

RTM is used to determine the demand for short length trips (less than 100 km) made by the following modes (Madslien, 2005):

- Car driver
- Car passenger
- Public transport (rail, subway, tram, boat and bus service)
- Bicycle
- Walk

The main difference of the public transport compared to the other modes is that the trip is divided in diverse stages being its time value different.

Despite of all the public transport modes are modelled together, it is important to mention the *rail factor*. Whilst the measurable conditions of the trip remain equal and passengers are seated, they prefer train (Stangeby & Norheim, 1995). Even in some cases where the train rides longer times, train is preferred against the bus (Tørset & Meland, 2002).

RTM is built following the four step model, although it is not a sequential model in all steps (Tørset, 2012). The sequence of the model can be seen in Figure 4.

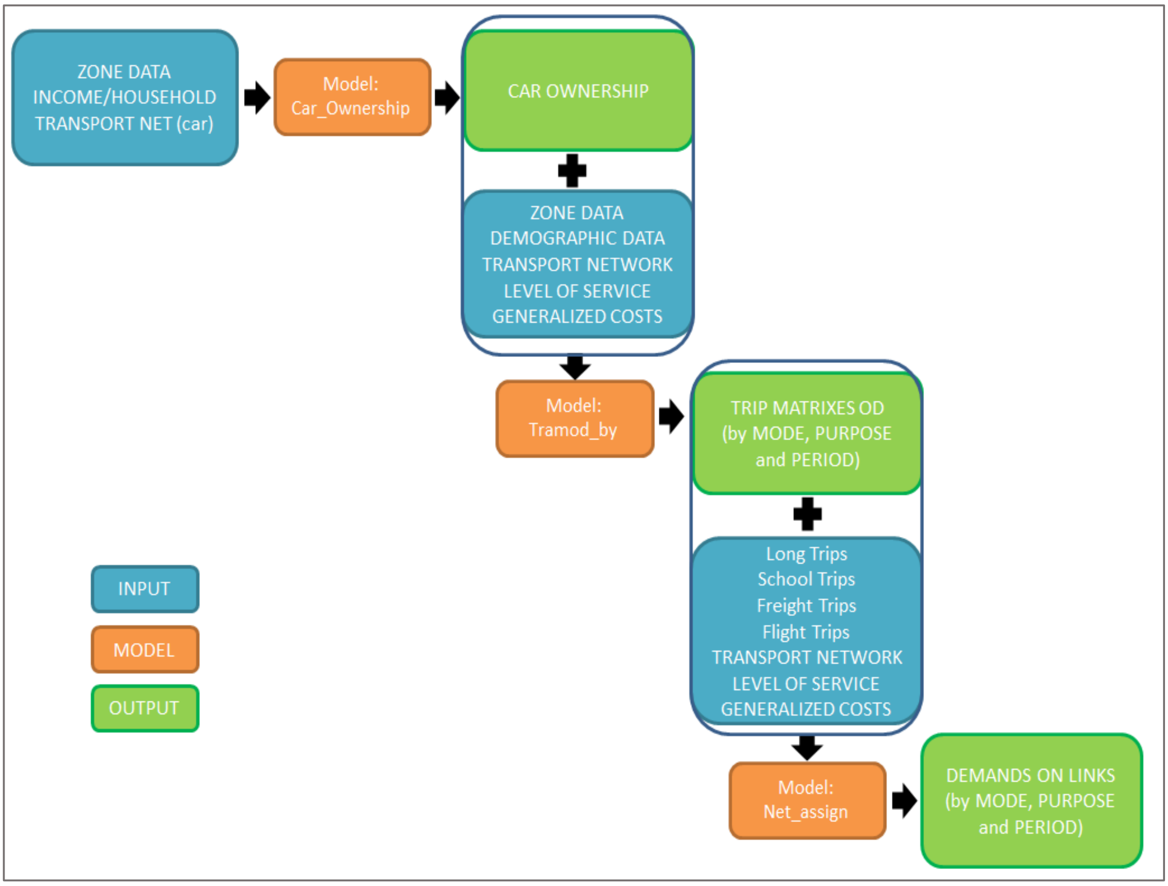

Figure 4: Model structure of the RTM version 3.0 (Source: modified after (Tørset, Malmin, Bang, & Bertelsen, 2013))

Car ownership model

Firstly, the car ownership model is run based on: *personal characteristics* (age, sex, household type, income); *zone data* (area, land use, population, workplaces, parking); and *transport service* (travel time among zones in the most congested rush hour and congestion charge) (Tørset, Malmin, Bang, & Bertelsen, 2013).

Demand model (Tramod_by)

Secondly, the demand model (Tramod_by) is run, which is a modal-distribution split multinomial logit model.

Most discrete choice models are based on the Random Utility Theory, (Domencich & McFaden, 1975) (Ortúzar & Willumsen, 2009) which states that an individual (q) associates to each alternative (j) an index of preference, called utility (U_{jq}). It is assumed the individual chooses the alternative which maximizes its utility, according to the utility maximization rule (Ben-Akiva & Lerman, 1985). The general form of a multinomial logit model is below (1).

(1) $$U_{jq} = V_{jq} + \varepsilon_{jq}$$ (Ben-Akiva & Lerman, 1985)

where: V_{jq} is the systematic utility (measurable by analysis).

ε_{jq} is the stochastic component that reflects everything the modeller cannot measure.

The systematic utility consists of the sum of a constant, called alternative specific constant (ASC), for all the modes but one, and the variables (X) multiplied by coefficients (β) for each alternative (which should not be correlated). The number of variables involved in the process is designed by k. The coefficients are constant across individuals. The variables can be generic, holding the same coefficient in all alternatives or specific, having different coefficients (Ortúzar & Willumsen, 2009).

(2) $$V_{jq} = ASC + \sum_{K} \beta_{jk}.X_{jqk} \qquad \{\mathrm{k} \rightarrow 1 \ldots \mathrm{K}$$ (Ortúzar & Willumsen, 2009)

The demand model is carried out for each purpose (work, work related, spare time, drop on/off, private[2]) due to the coefficients and variables affecting the choice differ from one purpose to another. For example, the value of time is not the same whether the purpose is a commute or a leisure trip. The public transport variables involved in the logit model by purpose can be found in the appendix, Table 46.

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[2] Private trips: service, shop trips. A complete definition of the purposes is found in Table 45 in the appendix.

The variables included in all the demand models can be divided into three categories:

- Level of Service (LoS) data, depending on both origin and destination
- Zone data, depending on either origin or destination
- Travel survey (RVU) data, varying between observations

The general inputs of the demand model are: *car ownership model*; *transport networks* (road, ferry, public transport network and toll or fares system); *zone* and *demographic data* (divided by zones, year intervals of 5 years, sex and household category; and subdivided by five categories depending on the car availability and the possession of driving licence). The characteristics of the network are used to estimate the level of service and generalised costs (prices in base year 2010), which vary among rush and normal period.

This demand model is the combination of steps 2 and 3 of the four step method, and hence the output is the origin-destination (OD) trip matrixes already divided by purpose and mode. The demand can be simulated considering one (day), two (rush and non-rush period) or four periods, as shown in Table 4.

Table 4: Time periods (Source: modified after (Tørset, Malmin, Bang, & Bertelsen, 2013))

Time period (car)	Hours
Morning rush	06-09
Day	09-15
Afternoon rush	15-18
Evening-Night	18-24

The trips are estimated for a working day (whole year minus eight weeks summer period and two weeks Christmas and Easter), the relation among week and weekend day is 0,9. They are modelled in two types: tour-retour (leg 1[3] + leg 3) or chain-travel trip (leg 1 + leg 2 + leg 3), illustrated in Figure 5. (Tørset, Malmin, Bang, & Bertelsen, 2013)

Figure 5: Trip types

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[3] leg 1 (from home to destination) / leg 2 (from dstn. 1 to dstn. 2) / leg 3 (from destination to home)

It is worthy to note some characteristics of the mode-destination model. The work related trips do not include driver jobs (taxi, bus drivers…) (Tørset, Malmin, Bang, & Bertelsen, 2013). The sub-model for work purpose is denoted by a nested logit model[4] to represent the effect of seasonal tickets. There is a slight correlation among time and cost as they reflect distance, which is underestimated for short trips and overestimated for long trips. (Madslien, 2005). Travel time savings are calculated without taking into account capacity constraints on the network and there is no possibility to choose departure times (Rekdal, Larsen, Løkketangen, & Hamre, 2013).

The OD fixed matrices added into the RTM represent *long*, *buffer*[5], *freight*, *school* and *flight* trips. Trips longer than 100 km are added from the National Transport Model (NTM5), where trips to-from Sweden have been previously included. Goods trips on roads are included from the Freight Transport Model, based on truck surveys and traffic counts (vehicles longer than 5,6 meters). School trips are not covered by the travel survey as the participants are older than 13 years. They are built in three separated gravity models for primary, secondary or university level, having as inputs the distance, number of schools, school places, and number of people in the year groups.

Network assignment

Finally, the network assignment is run with the inputs: *OD matrixes*, *transport networks*, *generalised costs* and *level of service*.

The RTM allows accounting for capacity constraints on the road network in an iterative way. Moreover, it allows accounting for delays on bus services, affected for total traffic on the lanes. This is important for rush periods. Despite that, there are not capacity constraints for passengers as the boarding time is unaffected by the number of people at stations or on board.

---

[4] Nested model is two-dimensional and consequently based on two-level utilities [U(d,m) -> d: type of ticket, m: transport mode]. Not only the specific transport mode is included, but also the relation between this mode and the general classification ($U_{jq} = U_d + U_{dm} = V_d + V_{dm} + \varepsilon_d + \varepsilon_{dm}$).

[5] Trips generated outside the influence area.

The output is the demand on each link split by purpose and transport mode. Since each link is associated to the demand, in this step train and bus are considered as different modes, given the differences in the link features.

The model can be run in two different ways regarding how the demand will be shown on the network. On one hand, the demand is split between normal and rush period. In this case, it is observed a considerable understimation due to the trips in the rush period are automatically assigned to be only commute and school trips. On the other case, the demand is divided between hours for the rush periods (morning and afternoon) and in two intervals for the normal hours, resulting in a total of eight periods. The total demand is distributed among the hours following the pattern revealed in the National Travel Survey, so all type of trips are assigned to the rush period, obtaining a higher demand.

Generalized costs – Level of service

Generalized costs are the sum of distance, time, and monetary value of a trip. Since the units of each of them differ, it is used a linear function of the attributes of the journey weighted by coefficients that represent passengers' relative importance (Ortúzar & Willumsen, 2009).

$$GC = \mathrm{a}_1 Time + \mathrm{a}_2 Distance + \mathrm{a}_3 Costs \qquad [a_i : weighted\ coefficients]$$

In addition to the generalized costs, every link has different level of service (LoS) depending on the transport mode, which is the impedance cost element. In the RTM the level of service of the public transport consists of (Rekdal, Larsen, Løkketangen, & Hamre, 2013):

- Distance
- On board Time between zones
- Walking Distance between zones
- Walking Time between zones
- Waiting Time between zones
- Number of Transfers between zones
- Ticket Cost single between zones (full price adults)
- Monthly Card Cost between zones (full price adults)

Generalized costs can be measured either in monetary or in time values. If the latter is agreed, the multiplier of time could be considered as the value of time. This value varies widely among the literature, being constant in Norway and other countries such as Chile or the UK, or varying by intervals like in the USA.

The theory of discrete choice is usually applied in order to numerically estimate the value of time. Individuals are assumed to maximize their utility function by choosing among different options from each other and mutually exclusively. Therefore, the value of time is commonly obtained through stated preferences survey (SP). In spite of that, the Norwegian values are obtained from the National Travel Survey (RP). The value of time depending on the purpose is shown in Table 5.

Table 5: In-vehicle values of time (NOK/hour 2009 base price year) for short trips (Source: (Johansen & et al., 2010))

	Car driver	Public transport
Commute trips	90	60
Other private trips	77	46
Business trips (at work)	380	380

The time values are more specific in the Regional Transport Model. These do not only depend on the purpose and mode but also on the household type, as defined in Table 6.

Table 6: In-vehicle values of time (NOK/ hour 2001 based price year) (Source: (Rekdal, Larsen, Løkketangen, & Hamre, 2013))

Week day				**Families with children**				**Male**			
	Private	Spare time	At work		Private	Spare time	At work		Private	Spare time	At work
CD	90	81	109	**CD**	76	60	98	**CD**	75	68	87
CP	74	79	96	**CP**	62	60	85	**CP**	74	64	85
PT	29	39	96	**PT**	24	26	83	**PT**	29	35	83
Weekend day				**Families without children**				**Female**			
	Private	Spare time	At work		Private	Spare time	At work		Private	Spare time	At work
CD	90	45	60	**CD**	104	76	98	**CD**	106	68	109
CP	74	45	48	**CP**	86	76	85	**CP**	74	64	85
PT	29	28	48	**PT**	33	46	83	**PT**	29	35	83

Households with children have lower time values than households without children. This pretends to model the fact that families with kids travel more and further. The same theory applies for men and women, being the latter who have a higher value of time. (Rekdal, Larsen, Løkketangen, & Hamre, 2013).

Even though travel time can be estimated as monetary value, it varies depending on the part of the trip for public transport, i.e. waiting at the stop is not perceived as traveling seated in the vehicle. Instead of assuming different values of time for each characteristic, travel time multipliers are used to simplify the process, some of them are shown in Table 7.

Table 7: Recommended weights for short trips (Source: (Johansen & et al., 2010))

	Public transport
Waiting time 0 – 5 min	2,30
Waiting time 6 – 15 min	1,88
Waiting time 16 – 30 min	0,92
Waiting time 31 – 60 min	0,56
Waiting time over 61 min	0,28
Access / Egress time	1,00
Fixed cost per transfer	2 – 10 min

Additional time value and time multipliers in Norway are obtained from a local survey based on stated preferences (SP) and panel data (Madslien, 2005). The interviews were done in the Oslo-Akershus area in 2010, interviewing over 2.000 public transport users (Ruud, Ellis , & Norheim, 2010). These values are higher than the National ones (used in the RTM) and the travel time on-board differs whether standing or seated. The time multipliers are presented in Table 8.

Table 8: Recommended weights for short trips (Source: (Ruud, Ellis , & Norheim, 2010))

	Public transport
Travel time (seated)	1,00
Travel time (standing)	1,70
Waiting time	1,90
Access / Egress time	1,20
Transfer time	2,40
Delay time	6,30

3.3 DOM_JÆREN

More specific projects are based on part-area-models of the Regional Transport Model as they can hold more particular information related to the area of interest.

The model DOM_Jæren is a part-area-model of the RTM covering a smaller area (divided in 691 zones) in the West part of Norway, ilustrated in Figure 6. The method of simulating the demand is the same as in the Reginal Transport Model (Figure 4). The travel patterns in the model are the same as for the RTM West, RVU2001. They have been posteriorly calibrated by a local travel survey in 2005 (RVU Jæren 2005) (Meland, Thorenfeldt, & Malmin, 2013).

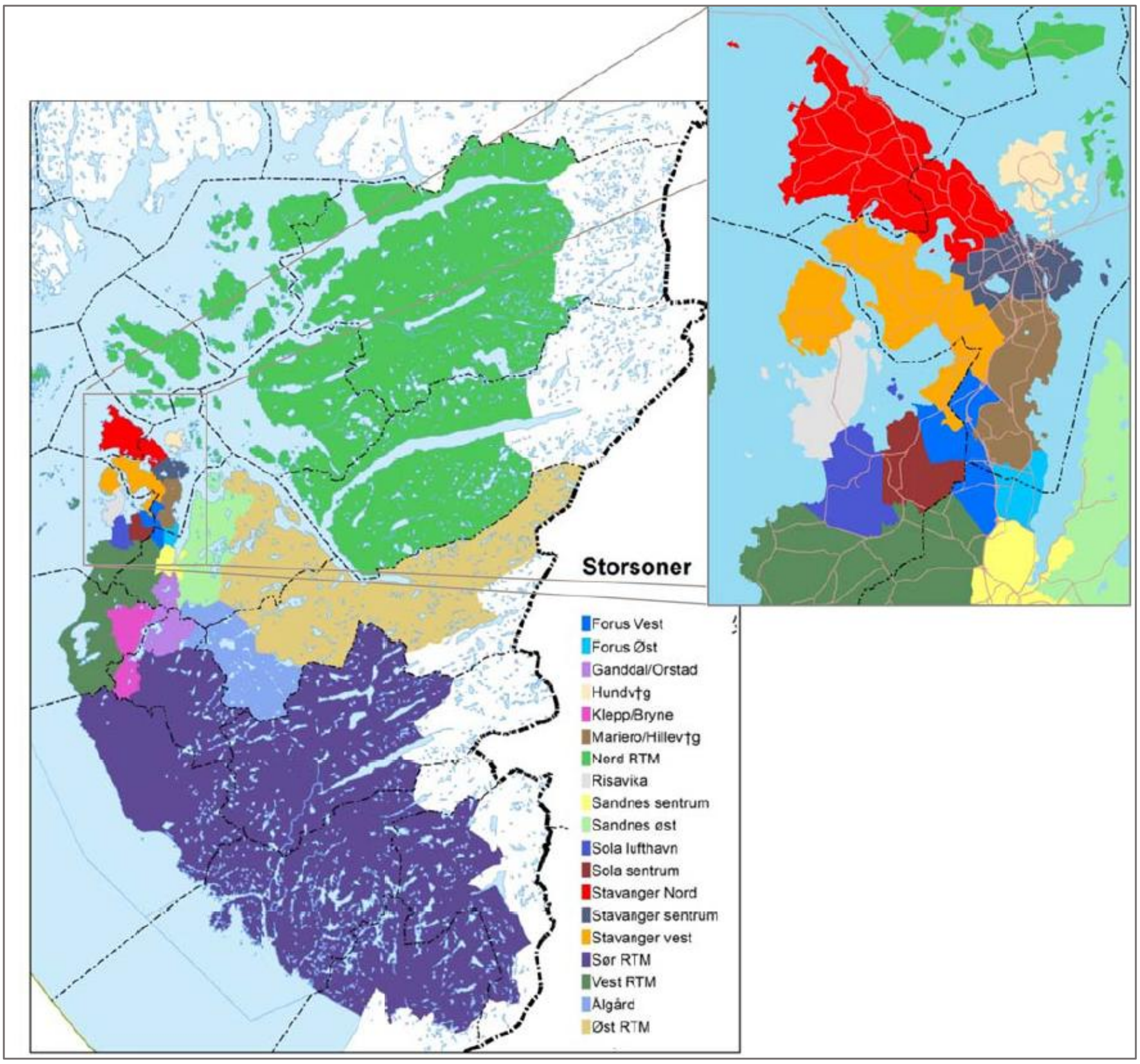

Figure 6: DOM_Jæren area (Source: (Meland, Thorenfeldt, & Malmin, 2013))

The model area includes 19 municipalities in the county of Rogaland with a population of 325.000 inhabitants. There are 168.000 jobs and 63.000 places for students within this area (Meland, Thorenfeldt, & Malmin, 2013).

Statistics Norway estimates an important growth in the area, approximately 45% by 2043. The municipalities that present more development are Stavanger and Sandnes, which currently represents 58% of the population, 66% of the jobs and 61% of the school places (Meland, Thorenfeldt, & Malmin, 2013).

This project bases its analysis on this model, in particular on the local train lines between Stavanger and Egersund, Jæren line, since there are actual evidence of crowding on-board.

4. JÆREN LINE

Jæren line is a commuter train service in the West coast of Norway, between Stavanger and Egersund (see Figure 7), operated by the Norwegian State Railways (NSB). The line consists of 19 stops in a total length of 73 kilometres, being double track from Stavanger to Sadness (Sandnes (gamle) in Figure 7) and single track the rest of the section (58 km). The line is used by intercity (local), regional and freight trains. (Source: (Jernbaneverket, 2014)).

Figure 7: Jæren track (Source: retrieved from DOM_Jæren - CUBE)

Socio-demographic information

The most important stops along the Jæren line or the ones with more movement of passengers are Stavanger, Jåttåvågen, Sandnes sentrum, Bryne and Egersund.

Stavanger is the fourth largest city of Norway with a population of almost 130.000 inhabitants (Statistics Norway, 2014). There are residential, commercial and business areas. The parking spaces are limited and in some occasions people complain about the lack of them. The station is located in the center of the city close to the bus central station, operated by Kolumbus.

Jåttåvågen station is situated 7 km South, close to the Viking soccer stadium, with a capacity of 16.000 spectators (Viking fotball, 2014). The station was moved and re-built in 2009 in order to satisfy better the needs of a new business area in actual growing, “Hinna Park”. New companies are positioning there their centrals, it is estimated to achieve between 5.000 and 8.000 jobs in the upcoming years (Hinna Park, 2014). In addition, there is a relatively new (openning year 2007) secondary and vocational school with around 1000 places (Rogalandsavis, 2014), and a new nursery school for 240 kids (Jåttå barnehage, 2014). The upward demand for the area is generating the creation of new residential areas in the surroundings.

Sandnes is a large city with 70.000 residents (Statistics Norway, 2014). The facilities can be thought to be as in Stavanger although in a smaller size. There are two train stations, the main one in the center, called Sandnes sentrum, which serves as stop for both local and regional trains, sited 15 km South of Stavanger. Sandnes, on the outskirts towards South, was the principal station until 1997 when the other was built. Nowadays, there is no much passenger movement (Jernvaneverket, 2014).

Bryne has a population of 10.000 inhabitants (Statistics Norway, 2014). There are new residential and business areas and it is expected to grow in near future. There is also an important primary school for the nearby neighborhoods, whose sites have been incremented in 2006. The station is located in the center of the town, 30 km South of Stavanger.

Egersund is a town with 14.000 inhabitants (Statistics Norway, 2014). The stop is not in the center, with a walking distance of around 15-20 minutes. It is the last stop of the Jæren commuter rail. Regional trains also use this station.

Schedules of the local trains

The local trains running along the tracks differ among normal or rush period. There are three different lines commuting Stavanger to Sandnes, Egersund or Nærbø. The latter is extended in the rush hours to provide higher frequency to the towns between Nærbø and Egersund. The Jæren line for weekdays presents a clock-face schedule, represented in Figure 8.

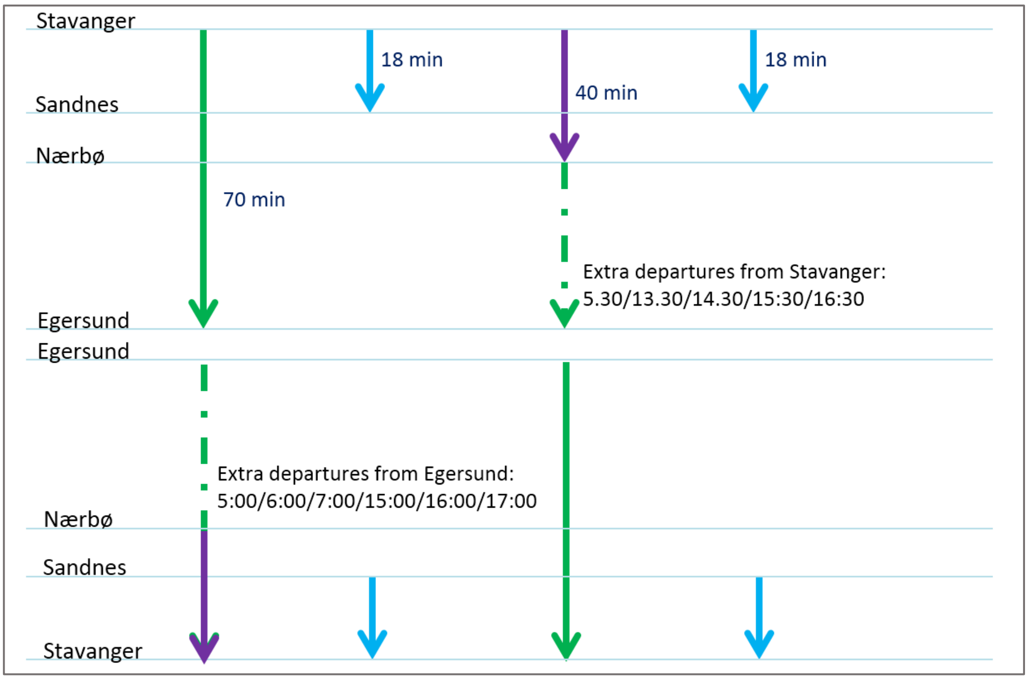

Figure 8: Services Jæren line and schedule (Source: modified after NSB schedule)

In the direction Stavanger – Egersund, the first train running the whole route departs at 05:00 and the last one at 22:00; during that time trains run every hour. An additional train from Stavanger to Nærbø departs every hour between 6:30 and 22:30, in rush hours this service is lengthen until Egersund (at 5:30, 13:30, 14:30, 15:30 and 16:30). Moreover, there is a service between Stavanger and Sandnes every 30 minutes from 5:15 to 19:45 (NSB schedule, 2014).

In the direction Egersund – Stavanger, the first train departs at 05:30 and the last at 23:30, trains depart every hour. An additional train departs from Nærbø to Stavanger every hour from 07:30 to 20:30, in rush periods these services are extended from Egersund (at 05:00, 06:00, 07:00, 15:00, 16:00, 17:00). The service from Sandnes to Stavanger runs every 30 minutes from 06:00 to 20:30 (NSB schedule, 2014).

This project is focused in the rush period where crowding is more likely to occur, so the lines studied are from Stavanger to Sandnes and Egersund. The rush period is assumed according to the time at Stavanger station, i.e. arrival or departing times at this station. The number of trains per direction in the rush period are in Table 9.

Table 9: Number of trains per line and direction in rush period (Source: retrieved from NSB schedule)

	06:00-07:00	07:00-08:00	08:00-09:00	15:00-16:00	16:00-17:00	17:00-18:00
EGS – STV	2	2	2	1	1	2
STV – EGS	1	1	1	2	2	1
SAS – STV	2	2	2	2	2	2
STV – SAS	2	2	2	2	2	2

The trains' schedules in CUBE are modelled as three lines in the normal period and two lines in the rush period, as shown in Table 10 and Table 11. (The numbers within brackets are the names of the trains modelled in the software).

Table 10: Trains Jæren line modelled in the RTM (normal period) (Source: retrieved from DOM_Jæren - CUBE)

Trains	Frequency (minutes)
Stavanger – Egersund / STV – EGS (5016, 5017)	30
Stavanger – Nærbø / STV – NBØ (5018, 5019)	60
Stavanger – Sandnes / STV – SAS (5020, 5021)	60

Table 11: Trains Jæren line modelled in the RTM (rush period) (Source: retrieved from DOM_Jæren - CUBE)

Trains	Frequency (minutes)
Stavanger – Egersund / STV – EGS (5016, 5017)	30
Stavanger – Sandnes / STV – SAS (5018, 5019)	30

Type and policies of the local trains

This project studies the local trains in the rush period (both morning and afternoon) where crowding is present. These trains stop at all the stops along the line. The train type is class 72, an electric multiple unit, made by Ansaldo Breda in 2002. The width of the vehicle is 3,1 meters and the total length is 85,6 meters. It is composed of four carriages, the two extremes are motorized (25 m) and the two interior do not (20,125 m), the space between the carriages in 0,03 meters.

There are eight doors per side; having a total seat capacity of 310 (folding seats) and a total standing space approximately of 40 m2. The plan can be seen in Figure 9 as well as some pictures of the exterior in Figure 10 and the interior in Figure 11.

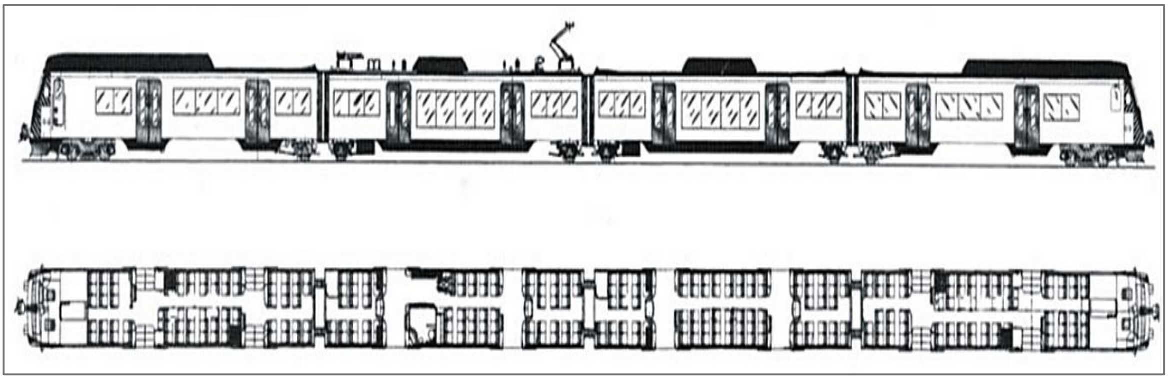

Figure 9: NSB train class 72 (Source: (Ansaldo Breda, 2002))

Figure 10: NSB train class 72 (Jæren line) (Photo: (Ansaldo Breda, 2002) and Díez, M.)

Figure 11: NSB train class 72 (Jæren line) (Photo: Díez, M.)

The conductor or inspector is present in only one carriage, where one can buy the ticket on board. In the other three carriages one must hold a validated ticket since in case of inspection a fine is expedited otherwise.

The most purchased tickets are monthly passes that combine buses and trains on the region. The prices go from 750 NOK for adults and zone 1, the map of the prices zones is included in the appendix (Figure 35). Single tickets can be purchased on the mobile or on the tickets machines in the stations at a price of 47 NOK or inside the train at 87 NOK (NSB, 2014). The model represent the different fares by distance instead by zones. Nevertheless, the results are not expected to be greatly affected by this, and then it is assumed correctly modelled.

5. BUILDING THE NEW MODEL

This project analyses potential changes in the modelled demand when introducing crowding[6] on board as new factor in the destination-mode choice. This refers to the decrease of comfort during the trip due to high occupancies on board, which directly affects the attractiveness of the transport mode.

Before including crowding in the simulation, the model DOM_Jæren is analysed in order to identify potential uncertainties that are, posteriorly, calibrated to reduce the biased results in the simulations.

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[6] Crowding is defined as the occupancy (the number of passengers divided by the number of seats).

5.1 VALIDATING AND CALIBRATING THE MODEL

In order to detect possible sources of errors in the model a validation is conducted, where the input data is analysed as well as the model simulation. Additionally, a calibration is carried out, where the model results are compared to observed train passengers counts provided by NSB[7]. After identifying where and why the differences between modelled and observed demand occur, the model is adjusted.

Observed demand -> NSB counts

Observed passenger counts provided by NSB correspond to the number of users boarding and alighting at every station on each train along three non-consecutive week days. Those trains belong to the short Jæren line (Stavanger – Sandnes), the long service line (Stavanger – Egersund) and the Jæren service at non-peak hours (Stavanger – Nærbø).

The average number of users are calculated based on hourly values for each day and for each Jæren line service. The volume of passengers between two stations (A, B) per hour is estimated as the number of people boarding at the station A minus the number of users alighting at station B plus the passenger volume already on board.

From the passenger volumes of the observed counts in the rush period, it can be stated that the occupancy rate on board is higher than 60% in the Stavanger – Egersund line between 07:00 and 09:00 from Varhaug to Stavanger and between 07:00 to 08:00 from Sandnes sentrum to Bryne. The transport demand in the afternoon peak is more evenly distributed, even though there are still high occupancy rates between 14:00 and 16:00 from Stavanger to Bryne.

In contrast, the Stavanger – Sandnes line do not present occupancy rates larger than 60%.

Modelled demand -> Scenario 0

Scenario 0 is based on data from 2010 and 2014 as defined in Table 12, where the year of the input files are shown.

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[7] Values of the counts are not included in this report due to confidentiality reasons.

Table 12: Scenario 0 - 2014 (Source: retrieved from DOM_Jæren – CUBE)

Scenario 0 – DOM_Jæren	
BASE YEAR	**2014**
Transport network	2010
Public transport network	2010
Car ownership	2010
Fixed matrices	2010
Zone/Demographic data	2014

The total trips modelled in Scenario 0 depending on the purpose are shown in Table 13.

Table 13: Trips (Scenario 0) (Source: modified after DOM_Jæren)

		PURPOSE					FIXED TRIPS			
	TOTAL	Com.	At work	Spare time	Drop on-off	Private	School	Flight	Freight	NTM5
Car (driver)	528.282	96585	34504	103087	103874	169706	7304	5420	7714	88
Car (passenger)	74.948	5761	784	27558	5542	35239	0	0	0	64
Public transport	96.400	21282	1995	17001	2294	17330	35639	851	0	8
Jæren line	8.135									
Walking	241.736	17362	6585	51112	13155	74693	78829	0	0	0
Cycling	24.144	5969	1018	8261	1756	7140	0	0	0	0
All modes	**965.510**	146959	44886	207019	126621	304108	121772	6271	7714	160

There is approximately one million trips on an average weekday in the Rogaland area. Car driver is the transport mode most used, representing 55%. Within the soft modes, walking trips are 25% of the total and public transport 10%. Trips by the local train service are around 8% of the total public transport trips.

Analysing the input data regarding the public transport network an error is found at Paradis station. Modelled train line services stop at Hillevåg station instead, the distance among both stops is approximately 150 meters, as shown in Figure 12.

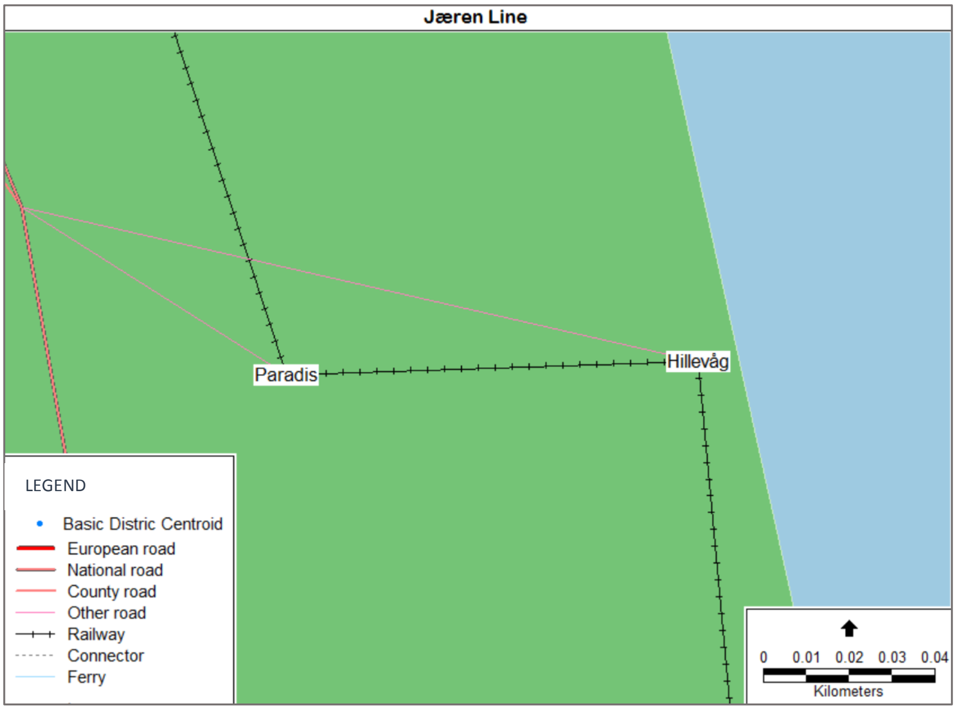

Figure 12: Paradis and Hillevåg stations (Source: retrieved from DOM_Jæren – CUBE)

Øksnevadporten station is not connected to the network, there are no links either to walk, cycle or drive, as shown in Figure 13. As consequence, there are no train trips starting or finishing at this station, despite that trains stop at this station.

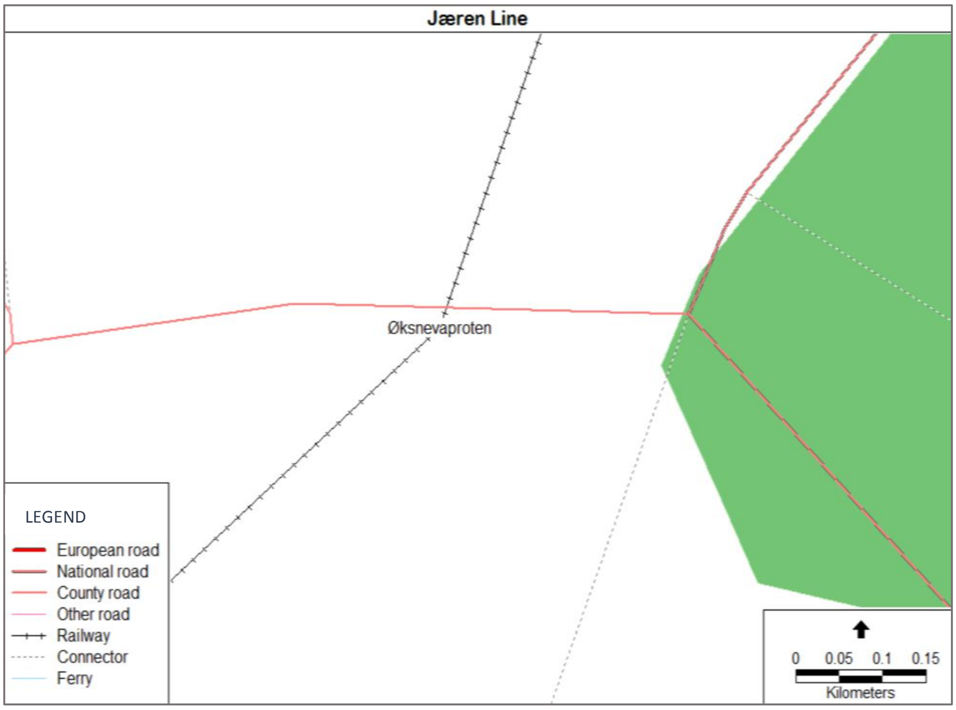

Figure 13: Øksnevadporten station (Source: retrieved from DOM_Jæren – CUBE)

Demographic data of the three most important municipalities in the study area, Egersund, Sandnes and Stavanger is also observed. The population, employees and workplaces observed (based on statistics) and modelled (simulated in the model) are shown in Table 14.

Table 14: Demographic data (Source: retrieved from DOM_Jæren – CUBE and Statistics Norway (2012))

	Population			Employees			Workplaces	
	Observed	Modelled	Diff. %	Observed	Modelled	Diff. %	Observed	Modelled
Egersund	14.636	14.819	1,3%	7.779	6.099	-21,6%		6.332
Sandnes	70.049	69.546	-0,7%	38.121	27.937	-26,7%		33.320
Stavanger	129.191	130.970	1,4%	70.828	52.245	-26,2%		77.022
ROGALAND	468.900	452.945		242.675	179.154		242.698	213.617

The population in the model corresponds to the real data from Statistics Norway (2012), however, the number of employees in the model is underestimated in 20-25%. These differences are due to the fact that the input data regarding employees and workplaces in the model was calibrated last time in 2005 (Meland, Thorenfeldt, & Malmin, 2013). The used values were forecasted in 2005 for 2012.

The total number of trips depends mainly on the population and consequently it is expected not to change when modifying the number of employees and workplaces in the area. In contrast, the destination of commuting trips may vary and taking the train could become an attractive option.

Differences modelled and observed demand -> Scenario 0 vs. NSB counts

By comparing modelled and observed volumes per each service line (Stavanger – Sandnes and Stavanger – Egersund) among stations per direction and hour (in rush periods), the differences of travel patterns can be observed.

In general terms, the total number of simulated trips is only around 60% of the observed passenger counts in 2014.

The model overestimates the passenger demand between 06:00 and 07:00 and from 16:00 to 18:00 for both local services and directions. Whilst there is a relevant underestimation between 07:00 and 09:00 as well as from 15:00 to 16:00, which is not compensated by the extra users modelled in the rest of the hours.

Trips starting at Stavanger station are underestimated for both lines and for both rush time periods, the reason might be the differences in demographic data with respect to the real data.

Trips with origin and destination Jåttåvågen station are clearly underestimated for both lines in all time periods. This might be caused into a large extend due to the underestimation in the input datasets of the activities at Hinna Park, close to the station. Moreover, the travel survey in which the travel patterns are based was conducted in 2005 and hence this new business and residential area did not exist.

Sandnes sentrum station gathers few trips compared to Sandnes regarding the short line, which is visible wrong modelled as most of the passengers board or alight at Sandnes sentrum. Figure 14 illustrates the passenger demand in Sandnes sentrum station.

Figure 14: Sandnes sentrum station at morning peak (Source: retrieved from (NRK, 2014), photo: Sjøstrand, D.)

The distance between the stations is roughly 750 meters. The reason why simulated passengers choose Sandnes station is probably due to the connectors in the area lead passengers first to this station as the distance is shorter. It is worthy to mention that train passengers on the long service line are well represented, only a small amount of them uses any of the Sandnes stations. Therefore, most of the train trips with origin or destination Sandnes area have the origin or destination towards Stavanger area.

Bryne station also shows a noticeable underestimation in the starting trips for both directions although higher towards Stavanger not only in the rush hours but also between 09:00 and 15:00. This could be due to the afternoon peak starting earlier in Rogaland region, probably because of some passengers are students.

There is also a trip underestimation from Egersund towards Stavanger in the morning, and in the opposite direction in the afternoon. The reason could be the underestimation of residential places, at the morning origin or workplaces at the afternoon origin.

Calibrating input data in the model -> Scenario 1

Given the differences found between the transport demand simulated and the observed passengers counts it is decided to change some of the input datasets in order to obtain a better approximation of the real trips in the Jæren line.

The demand model is simulated in four time periods and it is distributed by hours in the network assignment. This network distribution is based on the travel behaviour observed in the local revealed preference survey carried out in 2005 (Meland, Thorenfeldt, & Malmin, 2013). The shares are divided by purpose, direction (go out or return) and transport mode. Distributions of commute trips by public transport are shown in Table 15.

Table 15: Distribution of commute trips in the model based on the local travel survey 2005 (Source: modified after DOM_Jæren)

Time	06:00-07:00	07:00-08:00	08:00-09:00	15:00-16:00	16:00-17:00	17:00-18:00
Commute trips (PT) GO OUT	28%	34%	16%	1%	2%	0%
Commute trips (PT) RETURN	0%	0%	0%	38%	28%	11%

The modelled trips present a wrong simulation of the departure times, which should be higher between 07:00 and 09:00 in the morning peak and from 15:00 to 16:00 in the afternoon rush period. It is worth to mention that public transport trips also include bus services, so changes on these distributions should be also compared to observed passenger counts on that mode.

Since the aim is to improve the simulation of trips by train, a new distribution of commute trips by public transport is assumed. There is a reduction of 5% from 06:00 to 07:00 in go out trips, which increases from 07:00 to 08:00. In return trips the 5% increment is from 15:00 to 16:00 and the decrement between 17:00 and 18:00.

The train transport network is set to stop at Paradis station instead of at Hillevåg. Moreover, a new connector to Øksnevadporten station is built in the network for pedestrian and cyclist users in order to make the station accessible.

The input data regarding the new developed area of Jåttåvågen is analysed, finding a lack of residetial areas, workplaces and schools in the basic districts, as shown in Table 16 and Figure 15.

Table 16: Jåttåvågen characteristics Scenario 0 (Source: retrieved from DOM_Jæren – CUBE)

Basic District Number	Residents	Employees	Workplaces	Primary school places	High school places	University places
21031729	0	30	431	0	0	0
21031730	413	45	439	0	0	0
21031731	471	65	467	0	0	0

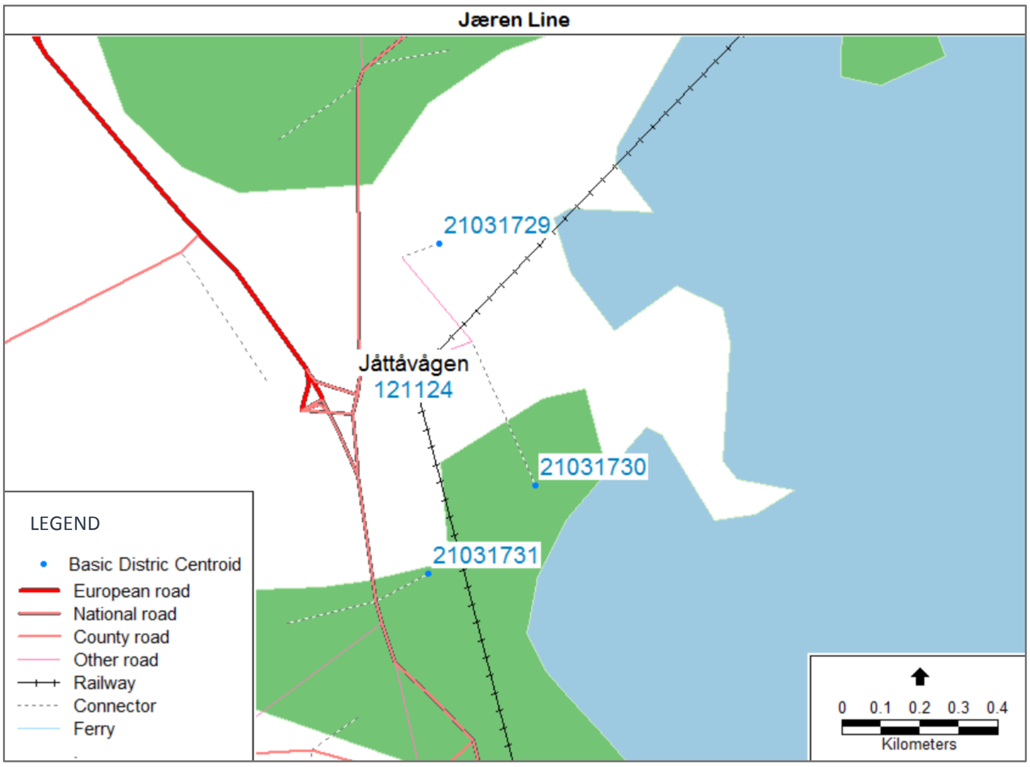

Figure 15: Centroids close to Jåttåvågen station (Source: retrieved from DOM_Jæren – CUBE)

Jåttåvågen area is updated by increasing the residential and workplaces areas as well as including the new primary and high school, as shown in Table 17.

Table 17: Jåttåvågen updated characteristics (Source: modified after DOM_Jæren – CUBE)

Basic District Number	Residents	Employees	Workplaces	Primary school places	High school places	University places
21031729	500	1.000	1.500	0	0	0
21031730	1.000	2.500	3.000	0	0	0
21031731	1.000	800	1.000	240	1.000	0

Sandnes area is analysed too, the districts with higher number of employees and workplaces are located between Sandnes sentrum and Sandnes station, these are shown in Figure 16.

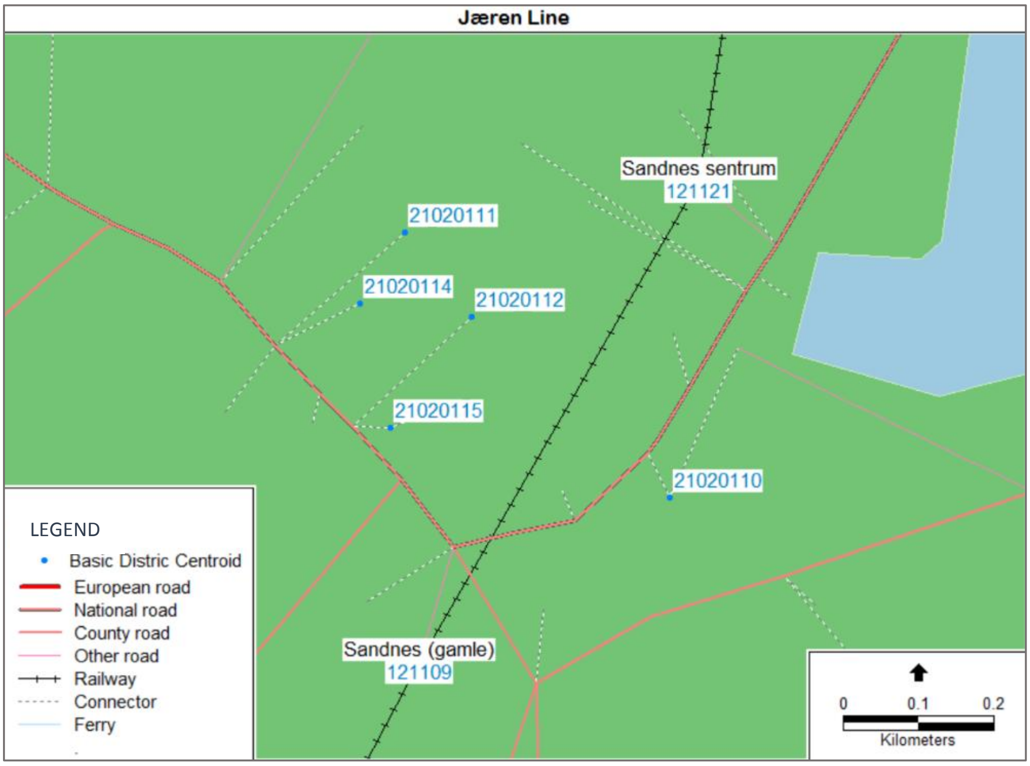

Figure 16: Basic district numbers (it is added 10.000.000 in the RTM) close to Sandnes station (Source: retrieved from DOM_Jæren – CUBE)

The conecctors[8] (dash grey lines) of these areas are joined to the network, having shorter distance to Sandnes station. Consequently, most of the modelled trips board or alight at this station instead of in the real station used, Sandnes sentrum.

In order to improve the representation of the travel patterns, new zone connectors are built with the same characteristics but joined to the network to a node close to Sandnes sentrum station. The new connectors are considered to be used only by pedestrian and cyclist to not modify the road network structure.

In addition, the number of employees and workplaces in some districts close to Sandnes sentrum station are increased, as shown in Table 18.

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[8] Connectors join the centroid (centre of activities of each zone) to the network. These represent theverage costs (time, distance) of trips with OD in the zone.

Table 18: Sandnes updated characteristics (Source: modified after DOM_Jæren – CUBE)

Basic District Number	Residents		Employees		Workplaces	
	Scenario 0	Scenario 1	Scenario 0	Scenario 1	Scenario 0	Scenario 1
21020104	0	0	12	312	26	126
21020105	108	108	23	323	155	255
21020107	147	147	84	384	155	255
21020108	86	86	10	310	304	404

In general terms, the population is correctly represented so no modificacions are held. Regarding the number of employees, they are increased in 25% in Rogaland, with exception of 30% in Sandnes. The amount of workplaces is increased in 12% for the whole region to have a better approximation of the real data (Statistics Norway, 2014), in Table 19 can be found the new updated values for the simulation.

Table 19: Demographic data (Source: retrieved from DOM_Jæren – CUBE and Statistics Norway (2012))

	Population			Employees			Workplaces	
	Observed	Modelled	Diff. %	Observed	Modelled	Diff. %	Observed	Modelled
Egersund	14.636	14.819	1,3%	7.779	7.624	-2,0%		7.092
Sandnes	70.049	69.546	-0,7%	38.121	37.480	-1,7%		37.642
Stavanger	129.191	132.586	2,6%	70.828	69.431	-2,0%		37.642
ROGALAND				242.675	230.626	-5,0%	242.698	243.577

Differences modelled demand changing input data -> Scenario 1 vs. Scenario 0

Scenario 1 is built based on the characteristics of Scenario 0 including updates in the distributions of the commute trips by public transport, demographic data, the network regarding the connectors in Sandnes area and Øksnevadporten station, and the public transport network regarding Paradis station.

After updating the model in Scenario 1, the passenger demand by mode and purpose for an average day is compared to Scenario 0 in Table 20. The trips by the Jæren line are the sum of the three local running along the day, this value is also included as part of the public transport trips.

Table 20: Differences in trips (Scenario 1 - Scenario 0) (Source: modified after DOM_Jæren)

		PURPOSE					FIXED
	TOTAL	Commute	At work	Spare time	Drop on-off	Private	School
Car (driver)	740	202	681	-31	24	-137	2
Car (passenger)	-84	-11	27	-26	-1	-73	0
Public transport	1.675	603	105	229	70	668	778
Jæren line	1.139						
Walking	-585	-162	38	-124	-34	-303	2.180
Cycling	-79	-38	14	-16	-6	-34	0
All modes	1.635	594	865	32	53	121	2.960

The increase in employees and workplaces in Rogaland leads to an increment of trips of 0,17%; as expected the increment is not very high, as trip production depends mainly on population. It can be noted that half of these new trips are produced at work and done by car driver. New commute trips, on the other hand, use mainly public transport.

In general terms, there is a growth of trips by public transport and car driver, whilst the walking trips are reduced, this could be due to a higher attraction of the public transport given the new characteristics or a lenghten of the trip distances.

There is an increment of 1.139 trips in the Jæren line service, being the increase more noticieble between Stavanger and Paradis and between Jåttåvågen and Sandnes sentrum for the long service line. This could be possibly attributed to the new network configuration of the Paradis station and the higher number of employees and workplaces around the areas of Jåttåvågen and Sandnes.

The trip distribution along the rush periods is slightly better represented, it could be due to the increase in 5% of the commute trip distribution for the peak hours. Despite that, there are still differences in the departure travel times. It is important to mention that the new demographic data regarding Jåttåvågen area generates new school trips mainly by walking and public transport. School trips trigger a little shift onwards in the afternoon demand, meaning that passengers are taking the train earlier due to the academic shedules.

In spite of that, the new connectors towards Sandnes sentrum station do not improve the use of this station instead of Sandnes. Given the fact that the trips in the long line service are well represented those passengers are likely to commute towards Stavanger area.

Once the connectors are built, the public transport patterns of the new connected zones are observed. The paths from the zone centroids towards Northern areas close to any station along the line are shown in Figure 17. Each colour line represents all the possible paths for each origin-destination and the probability each path has to be used.

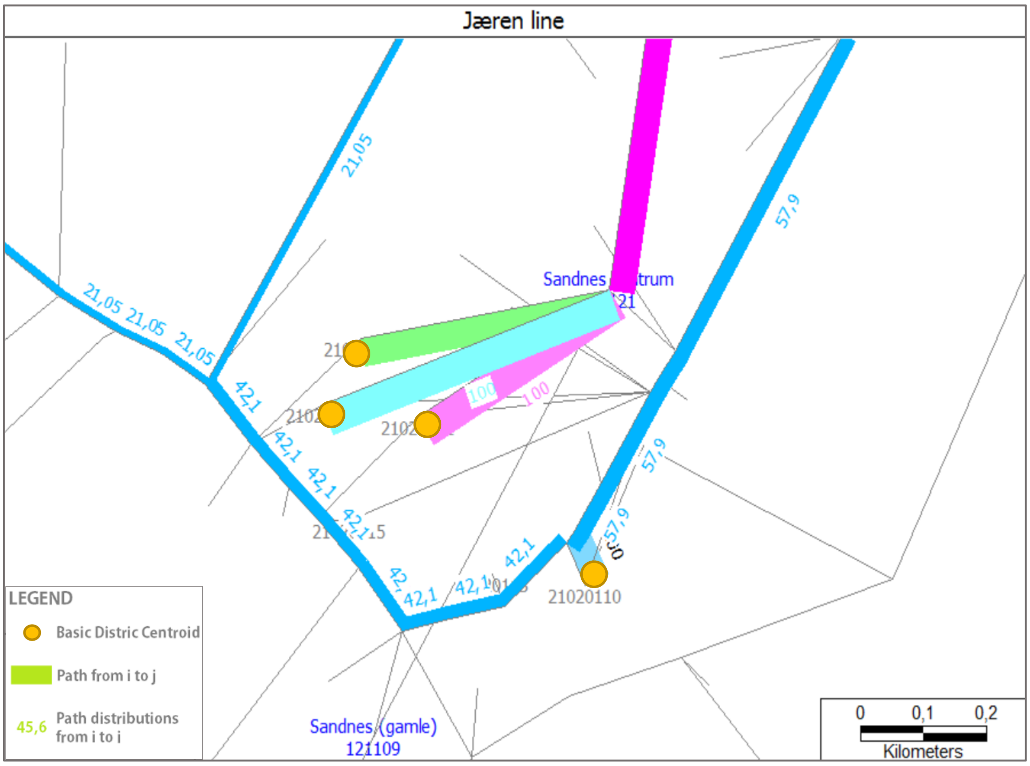

Figure 17: Public transport path trace - zones with new connectors (Source: retrieved from DOM_Jæren – CUBE)

As it can be seen, three of these four zones (represented with grey circles) are using train to travel towards Nothern destinations. The station used is Sandnes sentrum. However, these zones could not use the train line for commute trips as much as other areas. It is, therefore, recommended to have a further analysis regarding the origin and destination of the passangers using the Jæren service in Sandnes.

Some of the zones using the Sandnes station to commute towards Northern zones can be seen in Figure 18.

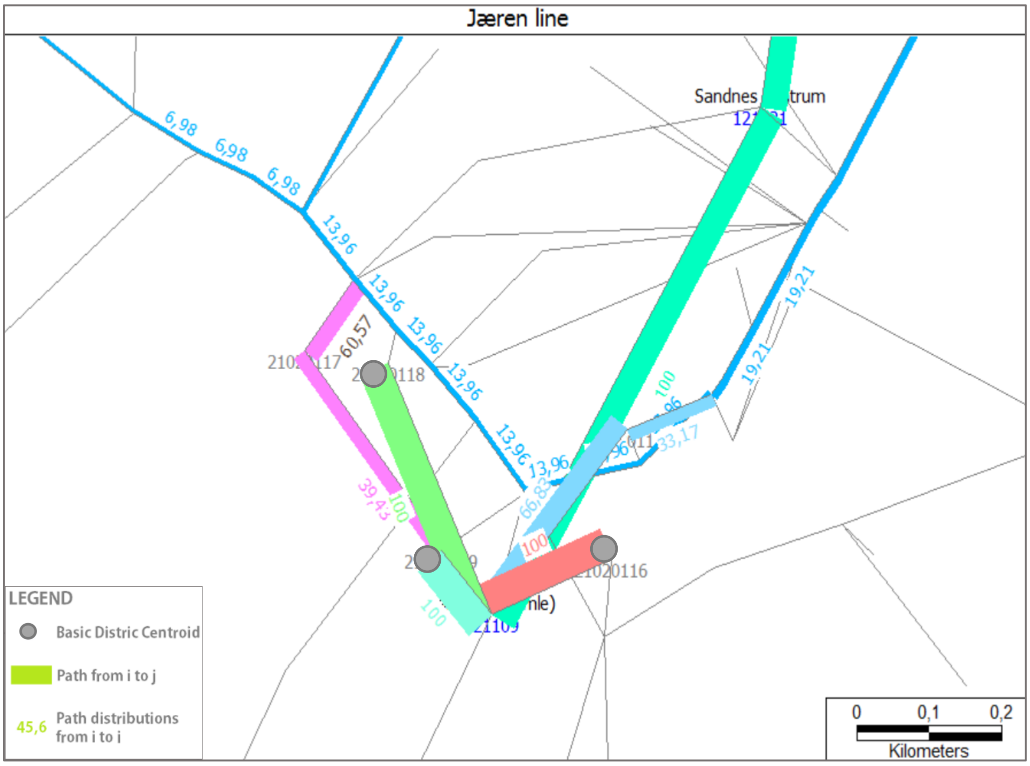

Figure 18: Public transport path trace OD using Sandnes station (Source: retrieved from DOM_Jæren – CUBE)

The demographic characteristics of each group of zones, with new connectors (Figure 17) or without (Figure 18) are gathered in Table 21.

Table 21: Demographic features zones with/without new connectors (Source: modified after DOM_Jæren – CUBE)

	Residents	Employees	Workplaces
🟡 Zones with new connectors	717	4.854	1.688
● Zones without new connectors	834	1.114	1.348

The zones without new connectors have a similar number of residents and workplaces, than those with the new conecctors, but the number of employees is four times lower. This fact could generate more commute trips in the zone without new connectors, which might be translated in an still high use of Sandnes station.

The zones that still use Sandnes station are not joined by new connectors to Sandnes sentrum station as, according to the position of their centroids these are in the influence area of Sandnes station. In spite of that and observing the modelled demand, the coding of these areas should be revised.

Comparing Scenario 1 to the observed counts, updating the network and the demographic data causes a minor improvent in the distribution of trips along the rush periods. However, the updated network and demographic data generate an increase of approximately 18% in the train trips for an average day. Even though, there is still an important understimation of the total number of trips.

Calibrating mode choice parameters in the model -> Scenario 2

Additional changes in the model, in particular in the mode choice, are tested in order to have a better approximation to the observed counts. The utilities of the transport modes and hence, the probabilities to use the transport modes are analysed.

The alternative specific constant (ASC) for the public transport mode is 0,5144. Increasing this value and according to the multinomial logit properties of the model, the overall mode choice is affected. The probability of chosing public transport is increased whilst the share for other modes is likely to be decreased.

After some simulations to find a value that shifts some of the total demand towards the train, the new value for the ASC is set to 1,5144 in order to obtain closer results to the observed data.

Differences modelled demand changing utilities -> Scenarios 2 vs. Scenario 1

Scenario 2 is based on Scenario 1, the previously adopted changes are also present in this scenario as well as the change for the ASC in the public transport utility.

The differences between Scenario 2 and Scenario 1 in average daily trips for each transport mode, including the Jæren line are found in Table 22.

Table 22: Differences in trips (Scenario 2 - Scenario 1) (Source: modified after DOM_Jæren)

		PURPOSE				
	TOTAL	Commute	At work	Spare time	Drop on-off	Private
Car (driver)	**-10.872**	-7.785	-731	-381	-477	-1.497
Car (passenger)	**-1.200**	-806	-49	-56	-62	-227
Public transport	**18.329**	13.248	1.134	663	762	2.523
Jæren line	**3.973**					
Walking	**-3.408**	-2.717	-133	-108	-101	-351
Cycling	**-1.978**	-1.285	-129	-88	-104	-370
All modes	**871**	655	92	30	18	78

The increase in the attractivenenss of the utility for the public transport generates a shift towards this mode. Since the demand model is a model-distribution logit model the total number of trips depends on the variables in the mode utilities. Henceforth, the total number of trips also rises, mainly, due to an increment of commute trips.

Most of the new public transport trips were previously done by car driver. The higher shift towards the public transport is reported in commute trips. Regarding Jæren line, there is an increment of 3.973 trips for the three local lines in average daily passenger demand.

Compared to Scenario 1, Scenario 2 simulates more train trips to better represent the observed traffic volumes. Nevertheless, some volumes are even more overstimated given that the increase in trips is almost evenly distributed.

Compared to the observed counts, Scenario 2 represents approximately all the observed trips in the Jæren train service, although the rush period demand is understimated around 15%. This might be also due to differences in the distribution of the travel patterns that are less spread along the day.

The main differences remaining in the Stavanger – Egersund service. There is an overstimation of the traffic volumes from Sandnes to Bryne in the afternoon peak and an understimation from Egersund, Vigrestad and Nærbø to Bryne, Sandnes and Stavanger in the morning peak. This might be caused due to a lack of representation of trips with origin in the South, where the residential areas are not so close to the stations. Trips combining car drive until the station and further train trip might not be well represented.

The change in the ASC of the public transport affects not only to the train demand. Therefore, in order to validate the model results, the trips of the other modes should be also compared to observed counts. Nonetheless, the main purpose of this project is to analyse the passengers’ behaviour against crowding in the train service, thus Scenario 2 can be considered to be a good approximation of the observed data.

5.2 IMPLEMENTATION OF THE CROWDING FACTOR IN THE MODEL

Crowding factor

First of all, in this project crowding is defined as the occupancy or load factor, i.e. the number of passengers divided by the number of seats on the vehicle. The decision is mainly based on both, the possibility of measuring these values and the desire to avoid including crowding as a probability since it adds even more uncertainty to the results.

Neither the vehicle design nor the subjective perception of crowding are included in the new model. This would require further analyses and the use of additional variables, which is beyond the scope of the present study.

Crowding is included as travel time multiplier rather than a fixed value per trip since, as revealed in the comfort chapter, passengers do not feel crowdedness equally for long or short trips. This factor also changes with respect to the purpose. The shares of commute trips within the rush period used in the Rogaland area by the Trenklin model for are shown in Table 23.

Table 23: Commute trips shared in Trenklin model (Source: retrieved from Trenklin model (Aarhaug, et al., 2013))

Time	06:00-07:00	07:00-08:00	08:00-09:00	15:00-16:00	16:00-17:00	17:00-18:00
Commute trips share	88%	89%	66%	76%	74%	54%

Conversely, a common crowding factor for all passengers on board is assumed in this project since most of the trips are commuting. Additionally, travel times in the demand model are already multiplied by an on board travel time coefficient in the public transport mode utility, which depends on the purpose of the trip.

The on board travel time coefficient for commute trips differentiates the travel time between female or male with coefficients -0,026 and -0,0299 respectively. Private trips hold a coefficient of -0,0239, whilst for leisure trips is -0,0174 and -0,0143 for trips at work. Therefore, the expected results imply commute and private trips being considerably more sensitive to changes in travel time and hence more affected by crowding on board.

Crowding factors vary depending on the occupancy of the vehicle and how the travel is made, standing or seated. Five levels of crowding are defined in this project, a summary table is available below the description of each level. For each level, different expressions are used to estimate the number of passengers standing or seated. The maximum number of passengers standing is estimated based on the Jæren line trains characteristics, which have a maximum seat capacity of 310. The standing passengers per square meter is also estimated based on their features, the space without seats is 40 m^2.

The values regarding crowding as time multiplier are based on assumptions and using the stated preferences studies (Baker, MacDonald, Murphy, Maunsell, & Myers, 2007) and (Wardman & Whelan, 2011) as starting point.

Level 1: Many seats available – no standing

Level 1 incudes occupancies rate up to 60%. Values below are not affected by crowding and it is assumed that all passengers on the vehicle take a seat.

As described before, in reality, passengers feel not so comfortable in an almost empty vehicle which would be translated into a higher value of time. Despite that, the assumption of crowding factor equal to 1 for these occupancy levels is considered valid.

Table 24: Level 1 crowding (Source: modified after (Wardman & Whelan, 2011))

Occupancy	# Passengers (P)	P_{max}-> (P_{stand}/m^2)	β_c
< 60%	$P_{stand} = 0$	0 -> 0 P_{stand}/m^2	$\beta_{stand} = 1$
	$P_{seat} = P_{onboard}$	186	$\beta_{seat} = 1$

Level 2: Some seats available – few standing

Level 2 contains occupancies from 60% up to 100%. The highest value indicates that the number of people on board equals the number of seats. Some passengers prefer to stand rather than sit close to someone else, whilst others do not care so much about the proximity to passengers if they can get a seat. Therefore, it is assumed that passengers after 60% of occupancy have a 50% probability of being standing or seated.

The perception of the value of time is altered depending on how passengers are traveling, whether standing or seated. The crowding factor for standing is assumed to be 1,2 given that the density of passenger per square meters is less than 1,6. The time multiplier if seating is 1,1 as there are still some seats available. Not all seated passengers experience crowding as the seat next to them might be free.

Table 25: Level 2 crowding (Source: modified after (Wardman & Whelan, 2011))

Occupancy	# Passengers (P)	P_{max}-> (P_{stand}/m^2)	β_c
60% - 100%	$P_{stand} = P_{onboard} - P_{seat}$	62 -> 1,55 P_{stand}/m^2	β_{stand} = 1,2
	$P_{seat} = 0{,}3 \,.\, N_{seats} + 0{,}5 \,.\, P_{onboard}$	248	β_{seat} = 1,1

Level 3: Few seats available – standing around doors

Level 3 encloses occupancies from 100% up to 140%, where there are no more free seats. The probability to get a seat is still assumed 50%.

The maximum density of passenger per square meter is approximately 3, and the crowding factor for standing is assumed to be 1,7. The factor for seating is 1,35 as on average there are still some seats available but only a few.

Table 26: Level 3 crowding (Source: modified after (Wardman & Whelan, 2011))

Occupancy	# Passengers (P)	P_{max}-> (P_{stand}/m^2)	β_c
100% - 140%	$P_{stand} = P_{onboard} - P_{seat}$	124 -> 3,1 P_{stand}/m^2	β_{stand} = 1,7
	$P_{seat} = 0{,}3 \,.\, N_{seats} + 0{,}5 \,.\, P_{onboard}$	310	β_{seat} = 1,35

Level 4: No seats available – densely packed

Level 4 covers occupancies from 140% up to 165%, at this level there are no more seats available, so all new passengers stay standing. The density of passenger per square meter is approximately 5 people/m^2. As mentioned in the comfort chapter, this level is considered as densely packed in Europe.

The crowding factor for standing is assumed to be 2,4 due to the high density of users. The factor for seated is 1,8 given that all seats are taken so all passengers feel a degree of crowdedness.

Table 27: Level 4 crowding (Source: modified after (Wardman & Whelan, 2011))

Occupancy	# Passengers (P)	P_{max}-> (P_{stand}/m^2)	β_c
140% - 165%	$P_{stand} = P_{onboard} - N_{seats}$	200 -> 5 P_{stand}/m^2	β_{stand} = 2,4
	$P_{seat} = N_{seats}$	310	β_{seat} = 1,8

Level 5: No seats available – completely packed

Level 5 refers to occupancies from 165%, where the density excesses recommended standards, although there is still capacity.

The crowding factor for standing is assumed to be 3,2 and for seating 2,3. Passengers are completely packed and the decrease of comfort is clearly felt by all users into a great extent, so the value of time is almost triple for both types of passengers.

Table 28: Level 5 crowding (Source: modified after (Wardman & Whelan, 2011))

Occupancy	# Passengers (P)	P_{max}-> (P_{stand}/m^2)	β_c
>165%	$P_{stand} = P_{onboard} - N_{seats}$	P_{stand}/m^2	β_{stand} = 3,2
	$P_{seat} = N_{seats}$	310	β_{seat} = 2,3

Summary crowding factors

The crowding coefficients are summarized in Table 29. These factors are used to adjust the perception of the trip depending on the crowding conditions.

Table 29: Crowding factors (standing or seated) depending on the occupancy

Occupancy	β_{stand}	β_{seat}
<60%	1,00	1,00
60 – 100%	1,20	1,10
100 – 140%	1,70	1,35
140 – 165%	2,40	1,80
>165%	3,20	2,30

These coefficients multiply the travel times or the value of time (modelled passengers might suffer changes in any of those). Representing the variations in the value of time could explain better the phenomenon.

The factors are considered linear for each interval in order to simplify the calculations. Moreover, the crowding coefficients before defined are assumed to represent the average for each occupancy level. The value of time is set to 60 NOK/hour in 2009 base price year (Johansen & et al., 2010). The value of travel time depending on the occupancy is represented in Figure 19.

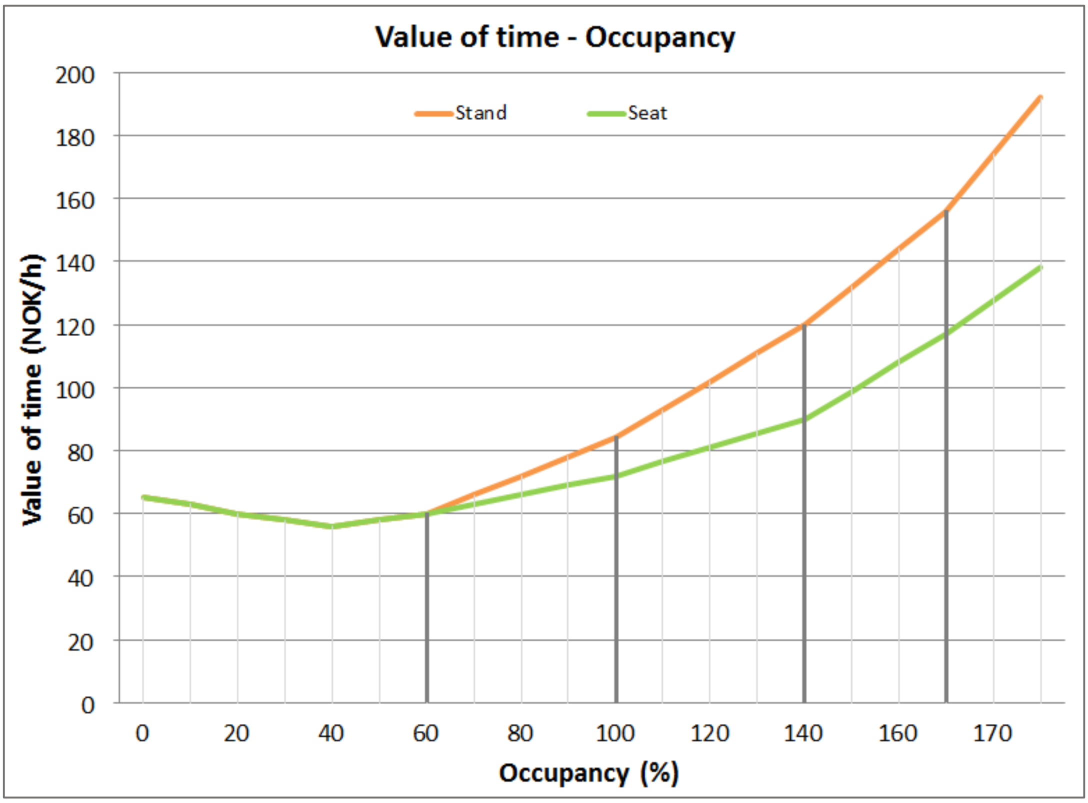

Figure 19: Value of time - Occupancy

The value of time for seated or standing passengers for values of occupancy lower than 60% is equal. The lowest value of time correspond to 30-50% of occupancy, which could be seem as the best occupancy level to travel. From 60% of occupancy, increasing the load factor the value of time rises exponentially, being higher for standing passengers. For occupancies larger than 140%, standing passengers experience a value of time double, whilst for seated users it is after approximately 170% occupancy.

Implementation in the model

Scenario 2 is the baseline scenario chosen to implement the crowding factor in the model.

First of all, Scenario 2 is run without including any crowding effect. It is settled to perform seven iterations in order to account for capacity constraints on roads. The output of the simulation is the demand between stations per direction for each of the lines and time period. The demand is hourly represented in the rush period (06:00 – 09:00 and 15:00 – 18:00).

Based on the demand output, the occupancy per line, link and hour is estimated as the total number of passengers in the link divided by the number of seats. The occupancies are only estimated for the rush period.

The real number of trains per hour is shown in Table 9. Despite that, both lines (Stavanger – Sandnes and Stavanger – Egersund) are modelled with a frequency of 30 minutes in CUBE. This means that there are two trains per hour. Nonetheless, it is assumed the worst scenario where all passengers are boarding to a unique train. The number of seats is then, 310 for this hypothesis.

The demand per line, link and hour is split whether or not the passengers are seated. The number of people standing or seated is calculated according to the equations for each crowding level, previously defined.

At this stage, the number of passengers seated or standing per line, link and hour as well as their corresponding occupancy levels are known. The crowding coefficients per line, link and hour are calculated multiplying the number of passengers of each type by the corresponding crowding factor and dividing it by the sum of both type of passengers.

As previously described, there is a unique public transport dataset for the rush period. Therefore, the travel times between stations in rush hours are common. For this reason a unique crowding factor per line and link can be used.

In order to obtain a unique crowding coefficient, the average value based on the amount of passengers is estimated. The crowding coefficients for the six rush hours are multiplied by the number of passenger in the selected hours. These are summed and divided by the total number of passengers.

Finally, the crowding factor (β_c) per line and link in the rush period is obtained.

The travel times between stations in the public transport network rush file are updated. These are multiplied by the crowding factors, which weight the travel times. The model is run and this procedure is repeated iteratively in order to account for crowding on board, as graphically described in Figure 20.

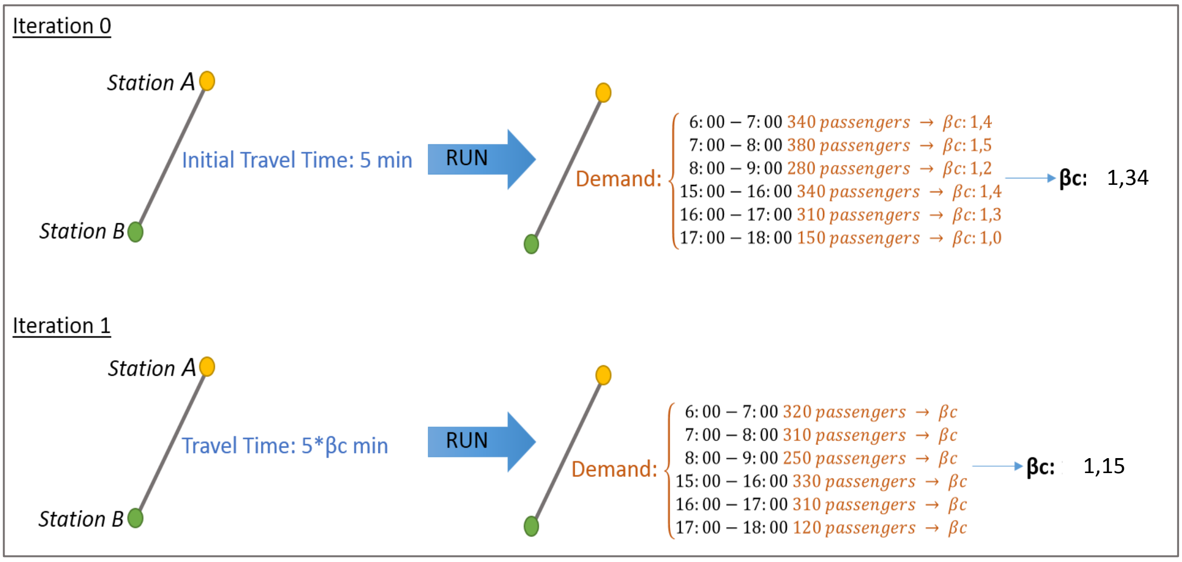

Figure 20: Procedure of the estimation of beta and new demand

The travel times of each scenario are manually updated based on the crowding factors of the previous scenario. Posteriorly, the scenario is simulated by the software CUBE and the new crowding factors are also manually obtained. This iterative process finish when the differences in the train demand (where the crowding is being implemented) between two consecutives scenarios are less than 0,1%. This difference is selected as it is the used in the iterative process of the road capacity constraints.

The crowding factor is only included into the train service. In particular, in the Stavanger – Egersund line. The other public transport modes do not present crowding as the occupancies are lower to 60% for the rush hours. Since not all the modes are affected by this crowding coefficient is not possible to include it as travel time coefficient in the utilities.

The fact of including the crowding factor only on the long train line could create a disadvantage facing bus however, it is assumed realistic given the flexibility of the bus service. The costs of including higher frequency cannot be compared with the costs of increasing capacity or frequency in the train service. In addition, the new competition between the two public transport modes allows to make rail oriented policies enough competitive to gain market shares from bus demand.

6. CROWDING SCENARIOS

The different scenarios simulated in this study are gathered in Table 30, where the changes made and the modified files are described.

Table 30: Scenarios description

	Changes	Modified files
Scenario 0	–	–
Scenario 1	Updated network, public transport routes, demographic data and commute trips distributions by public transport	dom_nj_2010_koll_NORMAL / RUSH nettverk_updated demogr2014_g2009_updated timeandeler_V15
Scenario 2	Updated network, public transport routes, demographic data and commute trips distributions by public transport New ASC in the public transport utility	dom_nj_2010_koll_NORMAL / RUSH nettverk_updated demogr2014_g2009_updated timeandeler_V15 par_arbeid_V15
Based on Scenario 2:		
Scenario 3	Scenario 2 run with 1 iteration	–
Scenario 4	Updated travel times with crowding factors from Scenario 2 (Beta 1)	dom_nj_2010_koll_rush_node_BETA1
Scenario 5	Updated travel times with crowding factors from Scenario 4 (Beta 2)	dom_nj_2010_koll_rush_node_BETA2
Scenario 6	Updated travel times with crowding factors from Scenario 5 (Beta 3)	dom_nj_2010_koll_rush_node_BETA3
Scenario C	Updated travel times with crowding factors from Scenario 6 (Beta 4)	dom_nj_2010_koll_rush_node_BETA4
Scenario 7	Updated travel times with crowding factors increased in 15%	dom_nj_2010_koll_RUSH_INC1
Scenario 8	Updated travel times with crowding factors increased in 30%	dom_nj_2010_koll_RUSH_INC2
Scenario 9	Updated travel times with crowding factors increased in 45%	dom_nj_2010_koll_RUSH_INC3
Scenario 10	Updated travel times with crowding factors increased in 60%	dom_nj_2010_koll_RUSH_INC4

6.1 CAPACITY CONSTRAINTS ON THE ROAD -> Scenario 2 vs. Scenario 3

The scenarios are simulated with 7 iterations to account for capacity constraints on the roads. Before proceeding to further analyses, a scenario comparison is performed by running Scenario 2 vs. Scenario 3 (7 vs. 1 iterations), in order to understand the relation between road capacity and train service.

The model simulation based on several iterations allows accounting for capacity constraints on the road. The links are associated to a capacity index (CI), which represents a speed-volume curve. If the link volume from the iteration is lower than the capacity, the speed from the iteration is assumed as the real speed, but if it reaches the capacity then the speed is redefined by CI. The following iteration estimates the demand based on the new speeds.

The algorithm used is all or nothing, the equilibrium is reached when the demand difference between the last two iterations is lower than 0,1%. At equilibrium, all routes between each OD pair hold the same generalized costs (Madslien, 2005).

In case a unique iteration is done, the speeds and hence the travel times on the roads do not depend on the amount of traffic on those links, which is unreal and could lead to biased results.

Scenario 2 is compared to Scenario 3, which holds the same characteristics but it is perform with a single iteration. The differences are shown in Table 31.

Table 31: Differences in trips (Scenario 3 - Scenario 2) (Source: modified after DOM_Jæren)

		PURPOSE				
	TOTAL	Commute	At work	Spare time	Drop on-off	Private
Car (driver)	309	105	25	25	47	107
Car (passenger)	63	19	2	10	6	27
Public transport	-149	-89	-8	-11	-6	-34
Jæren line	12					
Walking	-87	-16	-7	-14	-6	-45
Cycling	-22	-9	-2	-3	-2	-7
All modes	114	10	10	7	39	48

When the road capacity is not considered there are, in general, more trips. The speeds on congested roads remain at the maximun projected, hence the travel times are lower. This affects, on one hand the utilitites increasing the share of road trips, and on the other reducing the generalised costs. The trip increment is mainly due to private and drop on-off trips which might mean that the new generalised costs of some road trips are now accessible by the population, triggering in new trips.

In general terms, there is an increment in car drivers and car passengers whilts there is a reduction of walking and public transport trips. In both scenarios the number of train passengers for the Jæren line is practically constant. This entails that the reduction in public transport trips is due to to a decrease in bus use and regional train services.

Additionally, it could occurr that the roads competing with the Jæren line have low car traffic, so there migth not be increments in travel times due to congestion. It is not possible to know the exact route passengers would take if they shift from train to car, although the road links close to the train tracks are observed. The traffic of some of those roads is close to capacity in terms of average daily traffic, and as expected it is reduced when capacity constraints are put into the model (several iterations).

As a result, it might be concluded that improving road conditions does not reduce train passengers, but reducing train conditions increases road trips.

6.2 CROWDING ON BOARD -> Scenario 2 vs. Scenario 4, 5, 6, C

The baseline scenario for implementing crowding factors in the line Stavanger – Egersund is Scenario 2.

The crowding factors (β) used in each scenario to update the travel times (TT), as well as these are shown in the appendix in Table 47 and Table 48. The crowding factors used as multipliers to update the input travel times in each scenario are the output of the previous scenario.

Equilibrium point

The occupancy and crowding factors in Scenario 2 are calculated as explained before. Afterwards, travel times in the rush period are updated including the crowding factors and using them as new input data for Scenario 4. New crowding factors are obtain from Scenario 4, these are used to update the initial travel times. The new travel times are used as new inputs for Scenario 5. This procedure is iteratively repeated in order to obtain a demand equilibrium.

Scenarios 2, 4, 5, 6 and C present similar characteristics. The volumes per direction, link and hour are observed for the scenario hypothesis where all passengers in each rush hour board on the same train. In the direction towards Stavanger, occupancies higher than 60% are registered between Bryne and Jåttåvågen from 06:00 to 09:00, extended from Varhaug to Stavanger between 07:00 and 08:00. In the opposite direction, the greater occupancies are between Stavanger and Varhaug from 15:00 to 17:00.

The total travel time of the line in the rush period and the total number of passengers per day (within the rush period) and direction for each scenario are represented in Figure 21 and Figure 22.

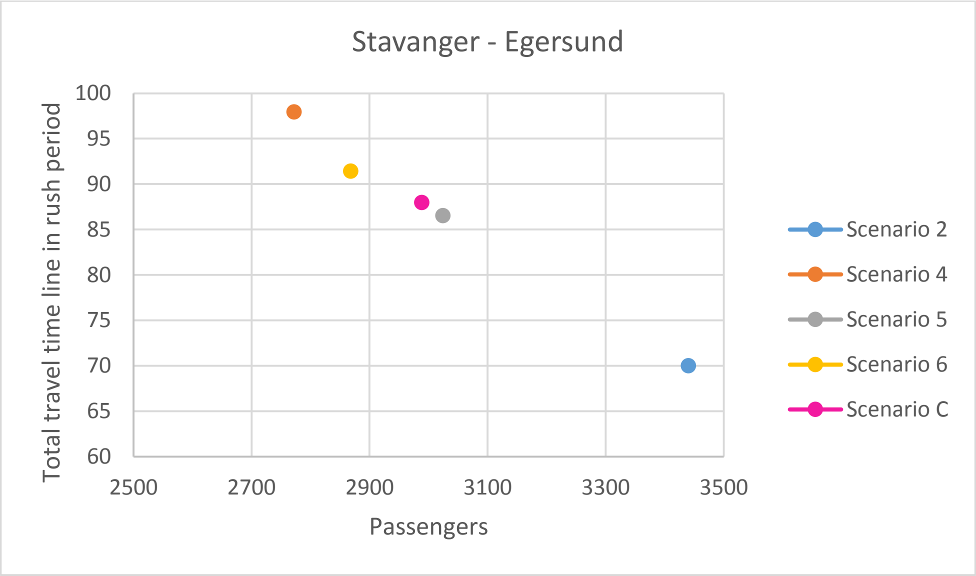

Figure 21: Crowding equilibrium for the demand Stavanger – Egersund (Source: modified after DOM_Jæren – CUBE)

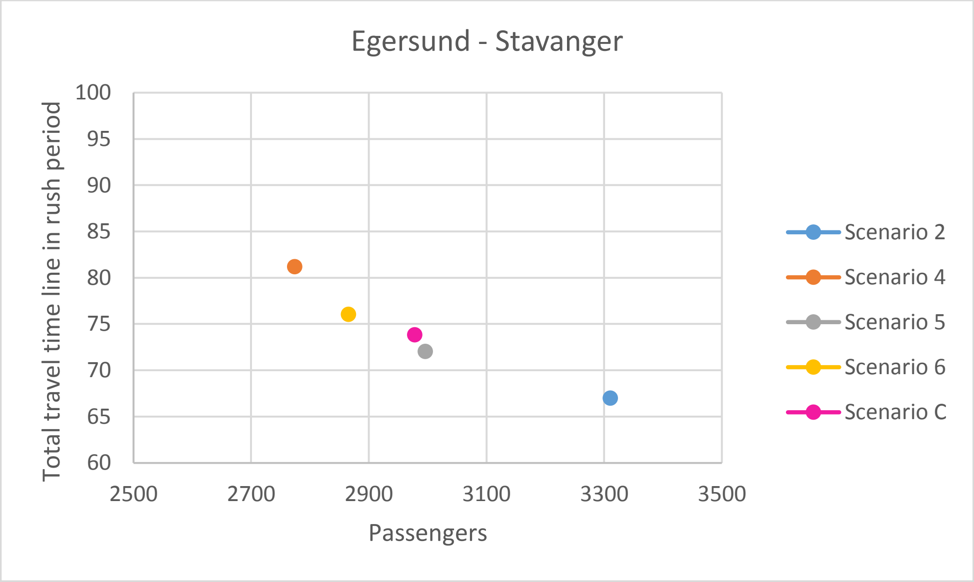

Figure 22: Crowding equilibrium for the demand Egersund – Stavanger (Source: modified after DOM_Jæren – CUBE)

Occupancies higher than 60% between stations imply a crowding factor, which is used to increase the travel time for the following simulation. Greater travel times generate a lower number of passengers on board and consequently a minor crowding factor to be used in the following simulation. Since the travel time is reduced with respect to the previous simulation, more users travel on board which imply again a high crowding factor.

This procedure is supposed to be repeated until the differences in train demand from two consecutive simulations are lower than 0,1%. However, given the character experimental of this project, the methodology and the time frame, it is assumed as correct 4 iterations.

Scenario 4 suffers a total reduction in the number of passengers of 14% (respect the previous scenario), on the contrary Scenario 5 results in 6,5% increase. Scenario 6 has a diminution of 3,7%. Scenario C presents an increase of 2,8%. It is assumed though, that the equilibrium is reached in Scenario C.

The total number of trips by mode and the trips in the Stavanger – Egersund line for the whole day and in the rush period for the Scenario 2 and the differences to the other scenarios with respect to this one are shown in Table 32.

Table 32: Comparison Scenario 2 - Scenario 4, 5, 6, C (Source: retrieved from DOM_Jæren – CUBE)

	Scenario 2	Scenario 4	Scenario 5	Scenario 6	Scenario C
TOTAL TRIPS					
Trips car driver	518.151	555	324	459	344
Trips car passenger	73.664	52	31	43	33
Trips public tranport	116.182	-925	-533	-760	-573
Trips walking	239.921	208	117	168	126
Trips cycling	22.087	69	38	56	42
TOTAL	971.005	-41	-23	-34	-28
TRIPS TRAIN (STV-EGS)					
Total train passengers	9.450	**-1.336**	**-811**	**-1.128**	**-899**
Rush train passengers	6.750	-1.203	-729	-1.017	-783

As it can be seen, the variations regarding total number of trips are practically insignificant against the other changes. The reason might be due to the few changes in the input data, which are only in some of the links between the stations in the line Stavanger – Egersund.

The trends in all scenarios are similar, there is a reduction in the demand for train service, the passenger loss is absorbed by other modes, mainly by other public transports and car driver trips.

The variations in the public transport network input file for the rush period triggers changes in the train service not only in the rush period. Since people do not normally do a single trip without the return one, this may be due to one of those trips is in rush period and the other not. For example, if a trip previously done by train it is now done by car in the rush hour the return trip, even at non rush, is by car.

Crowding Scenario -> Scenario C

Scenario C is further examinated to understand the passengers' travel behavior facing crowding on board. The differences in trip purposes between Scenario 2 and Scenario C are shown in Table 33. In this case, the differences in train trips are representing only the train Stavanger – Egersund and not the three lines serving the Jæren line.

Table 33: Differences in trips (Scenario C - Scenario 2) (Source: modified after DOM_Jæren)

		PURPOSE				
	TOTAL	Commute	At work	Spare time	Drop on-off	Private
Car (driver)	**342**	229	25	15	16	57
Car (passenger)	**33**	19	1	4	2	7
Public transport	**-575**	-369	-40	-36	-27	-103
STV-EGS line	**-899**					
Walking	**126**	71	8	14	6	27
Cycling	**40**	25	3	2	2	8
All modes	**-34**	-25	-3	-1	-1	-4

It is worth to mention that most of the trips within these crowding hours are commute trips, so they are the trips more affected by the changes due to the crowding factors, as well as private trips. Passengers travelling under these purposes have a higher value of time. Therefore, small variations in travel times at these hours are expected to change the demand greater than at other time periods. Despite that, the real variable desired to model is crowding and not delay, so other trip purposes may be more sensitive. For example, leisure trips might present more flexibility in order to avoid travelling in vehicles densely occupied.

In addition, there is a unique public network file for the rush period. The crowding factor is an average value per link depending on the number of passengers for the six hours in the peak period. So passengers travelling in the rush period at vehicles not highly occupied will be affected by non-existing crowding on board in the model.

Some passengers on the line Stavanger – Egersund are shifting transport mode, an analysis of the competitive modes is done hereunder.

The travel time on the short line (Stavanger – Sandnes) remains constant, henceforth any change on this line is associated to the variations on the long line. There is an increased in general terms, altough there is still under 60% of occupancy rates. There is an outstanding increment of the demand from Paradis to Sandnes between 15:00 and 17:00, which corresponds to the 40% of the loss in the long line for this period. This train shift might be caused by passengers commuting between Stavanger and Sandnes sentrum, who previously took any train out of the city but now, they wait for the short line service, given the reduction in travel time. Nevertheless, passengers travelling further than Sandnes sentrum are not changing line.

Some of the passengers are shifting towards the regional trains, which only stop at Stavanger, Sandnes sentrum, Nærbø, Bryne and Egersund. This shift is mainly in the afternoon peak from Stavanger to Bryne.

In the morning peak between 07:00 and 08:00 the bus services that experience changes in demand are shown in Figure 23.

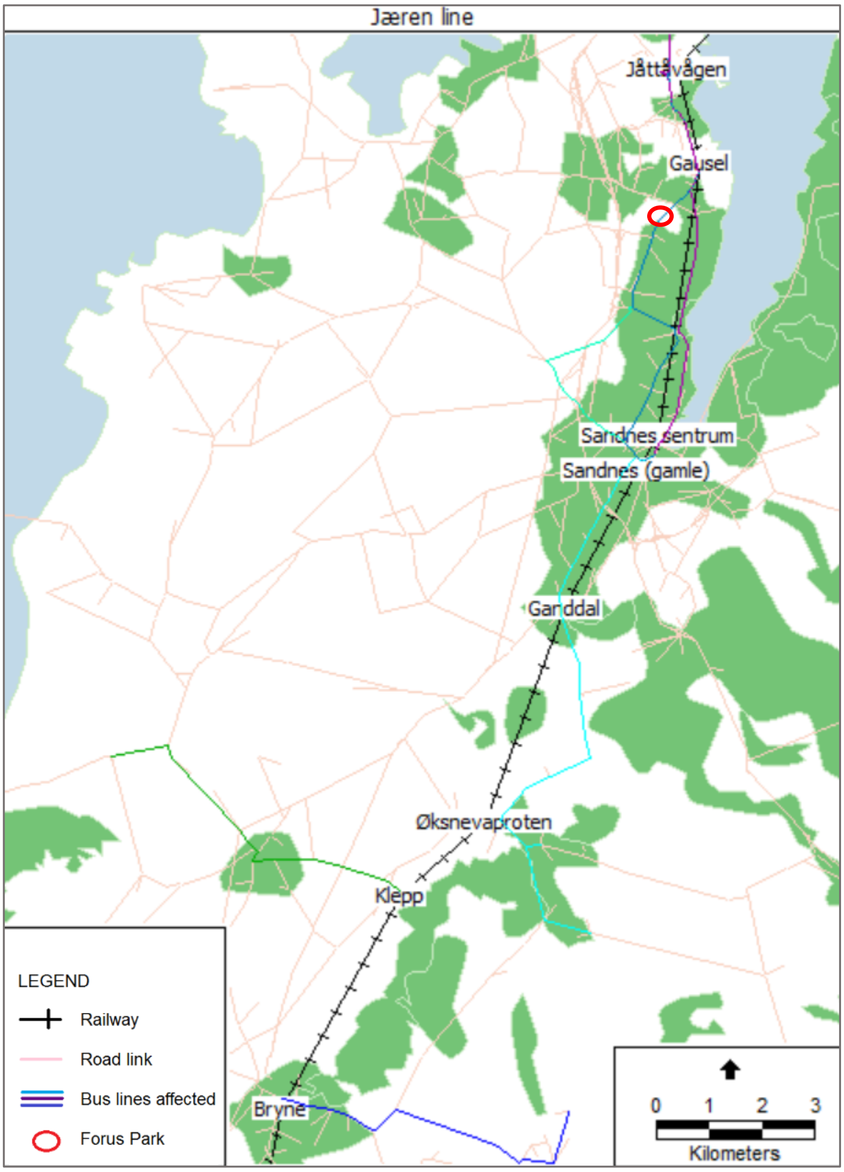

Figure 23: Buses competing to the train service (7:00-8:00) (Source: modified after DOM_Jæren – CUBE)

There is an increment on passengers between Sandnes and the business area close to Gausel (Forus Park), marked in Figure 23 with a red circle. Given that the destination is not close to any particular station, those trips might have been previously done by a combination of train and other transport mode from Gausel. When the crowding conditions are implemented, users may get off the train at Sandnes station and take a bus there. In addition, there is a shift towards buses from Øksnevadporten to Gandal.

In the opposite direction there is also an increased on bus trips between Jåttåvågen and Sandnes sentrum, these trips might have been made by train since the crowding conditions from Stavanger are not high. Despite that, the fact of having a unique file for both rush periods generates a wrong modelled of some users.

The crowding conditions on the train also entail a loss of bus passengers when using bus plus train as combined transport mode, this is the case for people living in the areas of Klepp and Bryne.

The bus services that experience changes in demand in the afternoon peak between 15:00 and 16:00 are shown in Figure 24.

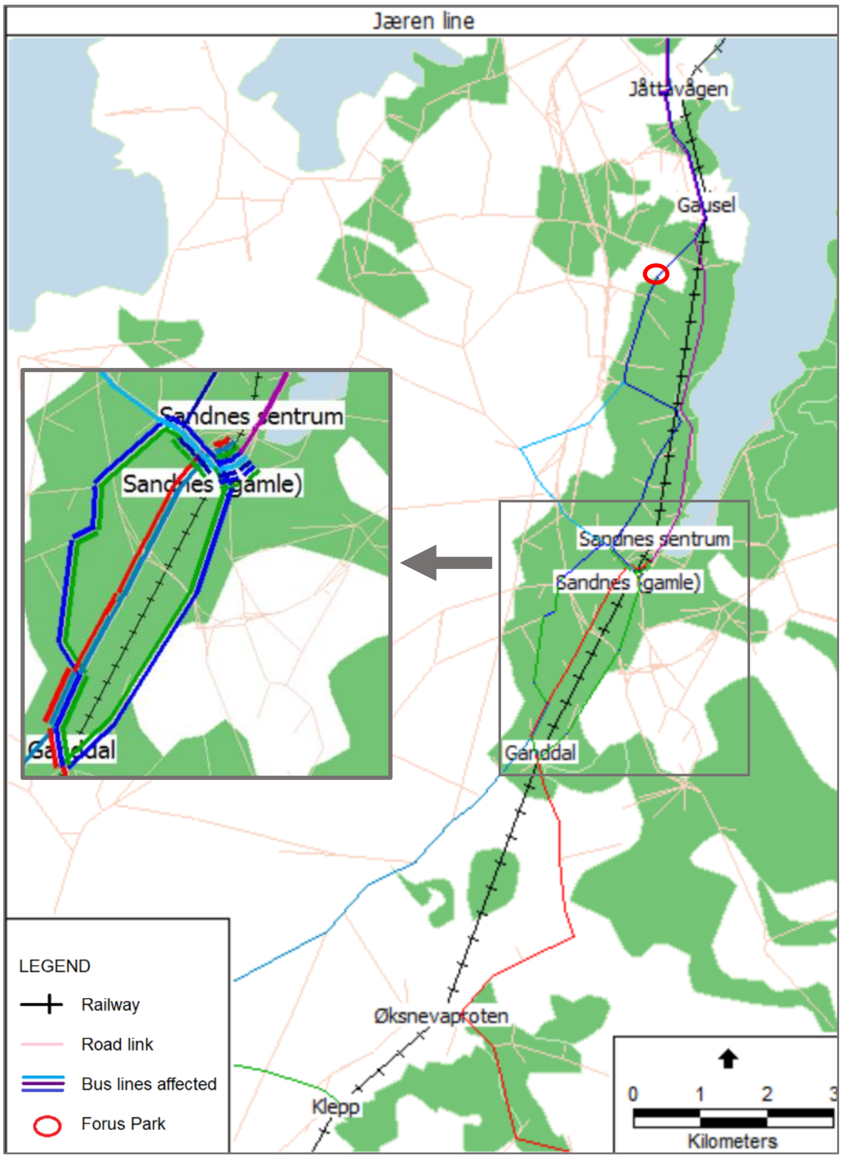

Figure 24: Buses competing to the train service (15:00-16:00) (Source: modified after DOM_Jæren – CUBE)

In the afternoon peak, there is an increase of bus trips from Mariero and Jåttåvågen area to Sandnes. These trips might have been made by the short train line (Stavanger – Sandnes), whose travel times remain constant. This train service has a frequency of 30 minutes, some passenger could prefer to take the bus, so they may experience more travel time but less waiting time to avoid the crowded train. Passenger boarding at Stavanger are likely to find a seat even in rush hour so their crowding perception is not as extremme as those boarding in the following stops.

There is also a rise between Sandnes sentrum and Gandal and viceversa, for these origin-destination trips the only public transport option to avoid crowded trains is to take the bus. There are four buses competing with the train to connect these towns, two of them have circular routes, so the lower waiting times migth compensate the travel times.

The bus serving Klepp station towards relatively close areas by car also present a reduction of trips, as they might be the same passengers that changed transport mode in the morning peak, probably they shift towards car.

The increase in road traffic is mainly in the areas between Bryne and the Forus Park, the business area shown in Figure 23. There is also an increased on car trips on the higway that runs paralel to the train between Sandnes and Stavanger. There are no relevant traffic variations far from Nærbø. Therefore, it is likely that the train passengers shifting to car have similar trip characteristics that the ones shifting to bus service.

Walking trips also increased, this could be referred to the fact that some of the train trips are short trips. New private trips by walking could be produced as they might shift destination to a closer shop for example, or include a stroll as part of the trip.

6.3 CROWDING SENSITIVITY -> Scenario 2 vs. Scenarios 7, 8, 9, 10

A different approach to analise passengers' reacctions towards crowding is to increased the crowding factors by a percentage for all the links along the line. The demand resulting from each scenario leads to a different crowding factors, which are related to the input increment in order to analyse the passenger crowding sensitivity.

Scenarios 7, 8, 9 and 10 represent the increment in crowding of 15, 30, 45 and 60%, respectively. The crowding factros and the travel times used as inputs for each scenario are defined in the appendix in Table 49 and Table 50.

Differential number of trips for the new scenarios regarding Scenario 2 can be observed in Table 34.

Table 34: Comparison Scenario 2 - Scenario 7, 8, 9, 10 (Source: retrieved from DOM_Jæren – CUBE)

	Scenario 2	Scenario 7	Scenario 8	Scenario 9	Scenario 10
Increased input crowding factor		+15%	+30%	+45%	+60%
TOTAL TRIPS					
Trips car driver	518.151	125	315	420	556
Trips car passenger	73.664	2	20	31	44
Trips public tranport	117.182	-157	-490	-671	-910
Trips walking	239.921	28	110	155	215
Trips cycling	22.087	15	41	54	73
TOTAL	971.005	13	-4	-11	-22
TRIPS TRAIN (STV-EGS)					
Total train passengers	9.450	**-421**	**-891**	**-1.127**	**-1.435**
Rush train passengers	6.750	-381	-799	-1005	-1276

The total number of trips is less affected by the rise of the train travel times than in the previous analysis due to these increments although along the entire line they are relatively small (maximum 60% against maximum 110%).

As the crowding factors increase, trips by train decrease. The loss in train passengers is absorbed by the other transport modes. Approximately 45% of the trips are now done by other public transport modes, such as bus or the other train services. Car trips are also increased in roughly 35%.

The demand model is a multinomial model with respect to the transport modes, however, train and bus are treated as a unique mode, public transport. These are divided in the network assignment. When the reduction in the attractiveness of the train is relatively small, the demand for other public transport modes increase greater than for car. This behaviour is similar to the experience if they are modelled as nested logit model, being train and bus in the same nest. In contrast, as the train attraction decrease the car is more affected, performance not consistency with a nested. This might be due to bus and train are not correlated (Cherchi, 2013).

After Scenario 8, posterior crowding factor increments do not affect as greater as for smaller rises. This might support the hypothesis that passengers are less sensitive to crowding when they are already in a vehicle with high occupancy rate.

Changes in the volume of passengers on board between stations in the Stavanger – Egersund line are also observed. The link between Sandnes sentrum and Gausel is further analysed, the volume of passengers in the rush period per direction is related to the corresponding value of the output crowding coeficient in Figure 25 and Figure 26.

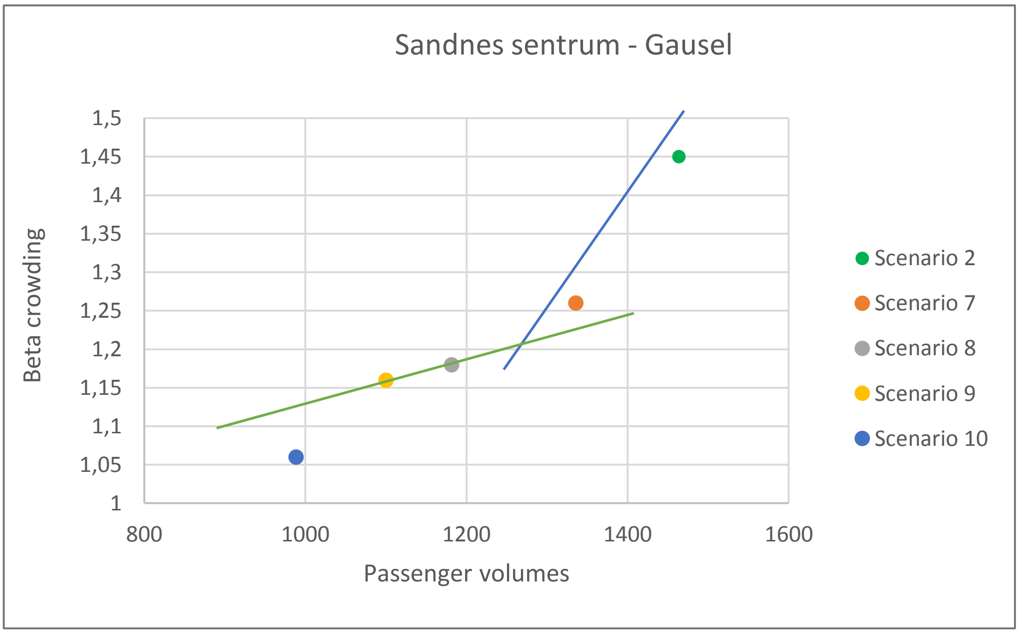

Figure 25: Crowding sensitivity Sandnes sentrum - Gausel (Source: modified after DOM_Jæren – CUBE)

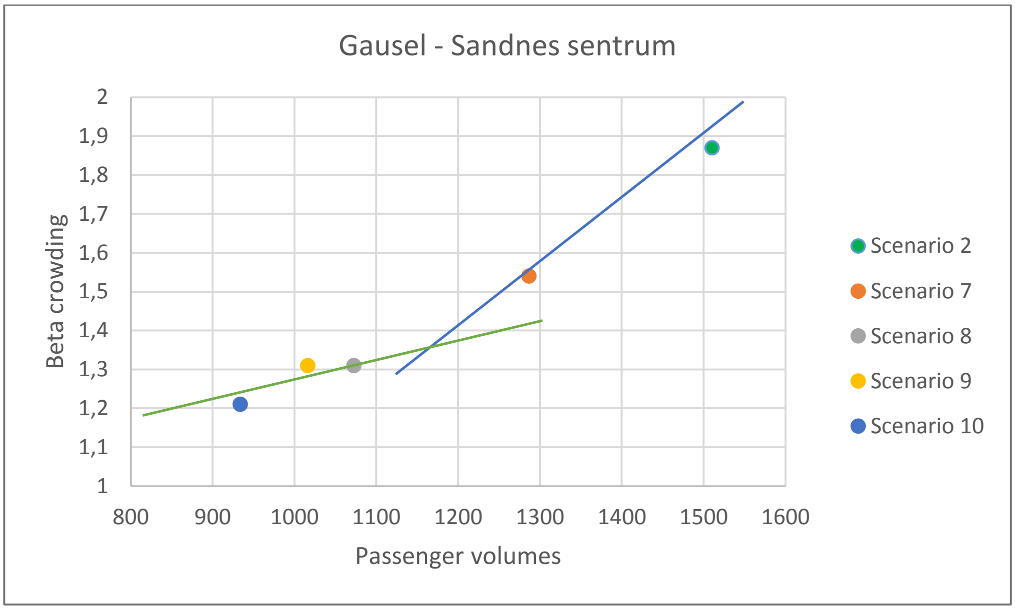

Figure 26: Crowding sensitivity Gausel – Sandnes sentrum (Source: modified after DOM_Jæren – CUBE)

Each scenario is built by increasing the crowding factors used as inputs in 15%, which generates even increments of the travel time among the line. Nonetheless, the demand does not change proportionally. In both direcctions, two different patterns are identified. Passengers present a higher sensitivity to increasing crowding conditions when the occupancy of the carriage they are is larger than 120% approximately. Therefore, most of the users can stand travelling up to 120% of occupancy, after that level they are more willing to change transport mode.

7. OPTIMUM SEATING CAPACITY

A further study is done in order to estimate the optimal seat capacity in the rush period in the commuter Jæren line, in particular in the long service Stavanger – Egersund.

The extra capacity might be given by additional carriages in the vehicle, actually composed of 4 (2 of them motorized). This method is used in the Southwest trains in London, where they increase from 8 to 10 the number of carriages in the peak hours (Southwest Trains, 2014), and in Ireland where it is possible to select the number of carriages depending on their actual needs (Barry, 2014). In addition, the extra capacity can be provided by assembling together various vehicles. In fact, this method is more widely extend in the Norwegian lines (Jernbaneverket, 2014).

The aim of this project is to estimate a number of seats, which implies a specific number of carriages or vehicles. Nonetheless, it is important to mention that the interior design of the carriage and the features of the seats are also important. NSB customers reported their discomfort due to “packed” seats in the new trains so the train operator, NSB, had to replace some of them (NSB Group, 2012). Despite that and to narrow the options in the study, the train type is assumed equal to the actual in use.

The technical limitations on the maximum number of extra carriages or vehicles are given, in general, by the power the substations along the line can provide, the needed power for the tractor vehicle (locomotive) to carry the additional carriages. Moreover, the parking space for idle time and the minimum length of the deflection tracks along the line can also be restricting.

The configuration of the stations at the end of the service, Stavanger and Egersund are shown in Figure 27 and Figure 28, respectively.

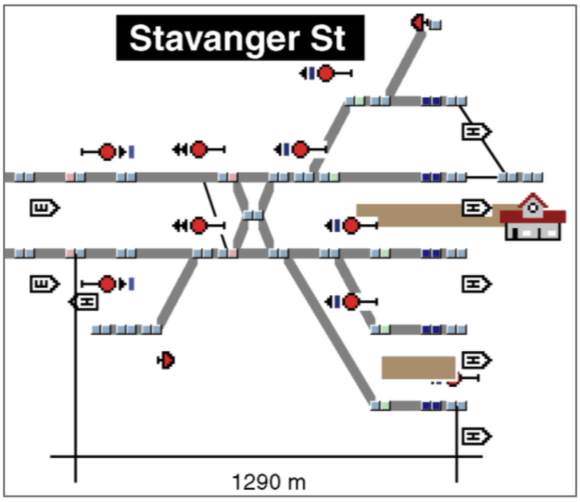

Figure 27: Stavanger station detailed plan (Source: retrieved form (Jernbaneverket, 2014))

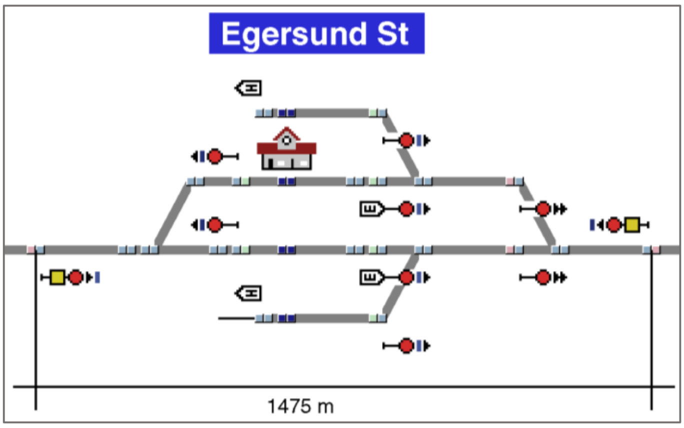

Figure 28: Egersund station detailed plan (Source: retrieved form (Jernbaneverket, 2014))

In the specific limitation by deflection track[9] longitude, the minimum deflection track is found at Helvik station, 300 meters (Jernbaneverket, 2014). According to this, the maximum number of middle carriages are 12, maintaining in the two extremes the power cars; or 3 based vehicles assembled, as shown in Figure 29.

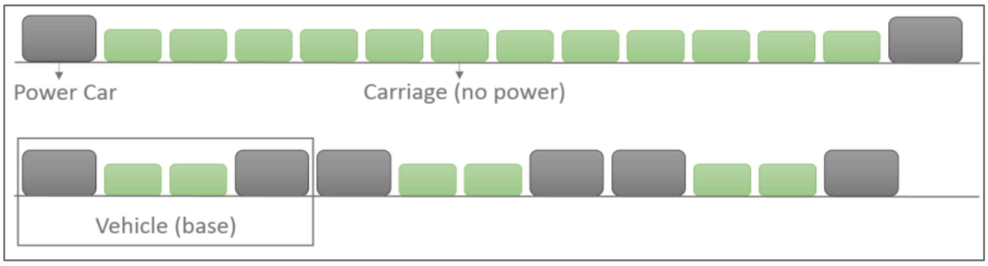

Figure 29: Train configurations (maximum length)

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[9] Due to the line is single track, when the trains in opposite directions are about to run between the same stations, one of them needs to wait aside to allow the other train to run along the track.

In order to estimate the optimal capacity in the vehicle, two approaches are described. One based on the intersection of marginal cost and marginal utility curves, and the other, based on the frequency and load demand profile to accommodate the passengers as little overcrowded as possible.

The baseline demand profile in rush periods for estimating the optimal seat capacity is based on Scenario 2, in which no crowding conditions are given. The reason is to study the possibility of accommodating all the initial passengers, avoiding the shift towards other transport modes as a results of the crowding.

The demand profile among stations for the line Stavanger – Egersund in both directions and per hour within the rush period are shown in Table 35 and Table 36.

Table 35: Passenger volume on board Scenario 2 (Stavanger -> Egersund) (retrieved from DOM_Jæren – CUBE)

PASENGER DEMAND (STAVANGER – EGERSUND) R1 (5017)									
STV – EGS	(km)	(min)	06:00-07:00	07:00-08:00	08:00-09:00	15:00-16:00	16:00-17:00	17:00-18:00	TOTAL
Stavanger - Paradis	1,330	2	48	87	45	288	224	79	771
Paradis - Mariero	2,754	3	68	123	64	434	331	114	1.133
Mariero - Jåttåvågen	3,096	3	70	127	66	452	345	118	1.177
Jåttåvågen - Gausel	1,697	3	62	114	61	574	432	143	1.386
Gausel - Sandnes	5,723	2	65	121	65	698	521	170	1.640
Sandnes - Sandnes hpl	0,580	3	50	98	54	794	610	202	1.808
Sandnes hpl - Ganddal	2,900	6	58	110	60	779	608	204	1.820
Ganddal - Øksnevadporten	4,450	3	68	125	66	760	598	203	1.820
Øksnevadporten - Klepp	2,160	3	63	116	61	699	547	184	1.671
Klepp - Bryne	4,640	4	67	121	62	627	490	166	1.534
Bryne - Nærbø	8,134	5	36	65	34	407	318	108	967
Nærbø - Varhaug	5,396	4	19	35	19	296	229	78	675
Varhaug - Vigrestad	6,020	5	16	29	15	209	162	56	488
Vigrestad - Brusand	4,980	5	16	28	14	140	108	39	346
Brusand - Ogna	3,930	3	19	33	17	105	81	30	283
Ogna - Sirevåg	2,100	2	19	33	16	89	69	25	252
Sirevåg - Hellvik	6,040	7	22	38	19	74	57	21	230
Hellvik - Egersund	7,140	7	31	53	26	59	46	18	233

Table 36: Passenger volume on board Scenario 2 (Egersund -> Stavanger) (retrieved from DOM_Jæren – CUBE)

PASENGER DEMAND (STAVANGER – EGERSUND) R2 (5016)									
EGS – STV	(km)	(min)	06:00-07:00	07:00-08:00	08:00-09:00	15:00-16:00	16:00-17:00	17:00-18:00	TOTAL
Egersund - Hellvik	7,140	5	24	43	21	63	52	22	225
Hellvik - Sirevåg	6,040	4	35	60	29	49	41	18	232
Sirevåg - Ogna	2,100	3	45	76	36	46	39	18	260
Ogna - Brusand	3,930	3	52	88	42	48	42	18	290
Brusand - Vigrestad	4,980	6	74	125	59	47	42	19	366
Vigrestad - Varhaug	6,020	4	113	190	90	56	51	26	526
Varhaug - Nærbø	5,396	5	163	274	129	70	65	35	735
Nærbø - Bryne	8,134	7	216	365	172	120	105	55	1.033
Bryne - Klepp	4,640	4	294	499	237	198	168	86	1.481
Klepp - Øksnevadporten	2,160	3	331	561	266	202	174	94	1.628
Øksnevadporten - Ganddal	4,450	3	349	592	282	216	185	101	1724
Ganddal - Sandnes hpl	2,900	3	362	614	292	202	175	97	1.741
Sandnes hpl - Sandnes	0,580	2	375	637	302	190	169	92	1.765
Sandnes - Gausel	5,723	4	331	563	266	193	171	78	1.602
Gausel - Jåttåvågen	1,697	3	274	467	221	184	160	75	1.381
Jåttåvågen- Mariero	3,096	3	208	356	170	182	154	70	1.139
Mariero - Paradis	2,754	3	199	341	163	177	149	69	1.097
Paradis - Stavanger	1,330	2	132	227	109	133	111	54	765

7.1 ECONOMIC APPROACH

Regarding an economic approach to the optimal number of seats, this is defined by the intersection between the marginal utility and the marginal cost curves. Knowing the crowding costs, it could be possible to justify capacity investments based on the benefits the crowding reduction might lead to.

The units of both marginal curves must be equal, so they express the marginal benefits or costs of an extra carriage. Since the costs of joining the carriage to the existing trains may be higher than purchasing an extra vehicle, the option of adding an extra vehicle is also observed.

Marginal cost curve

The marginal cost curve represents the cost of adding one extra carriage/vehicle. The costs associated to include extra capacity on the line consists of two main groups, fixed costs and variable costs.

The variable costs are associated to the use, i.e. the run distance. The rush period from Egersund to Stavanger is mainly concentrated between 07:00 and 08:00 and in the opposite direction between 15:00 and 16:00. Therefore the study is focused on extra capacity within these specific times and directions, illustrated in Figure 30.

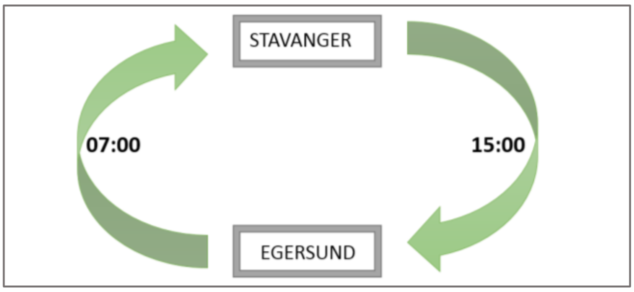

Figure 30: Times and directions for extra capacity in the line STV-EGS

Given the previous assumption, the total covered distance each day is approximately 150 km. The variable costs are electricity, maintenance of the carriage/vehicle and of the tracks. In addition, the costs for assembling the extra vehicle or carriages in the rush hours has an associated cost, this needs to be done in four occasions each day. The need for an extra conductor could be argued, however, given the above mentioned actual payments' policies in the line, this should not be required.

Contrariwise, fixed costs are independent of the use. They are the cost of the carriage/vehicle itself. The parking space in case new tracks are needed to be installed, however for simplification and given the only addition of a few extra vehicles it is assumed that the parking space is enough to hold the new carriages. The insurance could also be classified as fixed cost, although it is assumed as included in the maintenance costs.

The cost of the vehicle is 61,9 million of NOK (Metodehånbok JD 205, 2011), which is divided annually along lifetime estimated (25 years) with a discount factor of 4%. The assembly/disassembly costs are assumed to be equal to the set up costs of the train every day of used. The energy and maintenance costs are 2,78 and 15,21 NOK/km respectively (Metodehånbok JD 205, 2011). They are multiplied by the distance run each day, the days of the year and the week factor to adjust value to weekdays (0,9).

Costs fixed and variables as well as the total costs of an additional vehicle are gathered in Table 37.

Table 37: Costs associated to an extra vehicle (modified after (Metodehånbok JD 205, 2011))

COSTS (extra vehicle)	**ANNUAL**
FIXED COSTS	
Purchase vehicle	3.959.396
VARIABLE COSTS	
Assembly	516.734
Energy	136.835
Maintenance	749.473
TOTAL COSTS	**5.362.438**

The cost of an extra non-powered carriage is assumed to be 15% of the vehicle cost since the engine and most of the related pieces are not in this carriage. The same supposition is hold for the maintenance. The energy, on the other hand, is the needed for a vehicle divided by 4 (as it is the number of cars in a base vehicle). Despite that, it could be argue that weight of the powered and the non-powered cars are different so the energy needed is not share equally. The assembly/disassembly costs are assumed to be 75% of a complete vehicle, due to the differences in length for manoeuvring.

Costs fixed and variables as well as the total costs of an additional carriage are gathered in Table 38.

Table 38: Costs associated to an extra carriage (modified after (Metodehånbok JD 205, 2011))

COSTS (extra carriage)	**ANNUAL**
FIXED COSTS	
Purchase carriage	593.909
VARIABLE COSTS	
Assembly	387.551
Energy	34.209
Maintenance	112.421
TOTAL COSTS	**1.128.090**

In reality, the marginal cost curve is exponentially increasing. As the number of vehicles is increased, the costs associated to overcome the different logistic limitations are larger and larger. Some examples are: increase the number of power stations, expropriate land to build new lines or to enlarge the deflection tracks, expand stations, and improve installations to accommodate the technical needs among others.

In order to simplify the estimation of the optimal capacity and given the potential uncertainties, a linear marginal cost curve is assumed as valid. Moreover, few additional carriages or extra vehicles are likely to not face the above mentioned limitations. Therefore, the value of the marginal cost is the total cost for a unit of vehicle or carriage. This entails that each extra vehicle/carriage produces the same cost, regardless the existing vehicles already in use.

Marginal utility curve

The term utility is used in economics to refer to the aggregate sum of benefit or satisfaction an individual gains when consuming a good or service. Although utility is not directly measurable, it can be inferred from people’s decisions, which engage relative values. Usually the level of consumption can be related to the utility, that is, the more a person consumes the higher its utility becomes (Heakal, 2014).

The marginal utility, on the other hand, represents the additional satisfaction gained from each extra unit of consumption. Individuals gain more satisfaction when increasing their consumption at lower levels as for higher levels they are almost fully satisfied, and hence, they are willing to pay less for an extra unit (Heakal, 2014). Therefore, the representation of the marginal utility is an exponentially decreasing curve.

In the present study, the marginal utility curve represents the increment in utility when adding one extra carriage (78 seats) or one extra vehicle (310 seats). The utility for the train, common for all public transport in the Regional Transport Model, depends on several features. However, since the aim is to estimate this marginal utility, it is only worthy to focus on the variable of the utility affected by the number of seats. This is the travel time among stations, as it is multiplied by the crowding factors and the number of standing or seated passengers depending on the occupancy level. The general expression of the marginal utility of an extra capacity can be expressed as follows:

$$\begin{aligned}(V_{t,x+1} - V_{t,x}) = \sum_{l} [\, \{(\beta_{seat} \,.P_{seat} + \ \beta_{stand} \,.P_{stand})_x \\ - (\beta_{seat} \,.P_{seat} + \ \beta_{stand} \,.P_{stand})_{x+1}\}.TT \,]\end{aligned} \quad (3)$$

where, $V_{t,x}$ is the utility of the train with x or $x+1$ carriage/vehicle in the line (consisting of l links between stations).

TT is the travel time between stations .

β are the crowding factors.

P are the number of seated or standing passengers respectively.

The result is the marginal utility in time values per direction and hour (as the demand is given by hour). In order to be able to compare it with the marginal cost curve, the result is firstly multiplied by 365 and 0,90 to obtain the value per average annual day.

Secondly, it is multiplied by the value of time, which differs depending on the purpose of the trip. In this study, it is assumed all passengers are commuters so the value is 60 NOK/h (previously defined in Table 5).

Finally, the results for the direction and time periods where it is desired to analyse the extra capacity are added up, i.e. the marginal utility from 07:00 to 08:00 between Egersund and Stavanger and the marginal utility from 15:00 to 16:00 between Stavanger and Egersund.

The marginal utility curve for an extra vehicle is shown in Figure 31 and the marginal utility curve for an extra carriage is represented in Figure 32. The points of the marginal utility curve are represented in blue and its trend line with the equation in green.

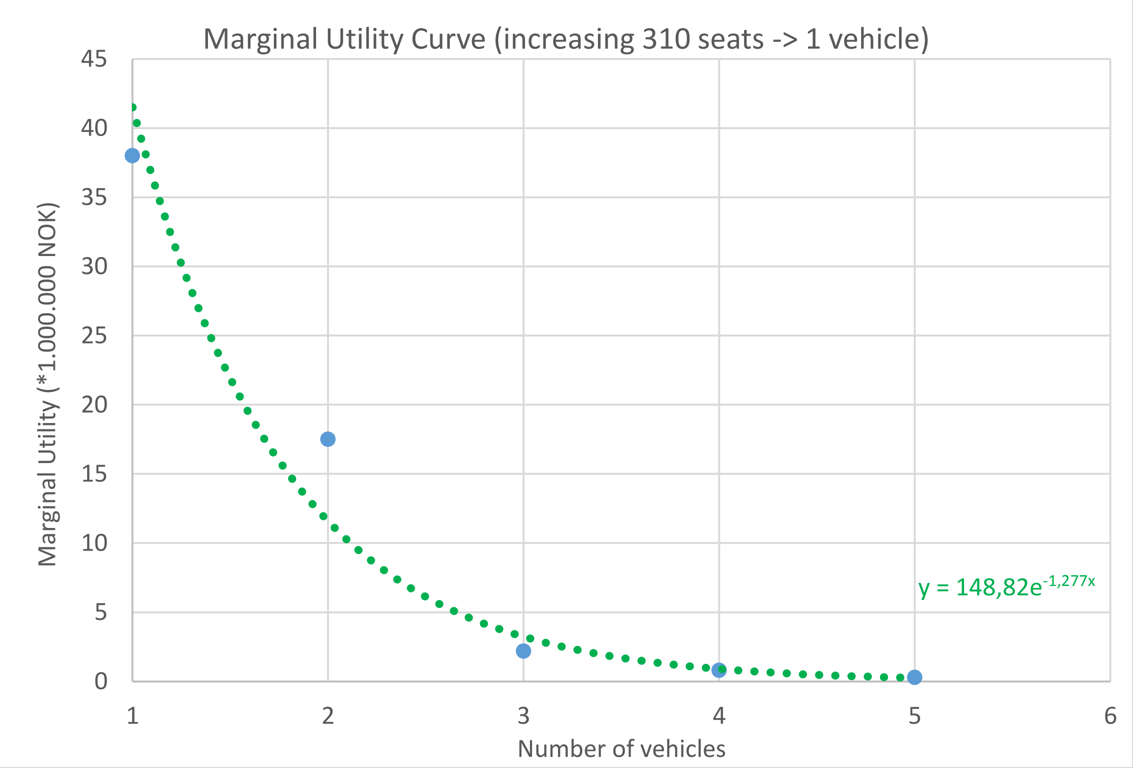

Figure 31: Marginal utility curve (increasing an extra vehicle)

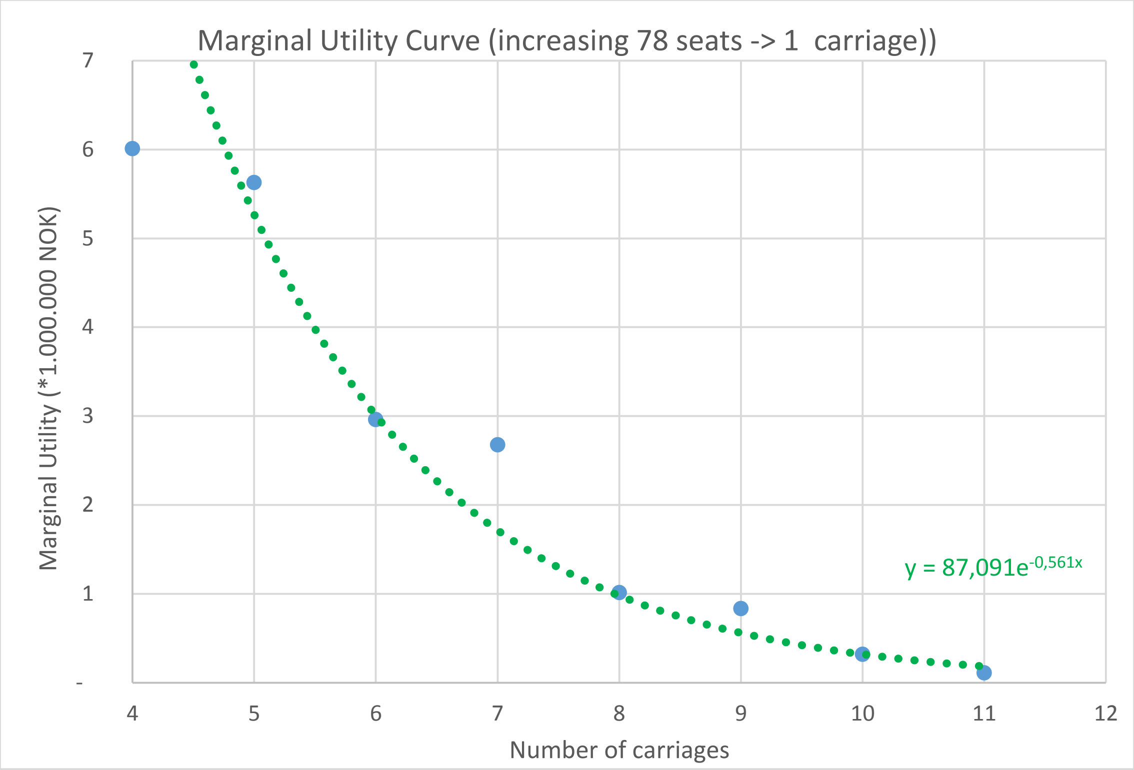

Figure 32: Marginal utility curve (increasing an extra carriage)

The marginal utility curve for an extra vehicle shows the character exponential. The benefit of adding an extra vehicle when the number of vehicles is low is considerably higher than to add the vehicle when there are already same in use.

Conversely, observing only the points of the marginal utility curve when adding an extra carriage the trend might seems a stepped linear. It can be seen that increasing from 4 to 5 and from 5 to 6 carriages the marginal benefit is similar, as well as from 6 to 7 and from 7 to 8. The reason lies on the formulation to obtain the utility, which depends on the crowding factors and the number of people standing or seated according to the occupancy level.

When the differences in occupancy levels do not vary, the marginal utility is the change of the number of seats multiplied by the differences between the crowding coefficient standing or seated. On the other hand, when the extra capacity triggers in a change of occupancy level for any of the links these differences are greater. These additional changes are due to the variations on the crowding factors for each occupancy level as shown when adding an extra carriage to 5, 7 and 9. In spite of that the exponential curve properly adjusts to the points.

In order to obtain the optimal capacity both exponential curves are used.

Optimal capacity

The optimal capacity is given by the intersection of the marginal utility and the marginal cost.

When the capacity is provided by an extra vehicle the method indicates two or three vehicles for the peak hour. In reality there are two trains per hour serving the line. According to this study, the discussion entails for the acquisition of an extra vehicle to be assembled in one of the trains within the hour.

Regarding the optimal number of carriages, the intersection between the marginal cost and marginal utility is found between seven or eight carriages. In the actual conditions the optimal capacity is covered. However, the costs of an extra carriage are more uncertain and hence this result is not conclusive.

Additional carriages could be studied to remain assembled. Due to the high costs associated to the assembly/disassembly this could be interesting.

These findings are partially bias as they are based on some data and assumption not compared to observed data or not simulated with total accuracy.

Regarding the modelled demand, some uncertainties previously described are still present in spite of having validated and calibrated the model. The base scenario for the study of the economic approach is Scenario 2, where crowding conditions are not included.

The marginal utility curve is estimated assuming that all passengers travel in the same train. This is unlikely given that there is two trains per hour in the actual situation. Therefore, the crowding coefficients present a source of bias. In addition, these coefficients have not been tested or obtained from Norwegian users.

The number of people standing or seated are also input for the marginal utility. These values are based on assumptions, so more uncertainty is added into the appraisal.

The marginal costs for a vehicle are quite precise since they are widely used in the train lines. However, the costs associated to an extra carriage are not certainly known. Moreover, there might be some more factors that generate costs, not included in this project.

Regarding the value of time it is assumed that all passengers have the same value, which is the value for commute trips. Most of the trips in the rush period belong to this type. These are 85% in the morning peak whilst, their share is reduce in the afternoon to 75% (Aarhaug, et al., 2013).

There are more leisure and private trips in the afternoon. These trips are more flexible and their value of time is inferior. Hence, benefits of extra capacity could be lower.

7.2 LOAD PROFILE APPROACH

A different approach to the seat capacity determination is to base the decision on the demand profile. Before proceeding to explain the method, the concept of capacity (c) and desired occupancy (d_0) should be defined for the Jæren line.

The previous analysis regarding the crowding sensitivity indicates that occupancies larger than 120% can modify passengers' travel patterns due to the uncomforting that travelling in crowded vehicles entails. In spite of that, the desired occupancy is assumed to be the number of seats, which generate 100% occupancy. The reason is that some passengers start feeling the crowding at this level.

For the actual train characteristics, the desired occupancy is 310 and the capacity of the vehicle is set to 520 passengers. This imply the maximum of 5,25 people per square meter and an occupancy rate larger than 165%. The relation between occupancy and capacity is, then, 0,6, value close to the relations used in bus services by (Ceder, 2007).

There are methods for determining the optimal number of seats based on the demand profile. The methods all relate the demand and frequency to the capacity or desired occupancy of the vehicle. Methods 1 and 2 are based on max loads and methods 3 and 4 on the passengers per trip length.

Procedure

First of all, the load profile density per hour (j) is examined by the density test (ρ_j). This coefficient supports the decision of the type of methods to use. The equation is shown below (4).

(4)
$$\rho_j = \frac{A_j}{P_{mj} * L}$$
(Ceder, 2007)

where: A_j is the number of pax. between stations in one hour multiplied by each link length.

P_{mj} is the maximum number of passengers in a link along the line in that hour.

L is the total length of the line.

Values larger than 0,5 indicate a relatively flat profile, meaning that demand variations among stations for each time period are not so different one from another. The recommended methods if this occurs are methods 1 or 2 (Ceder, 2007).

The values of the density tests for each direction and hour are shown in Table 39.

Table 39: Density test values

Hour	06:00-07:00	07:00-08:00	08:00-09:00	15:00-16:00	16:00-17:00	17:00-18:00
STV-EGS	0,572	0,572	0,573	0,462	0,464	0,472
EGS-STV	0,474	0,474	0,474	0,545	0,552	0,503

According to the results, the correct procedure is to estimate the optimal number of seats with methods 1 and 2 in the morning peak from Stavanger to Egersund and in the afternoon peak from Egersund to Stavanger. Methods 3 and 4 should be used for the rest of the hours, although it can be mention that the values do not differ greatly from 0,5 so the methodology could be further discussed.

Secondly, the chi-square statistical test aids in the choice of the method within the ones based on the maximum load methods. Method 1 is based on the most populated stop along the day, whilst method 2 is based on the most populated stop for each time period. The formulation is shown below (5).

(5)

$$\chi^2 = \sum_{j=1}^{q} \left[\frac{(P_{i*j} - P_{mj})^2}{P_{mj}} \right]$$

(Ceder, 2007)

where: P_{i*j} is the number of pax. in the period j in the most populated stop along the day.

P_{mj} is the maximum number of passengers in time period j between all the stops.

According to the chi-square distribution, for 17 degrees of freedom (number of links – 1) and 95% of confidence, the value is: X^2=27,59. If this value is lower than the resulting from equation (5) method 2 should be used, meaning that there are considerable variations of the data for each method (Ceder, 2007).

For the analysis of the line in both directions when the method recommended is based on the maximum load, method 1 is correct according to the chi-square test.

Thirdly, the decision of the method regarding the load profile (methods 3 and 4) is based on the accepted excess of passengers overload. In this project, both 30 and 40% of overload are studied. The overload is estimated as the percentage of the length that have an excess of passengers with respect to the total length. In order to know if a link suffers overload, the number of passengers in that link and hour is compared to the average passenger per kilometer.

(6) $$\frac{\sum_m l_{length}\,(overload)}{L}\ (\%) \quad \rightarrow \mathrm{P_{mj}} \sim \frac{\mathrm{A_j}}{\mathrm{L}} \begin{cases} > & overload \\ < & no\ overload \end{cases}$$ (Kaplan, 2013)

where: $\mathrm{P_{mj}}$ is the maximum number of passengers in time period j between all the stops.

$\mathrm{A_j}$ is the number of pax. between stations in one hour multiplied by each link length.

L is the total length of the line.

The overload values for the line in both directions are shown in Table 40.

Table 40: Overload values

Hour	06:00-07:00	07:00-08:00	08:00-09:00	15:00-16:00	16:00-17:00	17:00-18:00
STV-EGS	41%	41%	41%	49%	49%	49%
EGS-STV	49%	49%	49%	51%	51%	51%

Regarding these values there is an excess of overload in the line for both directions and periods. Based on the previous analyses, the recommended methods are shown in Table 41.

Table 41: Methods per direction and hour

Hour	06:00-07:00	07:00-08:00	08:00-09:00	15:00-16:00	16:00-17:00	17:00-18:00
STV-EGS	method 1	method 1	method 1	method 4	method 4	method 4
EGS-STV	method 4	method 4	method 4	method 1	method 1	method 1

Method 1 – maximum load

Method 1 relates the frequency and the daily max load point to the desired occupancy. The equation is shown below (7).

(7) $$\mathrm{F_{j1}} = \max\left[\frac{\mathrm{P_{mdj}}}{\mathrm{d_{0j}}}, \mathrm{F_{mj}}\right] \rightarrow \mathrm{d_{0j}} = \frac{\mathrm{P_{mdj}}}{\mathrm{F_{j1}}}$$ (Ceder, 2007)

where: $\mathrm{F_{j1}}$ is the frequency of the service (method 1).

$\mathrm{P_{mdj}}$ is the number of passengers for a period j in the most daily demanded stop.

d_{0j} is the desired occupancy of the vehicle.

F_{mj} is the minimum number of vehicles.

The hypothesis scenario considers that all passengers are boarding at the same train, and hence the frequency is 1. Consequently, the desired occupancy or the number of seats equals the number of passengers for each hour between the stations with more passengers along the day.

The number of seats recommended by the method 1 for each direction and hour can be seen in Table 42.

Table 42: Desired occupancy or number of seats using method 1

Hour	06:00-07:00	07:00-08:00	08:00-09:00	15:00-16:00	16:00-17:00	17:00-18:00
STV-EGS	68	125	66	-	-	-
EGS-STV	-	-	-	190	169	92

Method 4 – load profile

Method 4 consists of 2 independent equations, the desired occupancy is the maximum value of those. The first equation relates the occupancy to the frequency, length and the desired passenger per kilometre. The second, to the frequency, number of passengers and relation between occupancy and capacity on board.

(8) $$F_{j4} = \max\left[\frac{A''_j}{d_{0j} * L}, \frac{P_{mj}}{c}, F_{mj}\right] \rightarrow d_{0j} = \max\left[\frac{A''_j}{F_{j4} * L}, \frac{P_{mj} * \gamma}{F_{j4}}\right]$$ (Ceder, 2007)

where: F_{j4} is the frequency of the service (method 4).

A''_j is the new average passenger kilometer.

d_{0j} is the desired occupancy of the vehicle. L is the route's length.

P_{mj} is the maximum number of passengers in the period j.

c is the vehicle's capacity.

F_{mj} is the minimum number of vehicles.

γ is the relation between the capacity and the desired occupancy.

The new average passenger per kilometer (A''_j) is set manually in order to reduce the excess of overload until 30% or 40%. The technique is based on the load profile. Hereunder, it is explained for one case, from Egersund to Stavanger between 07:00 and 08:00, whose load profile is represented in Figure 33.

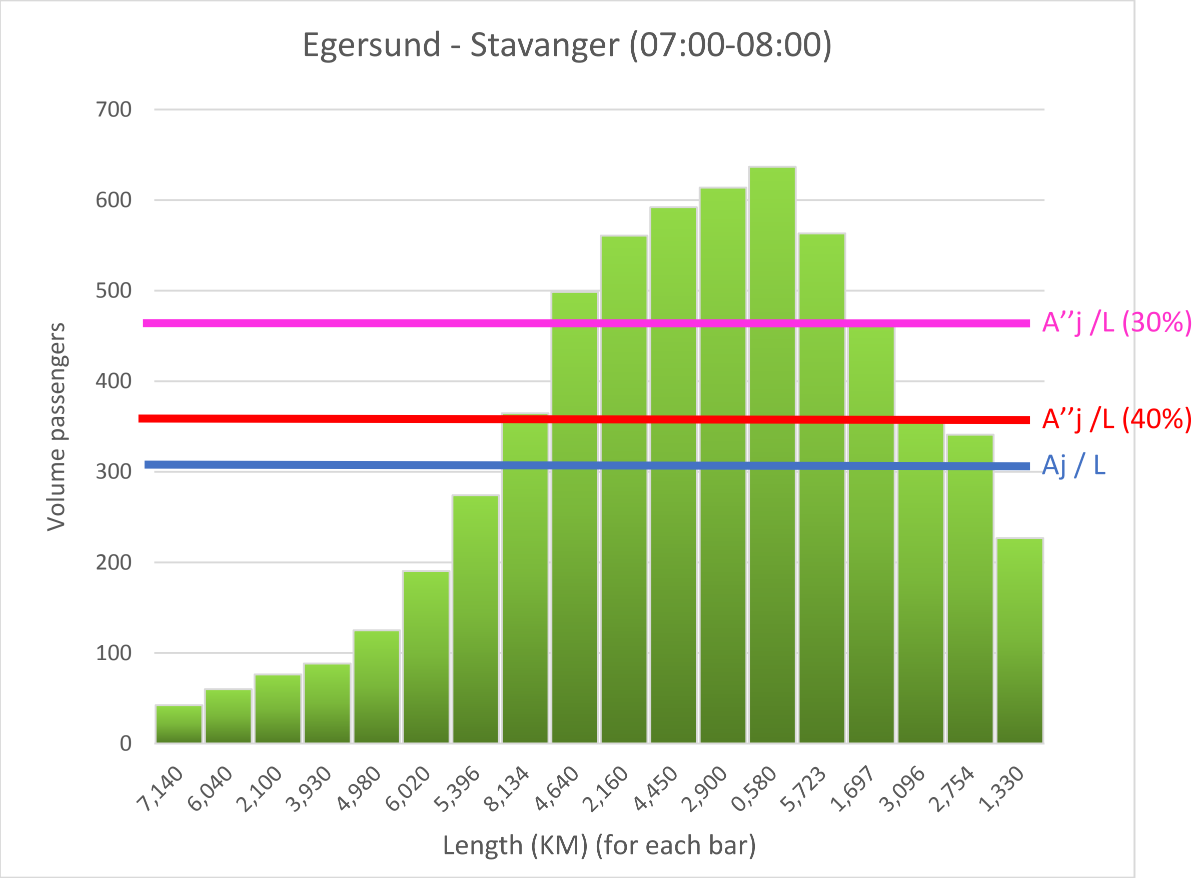

Figure 33: Load profile Egersund - Stavanger (07:00 - 08:00)

The bars in the figure represent the number of passengers between each pair of stations, whose length is defined below them. The average passenger volume is represented by the blue line (A_j/L), the passengers over that line are overcrowded (49%). The new average passenger per kilometer corresponds to the line over which there is an overload (equation (6)) of 40% (red line) or 30% (pink line). These lines matches with the volume of passengers of one of the links, so this and the ones below do not present overload any more.

The load profile from Stavanger to Egersund in the afternoon peak, between 15:00 and 16:00 is also represented in Figure 34.

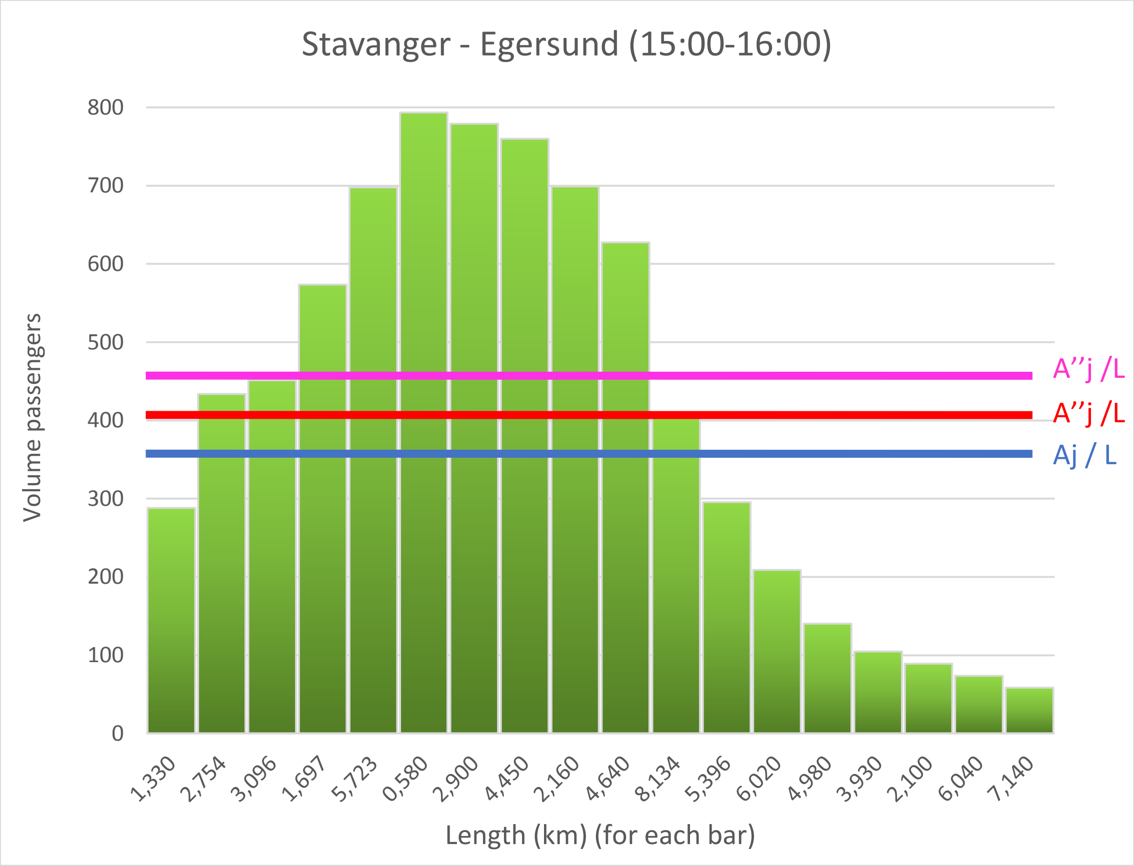

Figure 34: Load profile Stavanger - Egersund (15:00 - 16:00)

The number of seats recommended by the method 4 for each direction and hour can be seen in Table 43 for an overload of 40% and in Table 44 for an overload of 30%.

Table 43: Desired occupancy or number of seats using method 4 (40% overload)

Hour	06:00-07:00	07:00-08:00	08:00-09:00	15:00-16:00	16:00-17:00	17:00-18:00
STV-EGS	-	-	-	476	366	122
EGS-STV	225	382	181	-	-	-

Table 44: Desired occupancy or number of seats using method 4 (30% overload)

Hour	06:00-07:00	07:00-08:00	08:00-09:00	15:00-16:00	16:00-17:00	17:00-18:00
STV-EGS	-	-	-	476	366	122
EGS-STV	274	467	221	-	-	-

Optimal seat capacity

The optimal number of seats defined by the method 1 do not represent any matter since they are covered by the actual characteristics of the train.

On the other hand, the connection from Egersund to Stavanger between 07:00 and 08:00 and from Stavanger to Egersund between 15:00 and 17:00 (2 hours) require extra seats to satisfy the demand needs, assuming all passengers are boarding at the same train.

In spite of that, if the demand is distributed within the actual characteristics of two trains per hour the capacity satisfies the demand between 16:00 and 17:00. The occupancies remain lower than 100%.

In case the extra capacity is only considered, as in the economic approach, from 07:00 to 08:00 towards Stavanger and from 15:00 to 16:00 out of the city (Figure 30), the number of optimal seats requires two vehicles. The excess of overload for this configuration of 620 seats, is estimated by equation (6). It results in 1% in the morning and 16% in the afternoon.

Regarding the number of extra carriages for the peaks, the optimal number should be 3 in the afternoon from Stavanger to Egersund, generating 20% of overload. In the opposite direction in the morning peak, two extra carriage cover the demand with an excess of overload of 28%. In spite of that and given that there are already three carriages available, it is better to use all of them and keep them assembled. This leads to an excess of overload of 10% in the morning from Egersund to Stavanger.

The methods used in this section from (Ceder, 2007) are mainly used by bus services. The policies for bus services allow more standing passengers, indeed the vehicles' design is meant for these users. On the contrary, trains are mainly design to accommodate seat passengers as the travel times as longer. In fact, the maximum travel time standing on Norwegian trains is set to 15 minutes by the regulations (Jernbaneverket, 2014), hence desired occupancies with 30% of excess of overload might not satisfy this condition.

The service from Stavanger to Egersund between 15:00 and 16:00 supplied by two trains generate 16% of excess of overload, but 21 minutes of standing passengers and occupancies higher than 120% between Sandnes and Øksnevadporten stations. Therefore, a further discussion for extra capacity should be conducted.

8. DISCUSSION

This project studies the modelled passengers' demand of the local train line between Stavanger and Egersund by the transport model DOM_ Jæren (part-area-model of the RTM). Additionally, crowding conditions are included into the model and the passenger reactions are analysed. Finally, a study is conducted to estimate the optimal capacity of the line.

DOM-Jæren

The demand model considers as unique all public transport modes for trips shorter than 100 km. This means that bus and train are considered to hold the same characteristics in the trip distribution and mode choice steps. Splitting the public transport modes might cause more complexity in the calculations not compensated by the accuracy improvement. Nevertheless, a dummy variable in the public transport utility representing the rail factor could be of interest.

The modelled demand is based on demographic data and travel patterns from a local survey in 2005. Rogaland area is in constant development, hence the use of values from 9 years ago might imply differences to the observed demand. In this report, some demographic data are updated based on recent observed statistics. The results show a better demand representation. Thus, some users' behaviour have changed due to new residential and business areas, developed close to the stations.

A remarkable difference between modelled and observed demand is generated in Sandnes area. Most of the modelled passengers are using the old Sandnes station instead of Sandnes sentrum station. Zones located between both stations are joined by new connectors to Sandnes sentrum station. The simulation is improved as residents from these areas can faster connect to the new station. Despite that, there are many train passengers going towards Stavanger using Sandnes station. These users have their residences geographically closer to Sandnes station. Hence, the model could wrongly locate these residential areas or the travel patterns are misunderstood.

The model does not allow changes on departure times within the four modelled periods. The modelled demand in the rush periods (morning and afternoon) is divided by hours according to the mode and purpose shares from the 2005 survey. In this study, a slight change in the departure times of commute trips by public transport is done, which results in a better representation of the demand. The new developed areas might generate new origin-destination trips and different departure times. Therefore, the need for an update of travel patterns is again justified.

Paradis and Øksnevadporten stations are not connected to the network. The updated network generates new modelled passengers, improving the representation. In spite of that, the model does not represent parking spaces at the station areas, as a result, combined trips between car and train are not included in the model. Train trips generated outside the influenced walking area of train stations are not represented. This leads to an underestimation of train trips and overestimation of other modes.

Even after the previous updates of the model, the modelled demand is considerably underestimated with respect to the observed. The public transport utility in the demand model is modified in order to obtain passenger demands closer to reality. The alternative specific constant is increased, involving a higher share in the public transport trips by the diminution of trips by the other modes. This calibration implies a better representation of the train trips in terms of amounts, not in travel patterns. Despite that, the changes in the other transport modes against observed counts should have been checked.

The model accounts for capacity constraints on the road, which means that the travel times on a road depend on the amount of cars on it. Users' demand is estimated based on the real travel times, which involves that congested roads can lead to a diminution of road users. Based on the obtained results, road users under capacity constraints shift to bus service. The reason might be due to the bus services cover a wider area than the train service.

The capacity constraints are introduced in the demand model. If, on the other hand, they are introduced in the network assignments instead, there will be the same amount of road users but they will probably change the route.

Crowding-model

The Jæren service between Stavanger – Egersund is actually experiencing high occupancies rates, which will grow according to the demand prognosis of Rogaland area. Thus, crowding problems will increase, although it is not likely to have capacity limitations on the trains or stations in the upcoming years. Therefore, this project focuses only on implementing crowding on board in the rush period.

Crowding factors are included as on board travel time multipliers between each pair of stations. Hence, the subjectivity of the crowding perception depending on the duration of the trip is eliminated.

All trip purposes are affected by crowding in the same way. This is not likely as commute and business trips are more sensitive to travel time. As a few extra travel minutes might cause a delay in the job. Despite that, these trips might present less sensitivity towards crowding. As their time is very rigid. Unlike these, leisure trips are more flexible, so users can decide not to spend their spare time in a crowded vehicle by changing destination or departure time for example.

A different approach to account for the purpose differences could be to modify the travel time for each purpose in the public transport utility. Nevertheless, this procedure might generate longer running times and more complexity in the algorithms. Additionally, since most of the trips in the rush time are commute trips this procedure might not generate significant improvements.

Passengers are independent individuals whose feelings vary into a great scale one from each other. The crowding perception on board should be the one experienced by an average passenger, as it is very complex to model the characteristics of all users. There are no studies regarding crowding in Norway. The only validated fact is that the time value differs whether passengers are seated or standing. Despite that, the crowding factors used in this report are based on other European studies. In order to simulate better the users' behaviour, it would be recommended to conduct a survey to obtain national values for crowding.

In addition, the design of trains and stations could affect the perception of the crowding. The latter could be included on the waiting time coefficient, which might be different with respect to the station and the crowding level.

Service lines are sometimes supplied by different train types, as the Jæren line service, whose local trains differs from the regional. Therefore, it could be interesting to make a relation among different train types. This can be done by using different surveys, although it is important to only relate coefficients within each country or in similar regions as Scandinavia for example.

Crowding features are included in the demand model so users can decide whether or not to change transport mode. In contrast, if these conditions are introduced in the network assignment, the only possible shift will be towards others public transport services as the total number of public transport remain constant.

The implementation of crowding for the Stavanger – Egersund line in the model is manually done. The crowding factors are estimated based on the demand between stations from a simulation. These factors are used to weigh the travel times of the train service for the rush period. The following simulation use the new travel times as inputs. In so doing, an iterative process is built, in this project 4 iterations are done, representing 3% differences in the demands of the last two iterations. Given the methodology followed and that the demand model is a stochastic process, this approximation is assumed as valid. Nonetheless, if the process is automatically modelled, it will be recommended to reduce the difference to 0,1% as for the road capacity constraints.

Crowding factors depend on the occupancy, which is estimated based on the hypothesis that all passengers board to a unique train. In reality users are more evenly distributed, however, this approximation helps to model future demands.

A unique crowding factor per link for the whole rush period is considered. Its estimation is based on the average crowding factor among the hours in the period with respect to the number of passengers for each hour. This assumption might not be completely corrected since the links with crowding in the morning peak might not have high occupancies in the afternoon and vice versa.

Estimating the values with respect to the number of passengers results in factors closer to the peak hours, so the worst simulated passengers are those travelling at hours with lower occupancies. A solution might be to use two different public transport networks for the rush period, one in the morning and the other in the afternoon.

Passenger reactions towards crowding

The crowding is only included in the Stavanger – Egersund train service as it is the public transport mode that, actually presents crowding. The other modes, even with the migration of passengers, do not experience high occupancies, so this assumption seems correct.

The train passengers' reaction towards the crowding conditions on board in the rush periods differ from morning to afternoon. In the morning the schedule might be tighter since there are less shifts towards other transport modes. Passengers prefer to suffer crowding rather than change mode. This might be due to the fact that train is still the most attractive mean of transport, even with the crowding conditions.

Nonetheless, there is a loss of users from Bryne and Øksnevadporten. Passengers need to take the bus to get to the station and have a combined public transport trip. However, they prefer to take the car when there are crowding conditions in the train. There is also an increase of the trips ending at Sandnes station, these users connect by bus service to Forus Park. In the non-crowding conditions these passengers connected though Gausel station.

In the afternoon, additional trip changes are from Paradis and Jåttåvågen towards Sandnes by bus. Moreover, an increment on bus trips from/to Gandal to/from Sandnes. The local train Stavanger – Sandnes as well as the regional have an increased in demand. Passengers are more flexible in departure times so they prefer to wait to the less crowded train.

Trips stating or ending far from Bryne do not present remarkable transport mode changes. Thus, despite crowding conditions growth train passengers are not likely to shift to other transport mode for these trips types.

According to the analyses, the increase in crowding generates a reduction of passenger on board. This decrease is larger when the initial occupancies are higher.

Suggestions to increase train trips are to synchronise the arrival train time to the departure bus time at Sandnes station towards Forus Park. As well as other commute buses to the stations of Bryne and Øksnevadporten. Further investments in infrastructure might be to extend the double track until Bryne to increase the frequency, reducing the crowding on board.

The peak demand is concentrated in very specific hours. Thus, an infrastructure investment might not be justified, a detailed studied should be conducted at this respect. Nonetheless, adjustments in the seat capacity in the rush periods could be an interesting investigation thereupon discussed.

Optimal capacity

The optimal train capacity for the Jæren line might be achieved by adding extra carriages or vehicles. The rush period consists of six hours, although the demand is not evenly distributed. For this reason the extra capacity is studied from Egersund to Stavanger between 07:00 and 08:00 and from Stavanger to Egersund between 15:00 and 16:00.

The study is conducted by two different methods, economic and based on the load profile. The latter has less potential bias as it is mainly based on the modelled demand. The former additionally uses estimations of the travel time, crowding factors, distribution on the train regarding the seated and standing passengers and the costs of additional vehicles or carriages.

On the other hand, the economic method might seem more appropriate since more factors are involved in the investment decision criteria of extra capacity. The costs and benefits to the passengers take part, which indirectly occurs in a satisfaction of the capacity demand.

The results obtained by both methods are similar, which might reinforce the findings. There is a potential need for extra capacity from Egersund to Stavanger between 07:00 and 08:00 and in the opposite direcction between 15:00 and 16:00. The extra capacity could be covered by adding a carriage or vehicle to one of the trains running within those periods.

Since the demand is continously growing, the necesity of extra capacity might rise in near future. In addition, improving crowding conditions could promote the use of train services.

9. CONCLUSION

Regarding the actual model, some limitations found are recommended to further analyse. Those are the potential bias in the demographic data and travel patterns. Updating the demographic input to recent data and conducting a new revealed preference travel survey might improve the simulation.

In addition, the network should be revised. The option of including parking spaces at the stations could lead to a better representation of combined trips by car and public transport. Moreover, the option of computing two different public transport networks in rush periods, morning and afternoon, should be observed.

The implementation of crowding conditions on board of the public transports in the demand model should be further studied. An improved procedure entails time and economic resources however, crowding is a starting problem for some of the train lines in Norway. The possibility to automate the processs can be useful for near future.

Nonetheless, further research on crowding factors in Norway is recommended to understand the different perceptions depending on the purposes, trip time, even socioeconomic, or train design characteristics. This requires to conduct user surveys, stated preferences or revealed preferences together with counts on the vehicles.

The analysis of the optimal seat capacity suggests the need for extra capacity in the peak hours, that could be covered with an additional carriage or vehicle. Nonetheless, the decision of enlarge the capacity on the Jæren line should be backed up by more detail studies.

The benefits of a better demand understanding might lead to an improvement of the vehicle size and to the policies towards greener transports, assisting to satisfy the goals of the National Transport Plan.

10. APPENDIX

Table 45: Trip purposes RVU 2001 used in Tramod_by (Source: (Tørset, Malmin, Bang, & Bertelsen, 2013))

Travel purpose	Trip type
Work	- Work (to/from work)
Work related	- Work related (trips within work hours)
Spare time	- Cinema, theater, concert, exhibition, etc. - Café, restaurant, etc. - Football game, sporting event, etc. - Organized leisure activities, music, sports, training, etc. - Leisure boat trips - Trips to the mountains - Other holiday / weekend trips - Other purpose - Visit (family, friends, home visits)
Private	- Grocery shopping - Other shopping - Services, errands (bank, post office, agencies, etc.) - Medical care (doctor, dentist, etc.)
Drop on/off	- Pick up/bring/accompany children to/from the nanny, nursery, school, park - Pick up/bring/accompany children to/from sports, leisure activities - Pick up/bring/accompany children to/from other activities

Table 46: Variables in the logit model regarding the public transport by purpose (Tramod_by) (Source: (Rekdal, Larsen, Løkketangen, & Hamre, 2013))

Variable	Coef.	Work	Leisure	Private	Drop
Constant	PT_00	x	x	x	x
Dummy, 1 if distance between 10-20 km	PT_0510			x	
Dummy, 1 if distance between 20-80 km	PT_1040		x		
Spend time	PT_AC	x	x	x	x
Dummy, 1 if poor car access	PT_DBTF		x		
Dummy, 1 if workplace density > 10.000	PT_DENS		x	x	
Dummy, 1 if full car access	PT_FBTF			x	
Dummy, 1 if female	PT_FEM		x		
Waiting time (square root)	PT_rTWT		x	x	x
Dummy, 1 if multiple errants along the way	PT_SEKD		x	x	
Onboard travel time	PT_TM		x	x	x
Weekend travel time	PT_TMWKE		x		
Number of transfers	PT_XF	x	x	x	x
Waiting time	PT_WAIT	x			
Dummy, 1 if traveling at weekends	PT_WE	x			
Onboard travel time, women	PTF_TM	x			
Onboard travel time, men	PT_TM	x			

Figure 35: Price zones of Jæren region (Source: (Kolumbus, 2014))

Table 47: Input crowding factors (β) and travel times (TT) for the Scenarios 2, 4, 5, 6, C (Stavanger -> Egersund)

	Scenario 2		Scenario 4		Scenario 5		Scenario 6		Scenario C	
STV – EGS	β	TT	β	TT	β	TT	β	TT	β	TT
Stavanger - Paradis	1,00	2,00	1,08	2,15	1,04	2,08	1,04	2,08	1,04	2,08
Paradis - Mariero	1,00	5,00	1,30	6,04	1,07	5,30	1,19	5,65	1,08	5,31
Mariero - Jåttåvågen	1,00	8,00	1,51	10,56	1,08	8,53	1,19	9,24	1,19	8,88
Jåttåvågen - Gausel	1,00	11,00	1,70	15,65	1,22	12,18	1,32	13,18	1,22	12,54
Gausel - Sandnes	1,00	13,00	2,00	19,66	1,32	14,82	1,57	16,33	1,56	15,65
Sandnes - Sandnes hpl	1,00	16,00	2,06	25,85	1,75	20,07	1,94	22,15	1,75	20,90
Sandnes hpl - Ganddal	1,00	22,00	2,05	38,12	1,73	30,47	1,92	33,66	1,73	31,30
Ganddal - Øksnevadporten	1,00	25,00	2,02	44,19	1,71	35,61	1,90	39,36	1,89	36,98
Øksnevadporten - Klepp	1,00	28,00	2,01	50,21	1,71	40,73	1,88	45,02	1,71	42,10
Klepp - Bryne	1,00	32,00	1,88	57,72	1,55	46,91	1,69	51,76	1,55	48,32
Bryne - Nærbø	1,00	37,00	1,33	104,35	1,22	52,99	1,22	57,87	1,22	54,41
Nærbø - Varhaug	1,00	41,00	1,09	108,71	1,08	57,33	1,09	102,21	1,09	58,75
Varhaug - Vigrestad	1,00	46,00	1,05	113,93	1,04	102,54	1,04	107,43	1,04	63,96
Vigrestad - Brusand	1,00	51,00	1,00	118,93	1,00	107,54	1,00	112,43	1,00	108,96
Brusand - Ogna	1,00	54,00	1,00	121,93	1,00	110,54	1,00	115,43	1,00	111,96
Ogna - Sirevåg	1,00	56,00	1,00	123,93	1,00	112,54	1,00	117,43	1,00	113,96
Sirevåg - Hellvik	1,00	103,00	1,00	130,93	1,00	119,54	1,00	124,43	1,00	120,96
Hellvik - Egersund	1,00	110,00	1,00	137,93	1,00	126,54	1,00	131,43	1,00	127,96

Table 48: Input crowding factors (β) and travel times (TT) for the Scenarios 2, 4, 5, 6, C (Egersund -> Stavanger)

	Scenario 2		Scenario 4		Scenario 5		Scenario 6		Scenario C	
EGS-STV	β	TT	β	TT	β	TT	β	TT	β	TT
Egersund - Hellvik	1,00	5,00	1,00	5,00	1,00	5,00	1,00	5,00	1,00	5,00
Hellvik - Sirevåg	1,00	9,00	1,00	9,00	1,00	9,00	1,00	9,00	1,00	9,00
Sirevåg - Ogna	1,00	12,00	1,00	12,00	1,00	12,00	1,00	12,00	1,00	12,00
Ogna - Brusand	1,00	15,00	1,00	15,00	1,00	15,00	1,00	15,00	1,00	15,00
Brusand - Vigrestad	1,00	21,00	1,00	21,00	1,00	21,00	1,00	21,00	1,00	21,00
Vigrestad - Varhaug	1,00	25,00	1,04	25,15	1,00	25,00	1,00	25,00	1,00	25,00
Varhaug - Nærbø	1,00	30,00	1,04	30,36	1,04	30,20	1,04	30,21	1,04	30,20
Nærbø - Bryne	1,00	37,00	1,18	38,60	1,04	37,48	1,17	38,38	1,04	37,49
Bryne - Klepp	1,00	41,00	1,40	44,20	1,16	42,13	1,19	43,12	1,18	42,21
Klepp - Øksnevadporten	1,00	44,00	1,58	48,94	1,19	45,69	1,38	47,27	1,37	46,31
Øksnevadporten - Ganddal	1,00	47,00	1,58	53,69	1,19	49,25	1,40	51,46	1,37	50,42
Ganddal - Sandnes hpl	1,00	50,00	1,60	58,49	1,19	52,84	1,40	55,66	1,38	54,57
Sandnes hpl - Sandnes	1,00	52,00	1,61	101,71	1,39	55,62	1,52	58,70	1,40	57,37
Sandnes - Gausel	1,00	56,00	1,59	108,08	1,19	100,37	1,39	104,24	1,19	102,14
Gausel - Jåttåvågen	1,00	59,00	1,38	112,22	1,16	103,84	1,18	107,80	1,16	105,63
Jåttåvågen-Mariero	1,00	102,00	1,15	115,68	1,03	106,94	1,04	110,90	1,03	108,73
Mariero - Paradis	1,00	105,00	1,15	119,14	1,03	110,04	1,04	114,01	1,03	111,84
Paradis - Stavanger	1,00	107,00	1,03	121,20	1,00	112,04	1,03	116,07	1,00	113,84

Table 49: Input crowding factors (β) and travel times (TT) for the Scenarios 2, 7, 8, 9, 10 (Stavanger -> Egersund)

	Scenario 2		Scenario 7		Scenario 8		Scenario 9		Scenario 10	
STV – EGS	β	TT	β	TT	β	TT	β	TT	β	TT
Stavanger - Paradis	1,00	2,00	1,15	2,30	1,30	2,60	1,45	2,90	1,60	3,20
Paradis - Mariero	1,00	5,00	1,15	5,75	1,30	6,50	1,45	7,25	1,60	8,00
Mariero - Jåttåvågen	1,00	8,00	1,15	9,20	1,30	10,40	1,45	11,60	1,60	12,80
Jåttåvågen - Gausel	1,00	11,00	1,15	12,65	1,30	14,30	1,45	15,95	1,60	17,60
Gausel - Sandnes	1,00	13,00	1,15	14,95	1,30	16,90	1,45	18,85	1,60	20,80
Sandnes - Sandnes hpl	1,00	16,00	1,15	18,40	1,30	20,80	1,45	23,20	1,60	25,60
Sandnes hpl - Ganddal	1,00	22,00	1,15	25,30	1,30	28,60	1,45	31,90	1,60	35,20
Ganddal - Øksnevadporten	1,00	25,00	1,15	28,75	1,30	32,50	1,45	36,25	1,60	40,00
Øksnevadporten - Klepp	1,00	28,00	1,15	32,20	1,30	36,40	1,45	40,60	1,60	44,80
Klepp - Bryne	1,00	32,00	1,15	36,80	1,30	41,60	1,45	46,40	1,60	51,20
Bryne - Nærbø	1,00	37,00	1,15	42,55	1,30	48,10	1,45	53,65	1,60	59,20
Nærbø - Varhaug	1,00	41,00	1,15	47,15	1,30	53,30	1,45	59,45	1,60	105,60
Varhaug - Vigrestad	1,00	46,00	1,15	52,90	1,30	59,80	1,45	106,70	1,60	113,60
Vigrestad - Brusand	1,00	51,00	1,15	58,65	1,30	106,30	1,45	113,95	1,60	121,60
Brusand - Ogna	1,00	54,00	1,15	102,10	1,30	110,20	1,45	118,30	1,60	126,40
Ogna - Sirevåg	1,00	56,00	1,15	104,40	1,30	112,80	1,45	121,20	1,60	129,60
Sirevåg - Hellvik	1,00	103,00	1,15	112,45	1,30	121,90	1,45	131,35	1,60	140,80
Hellvik - Egersund	1,00	110,00	1,15	120,50	1,30	131,00	1,45	141,50	1,60	152,00

Table 50: Input crowding factors (β) and travel times (TT) for the Scenarios 2, 7, 8, 9, 10 (Egersund -> Stavanger)

	Scenario 2		Scenario 7		Scenario 8		Scenario 9		Scenario 10	
EGS-STV	β	TT	β	TT	β	TT	β	TT	β	TT
Egersund - Hellvik	1,00	5,00	1,15	5,75	1,30	6,50	1,45	7,25	1,60	8,00
Hellvik - Sirevåg	1,00	9,00	1,15	10,35	1,30	11,70	1,45	13,05	1,60	14,40
Sirevåg - Ogna	1,00	12,00	1,15	13,80	1,30	15,60	1,45	17,40	1,60	19,20
Ogna - Brusand	1,00	15,00	1,15	17,25	1,30	19,50	1,45	21,75	1,60	24,00
Brusand - Vigrestad	1,00	21,00	1,15	24,15	1,30	27,30	1,45	30,45	1,60	33,60
Vigrestad - Varhaug	1,00	25,00	1,15	28,75	1,30	32,50	1,45	36,25	1,60	40,00
Varhaug - Nærbø	1,00	30,00	1,15	34,50	1,30	39,00	1,45	43,50	1,60	48,00
Nærbø - Bryne	1,00	37,00	1,15	42,55	1,30	48,10	1,45	53,65	1,60	59,20
Bryne - Klepp	1,00	41,00	1,15	47,15	1,30	53,30	1,45	59,45	1,60	105,60
Klepp - Øksnevadporten	1,00	44,00	1,15	50,60	1,30	57,20	1,45	103,80	1,60	110,40
Øksnevadporten - Ganddal	1,00	47,00	1,15	54,05	1,30	101,10	1,45	108,15	1,60	115,20
Ganddal - Sandnes hpl	1,00	50,00	1,15	57,50	1,30	105,00	1,45	112,50	1,60	120,00
Sandnes hpl - Sandnes	1,00	52,00	1,15	59,80	1,30	107,60	1,45	115,40	1,60	123,20
Sandnes - Gausel	1,00	56,00	1,15	104,40	1,30	112,80	1,45	121,20	1,60	129,60
Gausel - Jåttåvågen	1,00	59,00	1,15	107,85	1,30	116,70	1,45	125,55	1,60	134,40
Jåttåvågen-Mariero	1,00	102,00	1,15	111,30	1,30	120,60	1,45	129,90	1,60	139,20
Mariero - Paradis	1,00	105,00	1,15	115,15	1,30	124,50	1,45	134,25	1,60	144,00
Paradis - Stavanger	1,00	107,00	1,15	117,05	1,30	127,10	1,45	137,15	1,60	147,20

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