UNIVERSITY OF BERGEN

The logistics of a city's human resources

A simulation model of Bergen's transportation system for strategic management of peak hour congestion

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Abstract

Traffic congestion is a problem of increasing magnitude in Bergen that inflicts costs on the commuters and social costs on the whole city of Bergen. Estimations of the peak hour traffic indicates that traffic on many roads have surpassed the roads' capacities during the time period 2000 to 2010. The objective of the thesis was to investigate how much of the increase is caused by commuters' choice of transportation mode and changes in the supply of transportation services, by developing a transportation model using a System Dynamics approach. The main insight from the model is that the increase in traffic is due to increased car ownership and total number of commuter's effect on the road traffic. Various policies were tested in the model. The tests showed that the park-and-ride policy is not very effective with the exception of Bergen South. This is because the-park-and-ride policy is only effective when combined with an already attractive public transportation service. Another finding is that the reduction in car users' commuting time caused by expanding the tram network to Bergen North and West goes a long way in covering the initial investment costs.

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1 Introduction

Traffic congestion is a problem in most large cities and occurs when the traffic volume exceeds the capacity of the city's road network. In Bergen[1] traffic congestion is a problem of increasing magnitude, which is acknowledged by city planners, politicians and citizens of the municipality alike (seeHellesnes & Andersland, 2011; Hordaland Fylkeskommune, 2012; Jean-Hansen, Hanssen, & Aas, 2009; *Regional planstrategi 2012-2016*, 2012). Traffic congestion inflict serious costs on the society such as noise, air pollutants, time delays and extra fuel consumptions (Anas & Lindsey, 2011). There are also less obvious costs of road transportation such as blocking for pedestrians, lack of parking and so on (Anas & Lindsey, 2011). This master thesis investigates the peak hour congestion in Bergen using a system dynamics (SD) modeling approach to develop a model that simulate the long term changes in peak hour traffic. The model's purpose is to uncover the reasons for the increase in traffic congestion and evaluate the long term effects of different transportation policies, resulting in a comparison of the likely outcome of the different policies based on the model.

1.1 Clients and Motivation

The transportation system is managed by the local government and its ruling politicians. Good decisions making tools should therefore be of the outmost importance for these groups. The overall goal of this project is to develop a tool that can be useful in management of the long term development I peak hour traffic on the Bergen road network and as an advisory tool in city planning.

This master thesis is part of project consisting of a series of master theses focusing on local issues in Bergen (called "the Bergen project"), initiated by Professor David Wheat in corporation with Councilmen Julie Andersland and Endre Tvinnereim of Bergen city council, and political secretary Tallak L. Rundholt, who are the clients for this project. Hopefully the project can provide some insights or findings of interest in the city planning. The client has in return provided guidance and insight into current policies so that the master thesis is more likely to be useful and relevant for planning and management effort. A wider definition of the projects clients would include all citizens of Bergen since traffic congestion is a

[1] Bergen is the second largest city in Norway. A coastal city surrounded by mountains, resulting in lack of ring roads in the road network. Making traffic management especially complicated.

problem for all citizens of Bergen that inflicts both individual and social economical costs for the whole city.

1.2 Research Question

This thesis is going to look into the causes to the increased traffic congestion and how it can be handled. The overall goal is to analyze policies that reduce the peak hour traffic. Given these goals two research questions can be formulated:

1. How much of the increase in the peak hour traffic from 2000-2010 is caused by commuters' choice of transportation mode and changes in the supply of transportation services?

2. What can be done with the transportation system to reduce future growth in (peak hour) traffic?

Commuting is defined as people travel between two zones with the purpose of going from home to work (or work to home). When people commute they must choose whether they want to use car, tram, bus, bicycle or another mode of transportation. This choice is referred to as transportation mode choice. The quality of these different transportation modes is determined by the frequency of bus departures, quality of the road network and other characteristics with the transportation modes that affects their attractiveness. The main purpose of the model is therefore to explain commuters' choice of transportation mode and how this affects the quality of the transportation services.

1.3 Some Model Specifications

The purpose of the model discussed so far is to explain the increasing traffic congestion and evaluate policies aimed to decrease the congestion, but an additional purpose is that the model should be compatible with models of land use and urban migration developed in two other master theses. The two other master thesis in the project deals with SD models of urban migration and land-use in Li (2013) and Schulze (2013). These three models can be coupled together as shown in Figure 1. The diagram was used to define the boundaries between the model and how they should connect into the larger model called *BergenSim*. The input to the transportation model is the commuters between different zones in the model. The transportation model provides travel time as input to the urban migration and land use model. It follows from this that commuters should be treated as an exogenous variable to make it easy to tie the models together. This makes it possible to join the models together to study the interaction between urban migration, land use and transportation. Land use and migration typically have a long time perspective spanning many years, if not decades. A 20-year time for the model perspective was therefore agreed upon since this would probably be sufficient to capture most of the important feedback processes in land use and urban migration in the long run. It follows that the transportation model also should have a 20-years perspective to be compatible with the land use and urban migration model.

An important aspect to city planning is the spatial dimension. Increased traffic in one area will affect traffic in another area. To capture this spatial dimension Bergen is divided into zones. The model developed in the thesis is therefore a spatial disaggregated model. It consists of the municipalities Bergen and Askøy. The municipality of Bergen are further divided into five zones, giving the model a total of six zones: "City Center", "North Bergen & Hordaland", "West Bergen & Hordaland", "Askøy" and "South Bergen & Hordaland". Following this scheme the system dynamics model developed becomes a spatial model. The main advantage of doing this is to simulate spatial interactions and system structures that are heterogenous over time(Todd k. BenDor & Kaza, 2012). Most of the city planning dsicussion do have some spatial characteristic to it. To include the spatial dimension is therefore important.

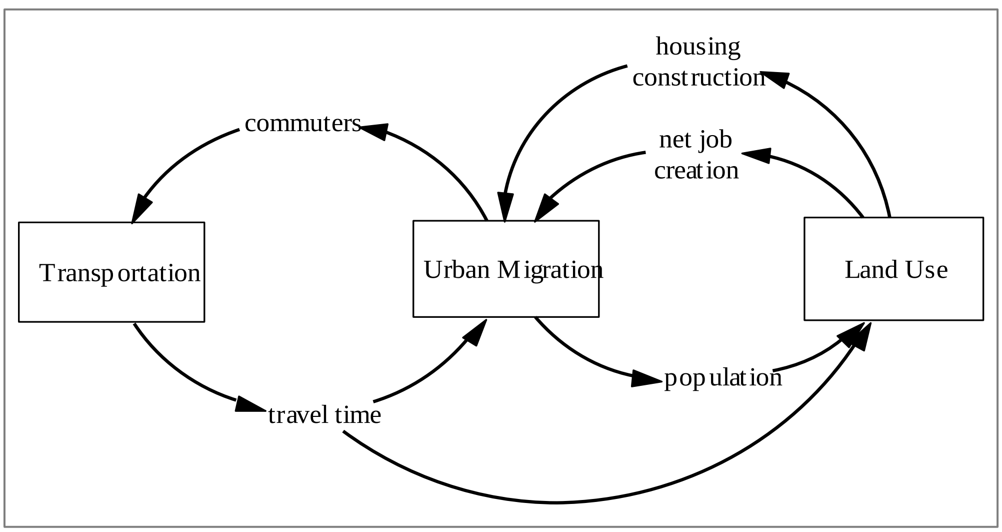


Figure 1 Interfacing the urban migration, land-use and transportation models.

In this section the following model specifications have been given: 1) the model is disaggregated into six zones, 2) 20-year time perspective is adopted, and 3) commuters should be treated as an exogenous variable. These specifications make it possible to join the models together to create BergenSim.

2 Literature Review

This review has three parts. First part is a review of some research related to transportation research in social science. Second part is a review of some of the modeling practices and transportation research within the field of transportation system engineering. The third and last part is a review of policy papers about transportation in Bergen. Transportation engineering has a long tradition of modeling transportation systems and is therefore a very relevant field of research to review. There are however some aspects regarding peoples travelling behavior regarding habits not covered by the research in transportation engineering, but which is explored in the psychology literature. Lastly it is necessary to take local policy papers into account if the model developed in this thesis is going to have any relevance for Bergen.

2.1 Transportation research in social sciences

Some of the aspect usually discussed in transport engineering literature is habitual change. When a person changes from one mode of transportation to another it involves breaching habits. Habits is automatically behavior that requires little consciousness decisions (Bamberg, Ajzen, & Schmidt, 2010). However behavioral experiments on people's choice of transportation mode indicates that persons change their habits if the environment changes, which is due to conscious decisions regulating the persons habits (Bamberg et al., 2010). Experiments shows that it takes time before a change in a transportations attractiveness is perceived by a person (Gärling & Axhausen, 2003). Experiments also shows that it takes time before the behavior eventually changes (Gärling & Axhausen, 2003). It also seems reasonable that time is needed for deliberation. In any case it means that the commuters' transportation mode choice has some inertia. In addition there other delays involved such as search time for alternatives, time needed to learn new routines and delays involved when changing transportation mode (Gärling & Axhausen, 2003).

2.2 Transportation system engineering models and research

This review mainly focus on two books: "Transportation System Analysis" by Ennio Cascetta and "Handbook of Transportation Engineering" by Myer Kutz used throughout the thesis. In addition it will also look at the system dynamical model called Metropolitan Activity Relocation Simulator ("MARS") developed by Pfaffenbichler.

Many of the models in transportation engineering tries to capture peoples travelling behavior and how it is affected by the transportation systems infrastructure (Cascetta, 2009). These models are often refered to as travel-demands models (Cascetta, 2009, p. 169). Models dealing with the infrastructure, travelling time and the network structure are often referred to as supply models (Cascetta, 2009; Kutz, 2004 l. 1361). This thesis is going to follow the same convention.

Transportation Mode choice models are models that explains which mode of transportation people uses (Cascetta, 2009). The purpose of this models is to answer questions like "how many people will use car instead of bus when traveling from A to B?" The choice model explains this by different characteristics with the transportation modes that determines there attractiveness. They can also explain different choice among different groups of people by including various socioeconomic variables or make different models for different groups of people if such characteristics of the commuters affect their preferences. For example people with high income may put less weight on monetary cost and more weight on time cost than people with low income. Using the bus and risk missing an important business meetings may be much more costly for a businessman than using a car and pay a huge p-house fee, but with the benefit of always be on time. For a low income worker on the other hand the cost of p-house fee will far outweigh the benefits of arriving on time. If this is the case then it may be necessary with two different random utility models for each of these two socioeconomic groups.

In more complex road network there may be more than one road segments leading to a given destination as illustrated by Figure 2. Drivers must therefore choose which sequences of road segments to use (Cascetta, 2009, p. 197). A sequence of road segment is called a path and a path choice model are used to model how many people that choose a given path in the road network (Cascetta, 2009).

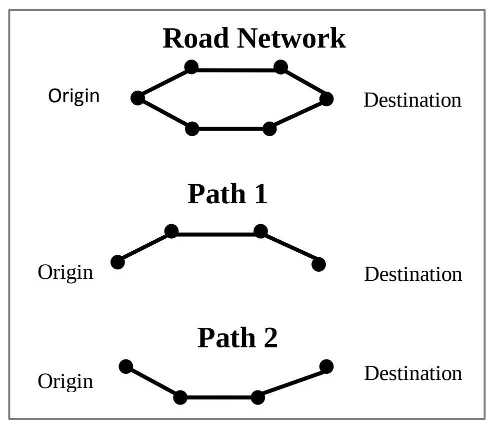


Figure 2 Paths through a simple network

There are potentially many paths to choose between in a large road network, but one can argue that one only should consider the feasible paths (Cascetta, 2009, p. 197), because it is unrealistic that all possible paths are considered by the user. There are two approaches to determine which paths are feasible. An *exhaustive approach* consider all possible paths from origin to destination (Cascetta, 2009, pp. 286-292).

Another approach is selective approach where feasible paths are chosen based on some criteria (Cascetta, 2009). There are some experimental support that generating the first n paths based on some criterion such as for example minimum time yields good results for interurban networks (Cascetta, 2009). Many of the demand assignment models usually try to find a network equilibrium where the flows don't change because there are no initiatives for the users to change their path choice (Cascetta, 2009; Kutz, 2004). To find this equilibrium link performance functions are used to calculate the cost of the different path. When the user has nothing to gain from changing from one path to another then the system is in equilibrium[2].

The most common way to model transportation mode choices is to use random utility models. In these models the commuters' choice of transportation modes are treated probabilistic (Cascetta, 2009). The probability that commuters' choose one transportation mode over another depends on the travel time and other variables determining the usefulness of a transportation mode relative to all the usefulness of all other transportation modes. If travel time for car decreases then car becomes more attractive and more people will choose to use car, but if travel time for all other transportation modes decreases to then the proportion choosing car remains unchanged. These models also acknowledge that there are unknown variables that influence commuters' choice of transportation mode; therefore even if car is better than bus in every way to our knowledge some people will still opt for bus. In practice this means that how easy the commuters' choice of transportation mode can be influenced by manipulating travel time or other known variables depends on how important the unknown variables are in the commuters' choice of transportation mode. For a more detailed description of the random utility model used in this thesis see appendix 12.1.

Transportation supply models aims to simulate the performance of the transportation network (Cascetta, 2009, p. 29). One central question when modeling traffic is how a flow into a road segment affects the average speed on the road segment and how does this flow propagate to other road segments in the road network (Cascetta, 2009; Kutz, 2004). A starting point in answering this question for the Bergen is to make graph of Bergen's transportation network and then translate the graph of the network into a mathematical model (Cascetta, 2009; Kutz, 2004). When the network is modeled, demand models are used to assign traffic flows to links in the network model, based on the costs of the

[2] The equilibrium condition is that the calculated flow vector equals the last calculated flow vector in a loop where flows are assigned based on path costs and then calculate new costs and assign new flows until the equilibrium condition is reached (Cascetta, 2009, p. 260).

different paths. One of the most important costs are travel time (Cascetta, 2009; Kutz, 2004; Pfaffenbichler, 2003).

There are basically two kinds of traffic assignment models that assigns traffic flow to the road links: assignment to uncongested network and to congested network (Cascetta, 2009). Uncongested assignment models is based on the assumptions that costs are independent on the flows and congested assignment models where costs are dependent on the flows. In the case of the uncongested assignment models the problem is reduced to find the shortest (given same free flow speed[3] on all road segments) paths through the road network for each origin and destination pairs (Cascetta, 2009). Under the assumption that the network are congested one must take into account the flow of traffic that enters the different road segments (Cascetta, 2009, p. 282). The travel time now becomes a function of not only free flow speed of the links, but also the flow of traffic that enters road segment. It is easily demonstrated that queues on the road is a result of variation in the cars' speed (Wilensky, 1997). As this queues becomes bigger and bigger the headway between the cars decreases and consequently the cars must decrease their speed to avoid colliding with the car in front of them (Cascetta, 2009). However on an aggregated level or long term perspective (years rather than seconds) one can treat this relation in a much simpler manner; the higher the car flow is into a road segment the lower is the average speed for the cars travelling on that road segment (Kutz, 2004). As long as the flow are below the capacity of the road the increase have little effect on the average travel time, but as it reach the capacity or goes beyond the capacity the average travel time explodes. See appendix 12.2. for more details on the function used for capturing the travel time in a long term perspective.

In many systems dynamics models the supply model is endogenous. Instead of just looking at how the travel time increases as the traffic volume increases they and how this effects commuters' choice of transportation mode they also includes road improvement as an endogenous response to increased traffic (Bossel, 2007; J. D. Sterman, 2000) . In these models the road capacity is therefore not fixed or exogenous determined, but will change with the traffic volume. More traffic is after all one of important reasons to build more roads and these models acknowledge this fact.

[3] The average speed when there is no traffic on a road segment.

2.3 A review of some local policy papers

The paper Statens vegvesen (2011a) is currently the most notable policy paper for the transportation issues and urban planning in Bergen. It is often referred to as the concept choice study or "KVU" for the transport system in the Bergen Region. The paper deals with from topics ranging from demography influences on the traffic in the Region to environmental consequences of traffic. The purpose of the policy paper is to evaluate six policies (and on "business as usual" scenario) referred to as "concepts" in the paper. These policies varied from congestion pricing, expanding the road network, removing tool booths and doing nothing. These policies was tested using two models referred to as RTM and UA (Statens vegvesen, 2011a). I have however not been successful in obtaining detailed documentation of these models. The conclusion of the policy paper is that building out both the road network and the tram is the best option (Statens vegvesen, 2011a). Among the other studies there have been a study of the park-and-ride policy (Bergensprogrammet, 2008) and the wider planning issues (*Regional planstrategi 2012-2016*, 2012). An interesting conclusion from the study of the park-and-ride policy is that park and ride only is efficient combined with other policies that improves the public transportation or reduces the usefulness of car in some way.

3 Dynamical Problem

3.1 Increasing peak hour traffic

Why is increasing traffic volume a problem? More traffic means more pollution in form of noise, emission of gases and particles. It also means longer commuting time if the number of cars grows beyond the road capacity, because this increases the probability for traffic breakdown (Wang, Rudy, Li, & Ni, 2010). The explanation why travel time increases on a microscopic level is that the headway between the cars is reduced when more cars enter the road (Cascetta, 2009). As a result the drivers must reduce the speed for safety reasons (to have sufficient margins to break without colliding with the car in front). At an macroscopic level this translate to the simple statement that increased number of cars causes the average travel time to increase everything else kept equal.

Figure 3 shows the rush hour traffic for an important road[4] leading from Askøy into the main roads towards Bergen. It is a rough estimations of the peak hour traffic based on traffic data for the road (Statens vegvesen, 2011b) and by assuming that half of all travels are commuting and half of this occurs in the morning rush[5] which is supported by data about traveling behavior in Bergen (Christiansen, Engebretsen, & Strand, 2010, p. 20). It is also assumed that these fractions have been constant over the last 10 years.

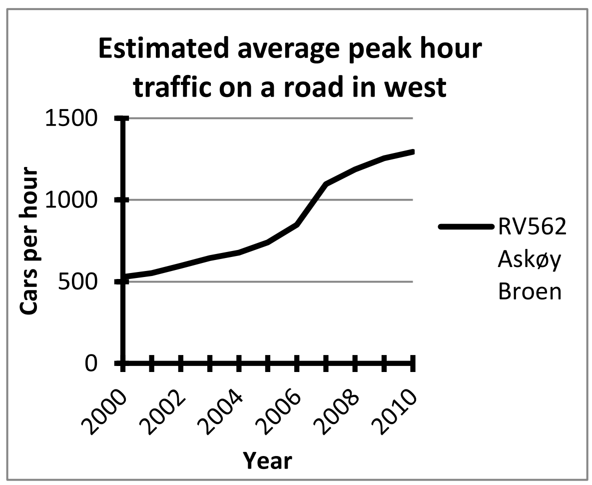


Figure 3 Peak hour traffic on a road in west

It is reasonable to assume that the capacity on the road cannot have changed much over the time period since no new bridges have been built to Askøy and it is unlikely that the improvements on the bridge can amount to a drastic increase in capacity. A road's capacity is the maximum traffic that can pass through a

[4] The roads are arbitrary chosen, however the graphs shows a behavior typical for many other similar roads in the outskirts of Bergen..

[5] In other words it is assumed that 25% of the traffic occurs in the morning and 35 % of this occurs in the peak hour.

road passage before severe problems with congestion occurs (Statens vegvesen, 1990, p. 11). Typically the numbers used for ideal[6] lane capacity is around 1200 cars per hour per lane (Brilon, 1994; Shunping, Hongqin, & Shuang, 2011; Statens vegvesen, 1990, p. 10). Traffic congestion occurs more frequently when the (car) traffic is above or close to the capacity of the road and the traffic. Askøy Bridge have one lane and therefore a capacity of 1200 cars per hour. The traffic on Askøy Bridge has since 2000 increased from being below the road/bridge's capacity to above the capacity. Hence the congestion on the bridge should have steadily increased since year 2000 and rapidly the last years since 2008 as the car traffic have increases above the capacity.

As shown in Figure 3 the traffic has increased significantly. In the case of the Askøy bridge (RV562) the traffic has gone from being below the capacity to grow to a level that slightly above the road capacity (1200 cars per hour) during the years 2000 to 2010. This supports the notion of an increasing traffic congestion problem. It also shows that some of the pressure on the transportation network of Bergen is caused by traffic coming from outside the municipality of Bergen.

Figure 4 shows the traffic on two other roads from year 2000 to 2010. N. Nygårdsbro is a bridge south for Bergen centrum and Sandviken is a road in the North, based on the same data (see Statens vegvesen, 2011b) and assumption as Figure 3. Both roads are important roads leading into Bergen centrum. At both roads the traffic has been increasing. At Sandviken the traffic is above the capacity of the road (assuming a capacity of 1200 car per hour) in 2000 and increased since then, which indicates that traffic congestion is an issue of increasing magnitude. While the bridge N. Nygårdsbro, where the traffic flow is measured, has three lanes in each direction (total of six lanes), but the subsequent road only has two lanes in each direction. If all the traffic measured on the bridge flows into the two lane road then congestion will be a frequent problem.

[6] See Statens vegvesen (1990) for specification of the condition for ideal road capacity.

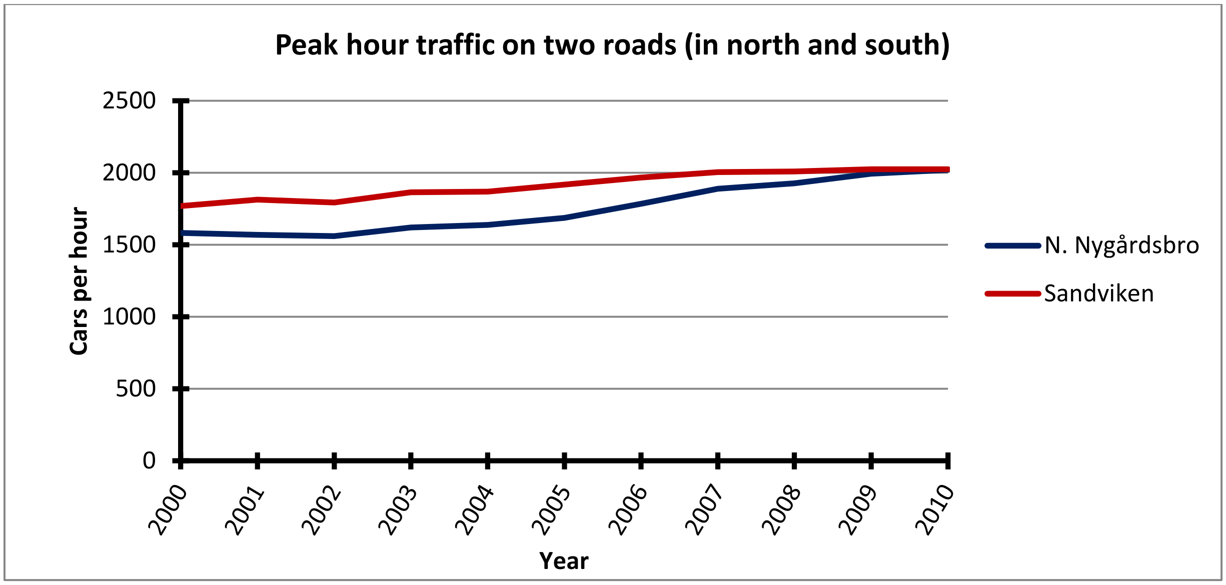


Figure 4 Peak hour traffic road on two roads (in north and south)

Figure 3 and Figure 4 is the reference mode for the model. Reference mode is a graph that characterizes the problematic behavior of the system that the model should be able to replicate, the time horizon of the model and makes it clear what behavior the clients are unsatisfied with (Ford, 2010, p. 150). However traffic congestion is a complex problem therefore more than one graph is used to explain the problem. These other graph functions as supplementary reference modes. Their purpose is to capture other relevant aspects of the problem that are often mentioned in discussion among planners, politicians and concerned citizens.

3.2 Decreasing usage of Public Transport

Figure 5 shows estimates how many people use car, boat or bus for commuting from their residence in Askøy to their workplace in Bergen. This is a rough estimate based on the number of people commuting from Askøy to Bergen (Fylkeskommune, 2012) and how many cars (yearly daily traffic) that passes the bridge connecting Askøy to the mainland (Statens vegvesen, 2011b). It is assumed based on aggregated data for travelling behavior in Bergen from TØI that 50 % of the trips are commuting trips (Christiansen et al., 2010). It is also assumed 50 % of the commuting trips are from home to work, and the other half is from work to home. The number of commuters using car is therefore roughly estimated by multiplying the yearly daily traffic over the bridge with 0.25. Data for number of boat users are obtained in a similar fashion using data for the yearly number of trips taken (Statens vegvesen, 2011b). Commuters using bus is then given by the number of commuters minus the commuters using boat and commuters using car.

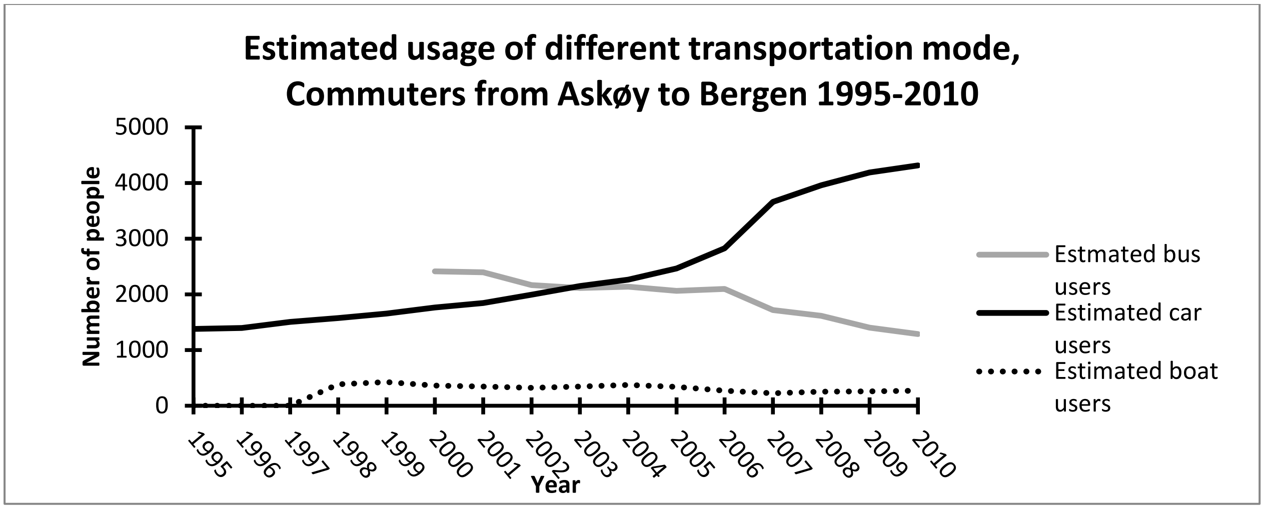


Figure 5 Car, bus and boat users Askøy to Bergen

Figure 5 shows that the car users are increasing from 1995 to 2007 and then starting to stabilize around ~4500 people. Car usage passes the usage of bus in year 2004. Over the same time period the number of bus users has decreased. While not obvious from the graph, the usage of boat has also decreased. This means that commuters in Askøy are more and more dependent on the usage of car, and the pressure on the road network is increasing. Coupled with rapid population growth this may be problematic, leading to more pollution and traffic congestion.

Similar development can be seen for Bergen as whole (Statens vegvesen, 2011b), but with somewhat more optimistic prospects the last years. The number of yearly bus passengers decreased from 37.6 to 31.9 million over the period 1991 to 2000, but increased to 34.9 million during 2000 to 2007 (Statens vegvesen, 2011b). Since 2003 until 2010 the increase in usage of public transportation (PT) have been bigger than the increase in car traffic, but both the increase in public transportation and road traffic seems to have stabilized somewhat the latest years (Statens vegvesen, 2011b).

4 Dynamical Hypothesis

In Bergen commuters can choose between to use their car or bicycle, take the tram, boat or bus, or simply walk to and from work. It is assumed that a collection of these six modes of transportation are the only options available and that the commuters must choose one of them.

4.1 The big picture

As discussed in the introduction the main concern is to reduce the traffic congestion. Studies shows that the probability for traffic congestion to occur on a road increases as the traffic density increases (Wang et al., 2010). How fast depends on the capacity of the road. At average, travel time tends to be almost unaffected by increase in traffic until the traffic surpass a certain level where it steeply increases (Cascetta, 2009; I. A. Lubashevsky, N. G. Gusein-zade, & Garnisov, 2009; Kutz, 2004; Wilensky, 1997). This level is often referred to as the practical capacity of the road (Kutz, 2004). Traffic congestion can therefore be understood as a result of either too many cars or too little road capacity. In other words it is necessary to explain changes in number of cars on the road and/or changes in road capacity when explaining changes in traffic congestion.

Road capacity increases(decreases) if the number of lanes increases(decreases), if the width of the road increases, if the road is made more flat(more varied in altitude) and so on (Statens vegvesen, 1990). For simplicity all of this can be pooled into a general variable denoted “road quality”, which is measured in kilometers of road. The concept is simple. If the average lane has a capacity of 1200 cars per hour, a road has a length of 5 km and an average capacity of 2200 car per hour then the road quality of this road is 10 km. Why 10 km? This is because the “effective number of lanes” can calculated as road quality divided by the road length, effective *number of lanes = road quality / road length = 10/5 = 2*. The road has a capacity equal to two effective lanes, meaning that it either has 2 lanes with the ideal capacity of 1200 cars per hour, more than two lanes with capacity less than 1200 cars per hour for each lane, or one lane with road improvements which gives it a capacity of two lanes. While somewhat abstract it is very useful to use the concept of road quality when dealing with multiple roads in a long term perspective, instead of dealing with road width, number of lanes and so on as separated variables.

So how does road quality change on a road? Road quality changes through road construction and road deterioration. Whether new lanes/road improvements are constructed depends on the perceived need for adding new lanes or improves the existing roads. Traffic is monitored by the government and the public road authority either by counting in toll both, manually or by sensors (Statens vegvesen, 2011b). Road construction occurs when the government and related agency deems the current road capacity as insufficient for the traffic volume (J. D. Sterman, 2000). It seems reasonable that they measure the peak hour traffic and uses this to calculate how many new effective lanes that are needed. Over time this new lanes are build and the road quality is then improved, but with a delay due to organizational processes, internal policies about how fast the road network is to be expanded and a delay related to the construction of the new lanes or installments of road improvements. There is also a continuous maintaining of the road going on to fix deteriorated parts of the road. Deterioration of the road quality is assumed to be a continuous exponential decay towards zero over a time period of 20-30 years in the absence of road construction and maintenance.

The number of cars on the road increases if the number of car users increases. The number of cars entering the roads increases also if more people become car users. A person is a car user if he has access to a car (either as driver or passengers) and chooses to use car instead of the other transportation modes. The number of people with access to car sharing increases if the car ownership (number of cars per person) increases, however increased car occupancy only means that more people use car as passenger and therefore this will not increase the number of cars on the roads, but only decrease the number of people using the other transportation modes.

Some people with access to car may choose not to use it. Whether a commuter with access to a car choose to use it depends on how attractive car is compared to alternative modes of transportation. Attractiveness of a transportation mode is determined by the expected travel time, the risk involved and monetary costs associated with each transportation mode. Expected travel time is the average travel time the commuter expect when using a given transportation mode, the risk is the variation in travel time experienced (standard deviation in travel time) and monetary costs are all kind of fees, fares, tolls and other financial expenses, associated with a given transport mode. This means that the monetary costs and expected travel time to car and bus may be equal, but because there is more variation in travel time when using bus (sometimes the commuter arrive early, sometimes late) people will at average prefer car. This is because car is perceived as a more stable mode of transportation. If all transportation mode is identical (meaning no difference in expected travel time, risk or monetary costs) then the proportion of people using this different transport modes will be equal. There is however one exception and that is intrinsic properties of the different transportation modes. For example car may be more comfy than tram and tram more pleasant than bus; therefore the proportion may not be completely equal even though there is no difference in travel time, risk or monetary costs.

Monetary costs are assumed to change over time as result gas price, government increasing tolls or the bus company increases ticket prices. These changes are treated as exogenous to the system, however the gasoline expenditure depends on the speed and the total gas expenditure is therefore endogenous. Risk and expected travel time on the other hand increases if the number of cars on the roads increases or if the road decreases. Hence a full circle is made. More cars on the road means longer expected travel time which makes car less attractive, consequently fewer people choose to use car and the cars on the road becomes less than what it otherwise would have been. Figure 6 is a conceptual diagram that summarizes this chapter so far.

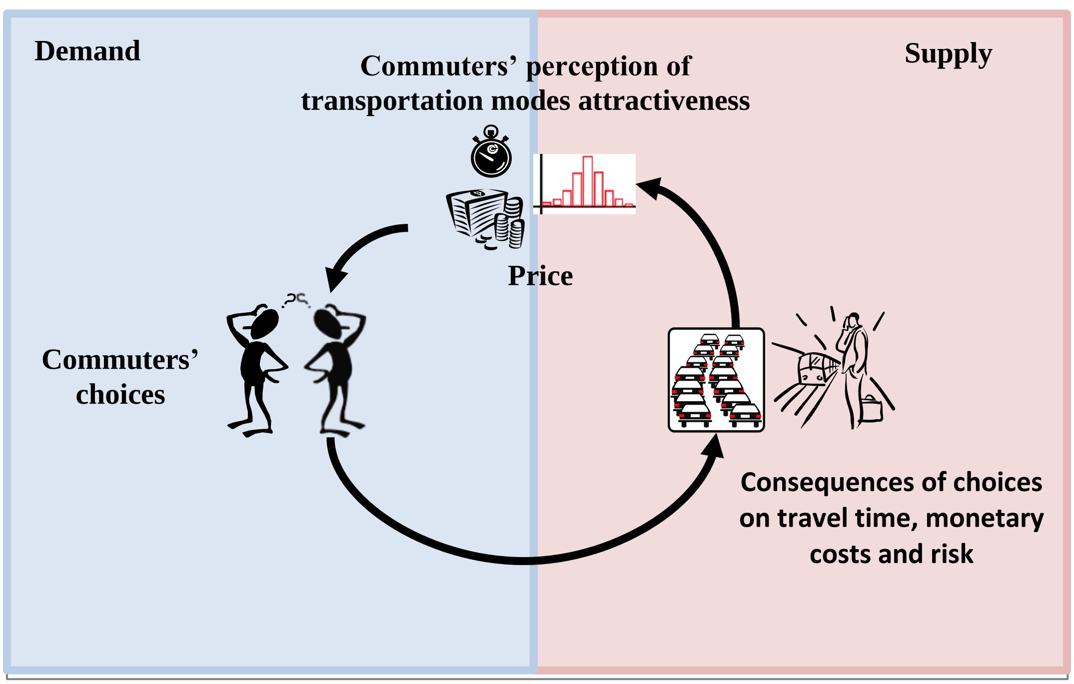


Figure 6 Conceptual diagram of interplay between supply and demand in the transportation system

A way to think about the transport system is as a market. The commuters are the consumers and the government and transportation firms the suppliers. Supplied quanta would be in terms of road capacity, public transport capacity, routes, frequency and so on. Total demanded quantum for transportation services equals the total number of commuters. Commuters can choose between different transportation products such as car, bus, bicycle and so on. Which transportation product they choose depends on the price/cost of each product and the consumer preferences. Some consumers may be more concerned about monetary cost than expected travel time and therefore choose a slow, but cheap transportation mode over a fast and expensive. Some may care more about risk than expected travel time and so on. However one can assume an average commuter and use this average person to make an aggregated model of what commuters' choice of transportation mode (Cascetta, 2009).

When every external factor is kept constant, as well as the number of commuters, then the system will equilibrate. What Figure 6 tries to demonstrate is this interplay between demand and supply that generates an equilibrated system. Lefts side is the demand and the right side is the supply. Commuters choose transportation mode based on the risk, expected travel time, monetary cost of the different transportation modes and the commuters preferences. If the demand for one transportation product exceeds the supply then the price of this product increases. This means that either the monetary, risk or travel time increases. In other words the attractiveness of the transportation mode decreases. Over time the commuters' perception of risk, expected travel time and monetary cost changes and some may opt for other transportation modes, if there is another transportation mode which is more attractive. In the end equilibrium will be reached where no commuters have any reason to change transportation mode at the given supply, their preferences and the total demand in the "market". What this diagram does not show is the details of how this happens. This will be elaborated in more detail in the following section using qualitative descriptions of the system and various diagrams.

4.2 Casual loop diagrams of the transportation system

Causal loop diagrams (CLDs) are tools meant to communicate how important feedback mechanisms generates the system's problematic behavior (J. D. Sterman, 2000). This sections purpose is to build understanding of the problematic structure that generates congestion in Bergen by explaining why people choose a certain transportation mode, how these choices affect the transportation modes' quality and how in turn a change in the transportation modes' quality affect peoples' choices. The aim of this section and thesis is therefore to explain how this feedback loop between demand (commuters' choices) and supply (quality of the transportation modes) contributes to Bergen's problem of increasing traffic congestion.

The causal diagram is a qualitative description a systems behavior over time (see Ford, 2010; J. D. Sterman, 2000 for more indepth description). It includes central variables, arrows showing causal links between the variables and a polarity on the causal links to signify the direction of the causality. $A \rightarrow^{+} B$

means that an increase in A causes an increase in B and a decrease in A causes a decrease in B. $A \rightarrow^{-} B$ means that an increase in A causes a decrease in B and a decrease in A causes an increase in B. Tied together the causal links can make up loops (paraphrasing here Ford, 2010 descriptions; J. D. Sterman, 2000). A positive loop can generate growth in the system, for example more cars lead to more roads which leads to even more cars ($A \rightarrow^{+} B \rightarrow^{+} A$). While a negative feedback loops counteracts any changes in the system, for example more cars on the road leads to a higher travel time and thus less cars on the road ($A \rightarrow^{+} B \rightarrow^{-} A$). Figure 7 shows a CLD of the basis for commuters' choice of using car, how these choices affects travel time, risk and monetary cars and thereby affects the commuters' future choices.

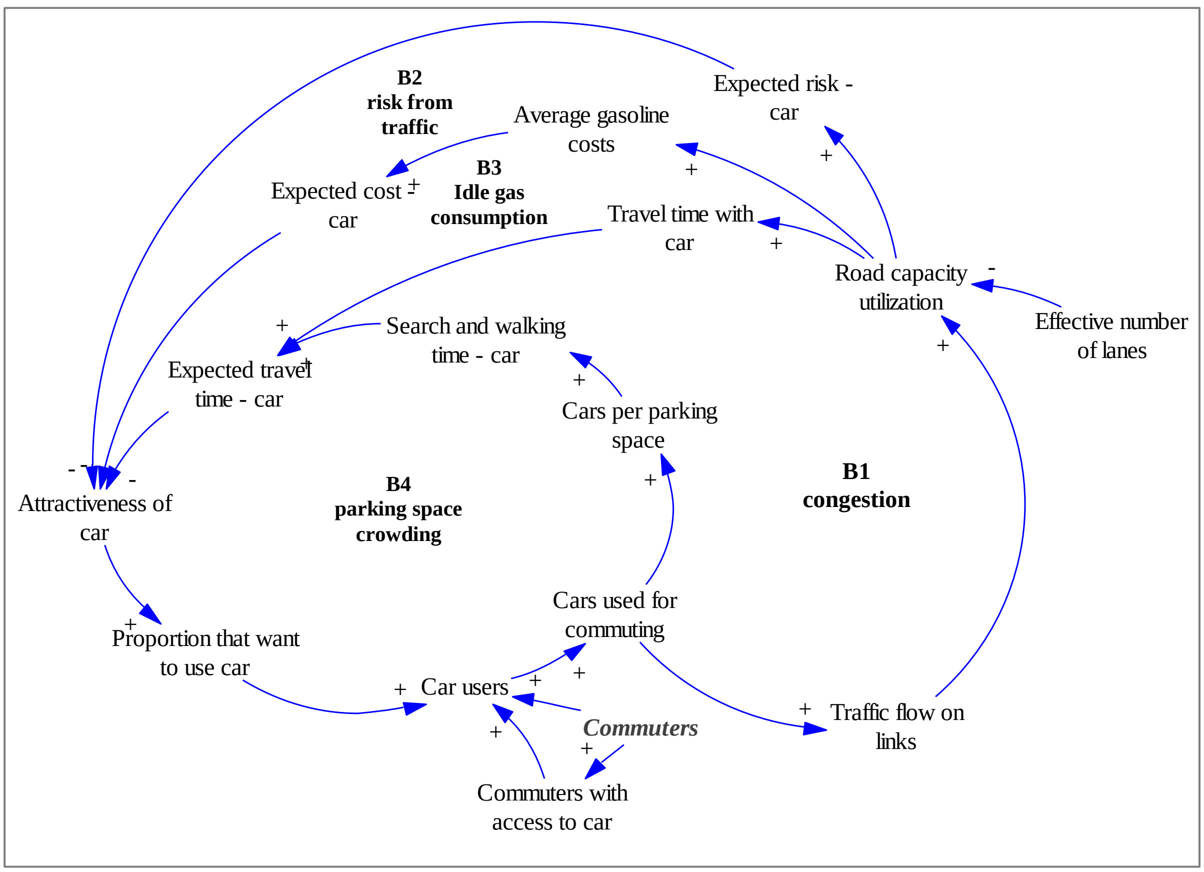


Figure 7 CLD of demand side of car commuting

Expected risk, travel time and monetary costs are the commuters' beliefs about the risk, monetary expenditures and travel time they will experience using car for commuting. These are mental states or memories that only exist in the commuters' brains and therefore not in practice directly measurable, but can be revealed through questionnaires. Expected travel time with car is the time the commuters expected to use travelling from their home to work using car. Expected risk is the variation around the expected/average travel time the commuter expect to experience when using car for commuting. A transport mode with high risk will be perceived as “unreliable” by the commuter. What is meant with risk is explained in more detail in appendix 12.3. Expected monetary cost is the monetary expenditure the commuter expect when using car. Attractiveness of car is determined by how the commuters' weight these expectations which neither is in practice directly measurable, but can be captured by stated preference and other experiments (Cascetta, 2009). The proportions that want to use car is the proportion of the people that would use car for commuting if they had access to a car. The proportion is determined by the attractiveness of car compared to all other transportation modes available to the commuters. Car users are the actual number of people that uses car, which includes both drivers and passengers. Cars used for commuting is the total number of cars used for commuting. It is equal to the number of drivers. Search and walking time with car is the time the car user at average uses to search for a parking space and walk from it to their work. Traffic flow on links is the number of cars that flows into the road links in the peak hour. Road capacity utilization is the cars entering the road link per hour divided by the roads capacity. The road capacity is determined by the effective number of lanes. More lanes mean more capacity on the road segment.

Congestion loop

The number of car users increases if the proportion that want to use car increases. If car becomes more attractive the proportion that want to use car increases. One of the characteristics determining the attractiveness of using car is the expected travel time. The higher expected travel time the less attractive car becomes. Their expectations are adjusted as the actual travel time with car changes. Travel time with car increases if the road capacity utilization of car increases. The road capacity utilization increases as more cars flows into the road links in the road network. The traffic flow on the links in peak hour increases when more cars are used for commuting which increases when the number of car users increases. Tied together this gives the first feedback loop in the system, shown as the *congestion loop* (B1) in Figure 7. It shows that if the number of car users increase then the expected travel time with car also increases, because of congestion. A higher travel time with car decreases the attractiveness of using car and therefore fewer commuters want to use car. Consequently the number of car users becomes lower than it otherwise would have been.

Parking space crowding loop

The parking space crowding loop (B4) is shown in Figure 7. When the number of car users increases the cars per parking space ratio increases. Car users must therefore use more time finding a parking space and the expected travel time increases, thus decreasing the number of commuters that want to use car. Consequently fewer people uses car than otherwise would have been the case without this feedback loop.

Risk from traffic loop

The expected risk of car increases when the road capacity utilization increases. The more cars there are on the road the higher is the variation in travel time. To understand this one can think of the difference between an icy road travelled by few cars and an icy road with many cars packed together in a queue. In the worst case scenario the car crashes with another car. However if there are many cars on the icy road the probability for a chain collision is high. If a chain collision occurs the road may be blocked and the average travel time for the commuters spikes much more than if just two cars crashes. In other words the more cars there are on the road the higher is the risk. Small random events can have much bigger impact on the travel time when the capacity utilization of the road is high. Road capacity utilization increases when traffic flow on the links increases. Traffic flow on links increases when the number of car users increase. All of this makes up the *Risk from traffic loop* (B2) in Figure 7. The more car users the higher is the road capacity utilization. Higher road capacity utilization means a higher risk of using car and thus a lower attractiveness. If the attractiveness of using car decreases the so does the number of car users.

Idle gas consumption loop

Expected monetary costs increases if the average gasoline costs increase. Average gasoline costs increases if the road capacity utilization increases. This is because more traffic results in lower average speed and longer travel time on the road, both leads to higher gas consumption.   This constitute another negative feedback loop in the system since road capacity utilization depends on the traffic flow on the links, traffic flow on the cars on the road and cars on the road on the number of car users. This loop is called the idle gas consumption loop (B3) in Figure 7 and can be summarized with the following description. If the number of car users increases then the road capacity utilization increases and the gas consumptions goes up. Higher gas consumption means that the expected monetary cost of using car increases. This makes car less attractive and the number of car users become lower that what it otherwise would have been.

Road expansion loop

Until now only negative feedback loops have been discussed. These loops only explain how an increased number of car users makes car less attractive. They balance the system so that more commuters will opt for other transportation modes when the traffic congestion becomes too bad. If the increased congestion problem is due to changes in the transportation system then there must exists feedback loops stronger than the ones discussed so far, loops that reinforce the number car users or at least balances the capacity of the roads so they can service a higher number of commuters. One possible explanation is road expansion. Road expansion refer here to new lanes are added to the road network or the roads' quality is otherwise improved. The highway capacity manual (see Statens vegvesen, 1990) sets certain standards on how much traffic a road segment can service. It seems reasonable to assume that the road authorities operate with a desired service level (that is a desired average speed on the road or traffic flow). When the traffic flow on the road links increases the effective number of lanes needed to retain this service level increase, hence the desired effective number of lanes on the road segment increases. This causes the road quality to increase and thus also the effective number of lanes. A higher effective number of lanes decrease the road capacity utilization and the expected travel time goes down, making car a more attractive transportation mode and hence more commuters' would opt for using car than otherwise would have been the case if the road quality was not improved. This constitutes the *road expansion loop* shown in Figure 8 as R1. The loop shows that the more car users there are the more the road quality is increased, which leads to more car users. However more roads also mean more capacity, hence less congestion. Therefore this loop cannot explain the problem of increasing congestion, but it can explain the problem of increasing traffic.

Parking space construction

Another change on the supply side of the system that can explain the increasing congestion is the *parking space expansion loop* shown in Figure 8. An increase in the car per parking space ratio causes an increase in the number of new parking spaces desired constructed, which is a function of the gap between desired cars per parking space and the actual number of cars per parking space. Number of parking spaces increases as the gap increases. Consequently the cars per parking space are reduced until it equals the desired cars per parking space ratio. It takes some time to build new parking spaces so this does not happened instantaneously, but with a delay.

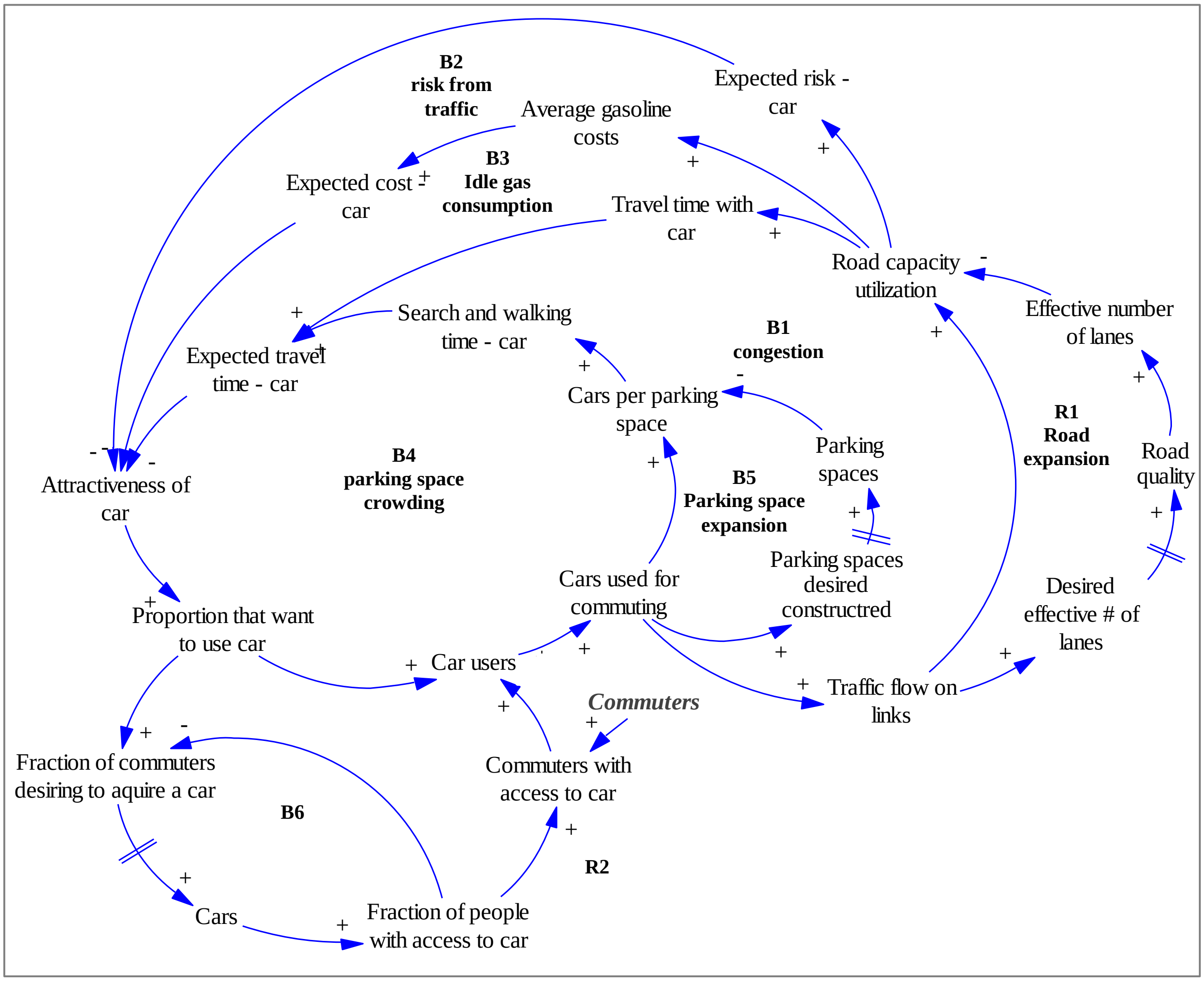


Figure 8 CLD of the whole Car system

Car ownership

Another explanation for the increasing traffic is that more people have access to car. The more people have access to car the more people can become car users. The faction of people with access to car depends on the number of cars in the area. The number of cars increases when the fraction of commuters desiring to acquire a car increases, but with a delay (indicated by the two lines crossing the causal link in Figure 8) because people use time to acquire a car. The fraction of commuters desiring to acquire a car increases when more people want to use car for commuting. Commuting is after all and decreases as the fraction of people with access to a car increases. The number of cars increases until the fraction of commuters desiring to acquire a car becomes zero. This is shown as loop B6 in Figure 8. If the proportion of commuters that want to use car increases then the number of cars will over time increase. Consequently more cars enter the road network. As a response to increased traffic the road authorities improves the road quality. The travel time therefore becomes lower and the proportion of commuters that want to use car becomes higher than it otherwise would have been. This positive feedback loop is denoted as R2 in the diagram. It generates growth in the number of car users and hence increases the traffic.

The whole car sector summarized

As follows is an abridged explanation of the six loops discussed above:

1. *Congestion loop.* If the number of car users increase then more car enters the road in rush hour. The road becomes congested and the travel time increases. This increase in travel time is perceived by the car users and consequently the number of car users decrease below what it otherwise would have been. This makes it less attractive for other commuters to choose car.

2. *Idle gas consumption loop.* If the number of car users increases more cars enters the road in rush hour. The road becomes congested and the average speed decreases. A lower average speed causes the gas consumption to increase, because the car uses gas standing idle in queue or simply because car motors uses more gas at very low speeds[7]. Higher gas costs are over time perceived and consequently fewer opt for car than they otherwise would have because of increased monetary costs.

3. *Parking space crowding loop.* If the number *of* car users increases then more people uses the parking spaces. An increase in the cars per parking space increases the search time for parking space for the average car users. This causes the travel time costs to increase. Over time the commuters perceive the increased travel time costs and fewer choose to use car than otherwise would have been the case if the parking spaces was not crowded.

[7] This is also true for very high speeds, however given the normal speed limits in the Bergen area this are not very important.

4. *Risk from traffic loop.* If the number of cars increases then more cars enter the road. This increased the standard deviation in travel time. Resulting in a decrease in attractiveness of car and the number of car users.

5. *Road expansion loop.* An increase in number of car users causes the number of cars to be greater than the road capacity of that road. This is perceived by the public road authorities which increase road construction as a response. Consequently the capacity of the road is increased and the travel time becomes lower than it would have been if there was no expansion of the road. Hence the travel time is kept low making car still an attractive transportation mode.

6. *Parking space construction loop.* If the car per parking space ratio increases then the pressure on the public administration and the incentives for the market to build more parking spaces increases. After a construction delay the parking space are build and the car per parking space ratio decreases below what it otherwise would have been. Keeping the travel time with car low.

Path choice loop

The path choice loop is shown in Figure 9*.* If the travel time on a path increases then this decreases the attractiveness of the path perceived by the commuter. A lower perceived attractiveness of a path result in fewer people using the path (given that there are feasible alternatives) and consequently the travel time on the path becomes lower than it otherwise would have been, as the other paths "takes of some of the pressure".

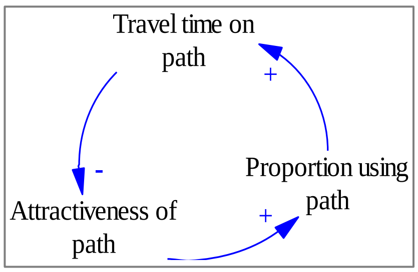


Figure 9 Path choice loop

Bus, tram and boat

Another possible explanation for the increase in traffic is that the attractiveness of PT transportation decreases. No crowding feedback loops are included for bus and tram. This does not mean that there are no feedbacks. When the number of bus or tram users exceeds the capacity of the transportation then the travel time increases, because some people must wait for the next bus or tram. Consequently less people use the tram or bus than otherwise would have been the case. However it seems reasonable to assume that this is not the case currently in Bergen.

An important feedback loop that is includes is that the more people using car the higher is the travel time for bus, because travel time for bus increases also when road capacity utilization increases if the bus uses the same road as the cars. If travel time of bus increases then the attractiveness of bus decreases and the proportion using car increases since more people will choose car over bus and the road capacity utilization increases even more. This is loop R in Figure 10. The more car users the higher is the road capacity utilization and the travel time with bus, the less attractive is the bus and consequently more people choose to use car. If loop B is stronger than R then an increase in car users will counteract any future increase since the attractiveness of bus increases. If R on the other hand is stronger than B then an increase in the number of car users will result in more and more commuters using car.

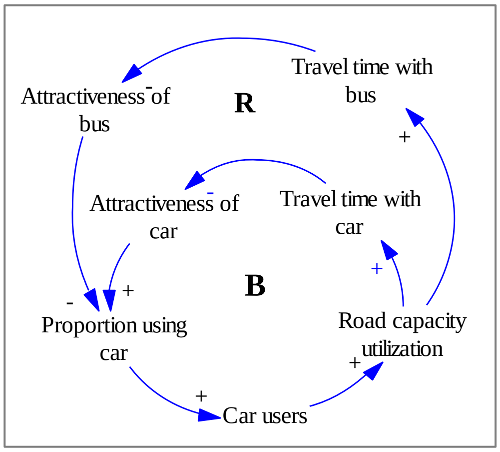


Figure 10 Effect of travel time with car on choice of transportation mode

Boat on the other hand has capacity constraints that are currently relevant. It is much harder to increase the number of boats and the capacity on the boat is likely to be stricter due to safety regulations. Waiting time therefore increases if the number of boat users surpasses the capacity of the boat. If the number of boat users is higher than the capacity some people must wait for the next boat or arrange transportation. Hence the attractiveness of using boat decreases and the number of boat users becomes smaller than it otherwise would have been if this was not the case. This is shown as the loop B9 in Figure 11. Since the proportion using the different transportation modes always must sum up to 1[8], because all commuters must use some transportation mode. If they don't then they are not commuters. Therefore if the proportion using bus increases then the proportion using the other transportation modes must decrease.

[8] Not true for the proportion shown in the diagrams here because commuters are divided into two groups, those with car and those without which makes it slightly more complicated since car are not an option for those without access to a car. But the general notion is correct.

In addition there is another negative feedback loop for boat, B8. Unlike tram and bus which stops many places the boat only stops/docks at the boat bay. This means that many people are dependent on driving a car to the boat bay. If the number of boat users increases then the number of cars per parking space increases, if the parking space is crowded then people must find another place to park. This increases the travel time which over time is perceived by the commuters. The expected travel time with boat increases as a result and the attractiveness of using boat goes down. Consequently fewer people uses boat than what otherwise would have been the case.

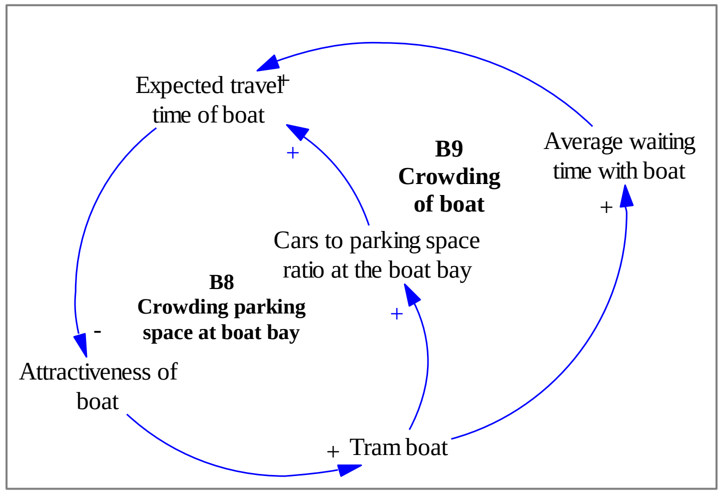


Figure 11 CLD boat crowding

4.3 Stock and flow diagrams[9]

Stock and flow diagrams (SFD) describe the states of the system (the stocks) and flows that changes the states (Ford, 2010). Stocks is symbolized with an rectangular square, ☐, and flows with doubles arrows and a valve, =ō=>. Stocks can only change through their flows and accumulates the effect of the flows (Ford, 2010). Number of cars in an area is an example of a stock. It flows is the acquisition rate which increases the stock of cars and scrapping which reduces it. If acquisition is greater than scrapping then the stock of cars grows, if acquisition is equal to scrapping rate then the stock remains unchanged and if acquisition is smaller than scrapping then the stock decreases. It accumulates the net change inflicted by the flows. The SFD also includes auxiliary variables/converters, ○, and causal links, $\rightarrow^{\pm}$. Converters are used to do give a more detailed picture of how the flow is calculated and causal links to show causality in the system. A causal loop is made by drawing a causal link from the stock to its flow. If the direction of the causality is positive between the state and its flow then the loop is positive and if it is negative then the

[9] A small side note regarding the stock and flow diagrams in this paper is that *diamonds* are used and not all variables will be discussed. This is because iThink 9.1.4 don't support built-in functions for linear algebraic operations such as cross-multiplication, however it is possible to work around this, but it requires additional variables. These structures are hidden away in the diamonds. For the same reason some variables are not explained because they are necessary for the arrayed structure of the system, but not very enlightening when trying to understand the system. All variables are however explained in the documentation in appendix y.

loop is negative. The interpretation of positive and negative feedback loops is the same in the SFD as the CLD. Positive feedback loops can generate growth in the system and negative feedback loops dampen growth and try drive the state towards a goal (Ford, 2010). The SFD uses the symbolic described over to outline the transportation system.

Commuters' choice of using car

Traffic on the road could be modeled as a stock of cars, increasing and decreasing as cars enter and leave the road. However it would not make a lot of sense to model cars on the road links as stocks when the time perspective is 20-years. After all the stocks are filled and emptied within the duration of one day. Given a ten years perspective they are "high-turnover stocks" and is therefore best modeled as an auxiliary variable (Ford, 2010, pp. 227-229). In a long term perspective the point of interest is what makes people choose car for commuting. People are assumed to make decisions based on their expectation about travel time, expected risk and the expected monetary costs of a transportation mode compared to the other available transportation modes. These three expectations for car are shown in figure Figure 12 in black. The number of car users depends on the proportion that wants to use car and the number of commuters with access to a car. The proportion that want to use car is determined using a multinomial logit decision sub model (see Cascetta, 2009). The sum of attractiveness (of other transportation modes) and the attractiveness of cars are the input of this multinomial logit model which determines the proportion that uses car. The attractiveness of using a car is given by the expectations shown as three stocks in the diagram.

Expected risk, monetary cost and travel time with car changes respectively if the standard deviation in travel time, total monetary cost or travel time (and search and walking time) with car changes. However the commuter's expectations do not change instantaneous. The commuters have adaptive expectations and therefore gradually changes theirs' expectations about travel time, risk and monetary cost until it equals the actual values of these stocks (J. D. Sterman, 2000, p. 428) . There are therefore a delay between a change in travel time, monetary costs and risk; and the changes' effect on the proportion that want to use car. The reason for this delay is that it takes time for commuters to update their expectations. The proportion using car is modeled as a stock which goal seeks the proportion that want to use car. If the proportion using car is different from the proportion that want to use car then the proportion using car changes over time until the proportion using car equals the proportion that want to use car. The time it takes to close the gap depends on the adaptation time. Adaptation time represent the time it takes for people to learn new travel routes, learn to use a new transportation mode, to acquire tickets or whatever is needed to switch from one transportation mode to another. A psychological reason is that people follow habits. Habits refer to some sort of behavioral script or programming (Friedrichsmeier, Matthies, & Klöckner, 2013). The role of such behavioral scripts are however controversial (see Bamberg et al., 2010; Friedrichsmeier et al., 2013; Gärling & Axhausen, 2003). Much of the research seems to point in the direction of transportation mode choice not being scripted. However it seems to be that the concept of behavioral scripts are much stronger than a merely delay in change of behavior. That there are some inertia involved in behavioral change seems reasonable and that people must "break out" of their current habits when they changes their behavior seems reasonable.

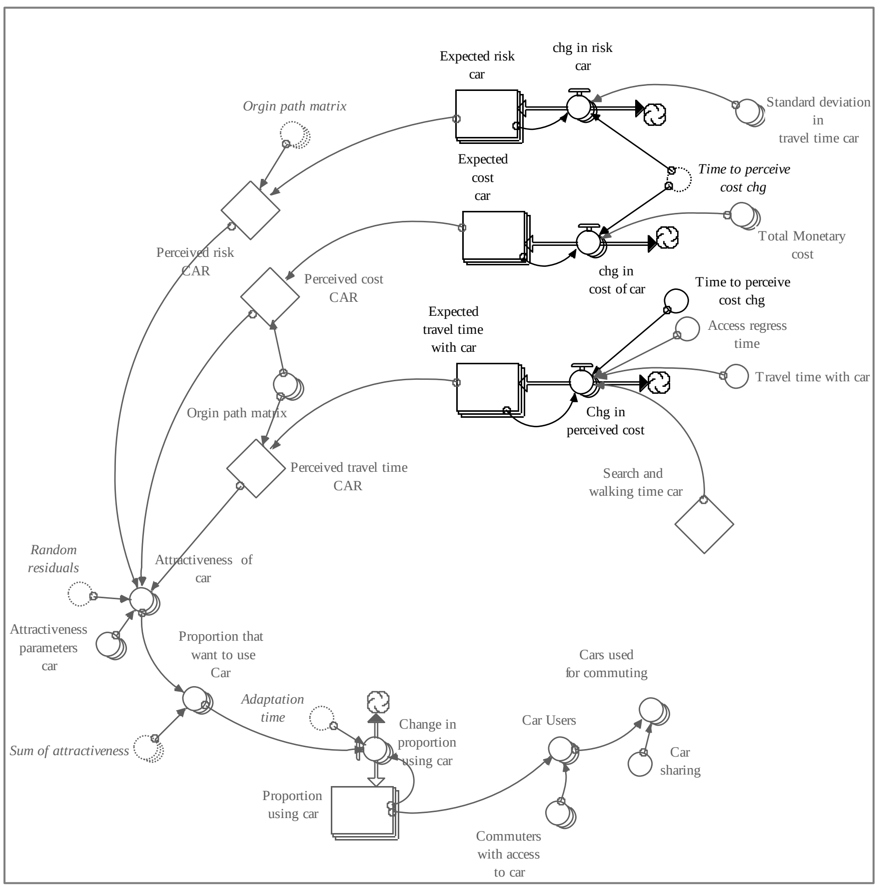


Figure 12 SFD of car users' expectation

Similar expectations of risk, travel time and monetary costs for the other transportation mode (boat, bus, tram, walking and bicycle) are included in the model, but first let's focus on how the expectations for by assuming that the attractiveness of other transportation modes are constant. In Figure 13 the connections between the number of car users and risk, travel time and monetary costs are added to the structure in Figure 12. The new connections are highlighted with black.

Expectation of risk depends on the road capacity utilization. As more cars are on the roads the capacity standard deviation in travel time with car above the normal standard deviation for travel time car. The connection between road capacity utilization and standard deviation with car ties together the variables that makes up the risk from traffic loop in Figure 8.

The expected travel time changes when the search and walking time and/or travel time on the road changes. The search and walking time with car depends on the number of car users. This connection constitutes the feedback loop B4 illustrated in the CLD in Figure 8. Car users and search and walking time are tied together through the cars per parking space ratio. A high number of cars per parking space mean that car users on average must spend more time searching for a parking space and park further away from their final destination. Parking further away from the destination results in longer walking time for the car user. How many cars that are used for commuting in the first place depend on the car sharing. More car sharing means that more car users are passengers and therefore neither adds to parking space crowding or traffic congestion. Travel time (on the road) with car depends on the number of cars used for commuting, the length of the morning rush and how the traffic is distributed over the morning rush hours. Furthermore it depends on how the traffic is distributed on the road network (determined by the array “fraction using path”) and the capacity of the road links in the road network. The connection between travel time and cars used for commuting makes up the congestion loop shown in Figure 8. As one can see there are many factors influencing the travel time and congestion level, both how the traffic are distributed over time, space and the capacity of the road network.

As discussed in the introduction the causes for why the number of commuters is changing are beyond the model’s boundaries due to project specifications. However the consequences of these are discussed in chapter about limitations and chapter 10 shows simulation results when the model is tied together with other models in such a manner that the number of commuters increases when travel time decreases.

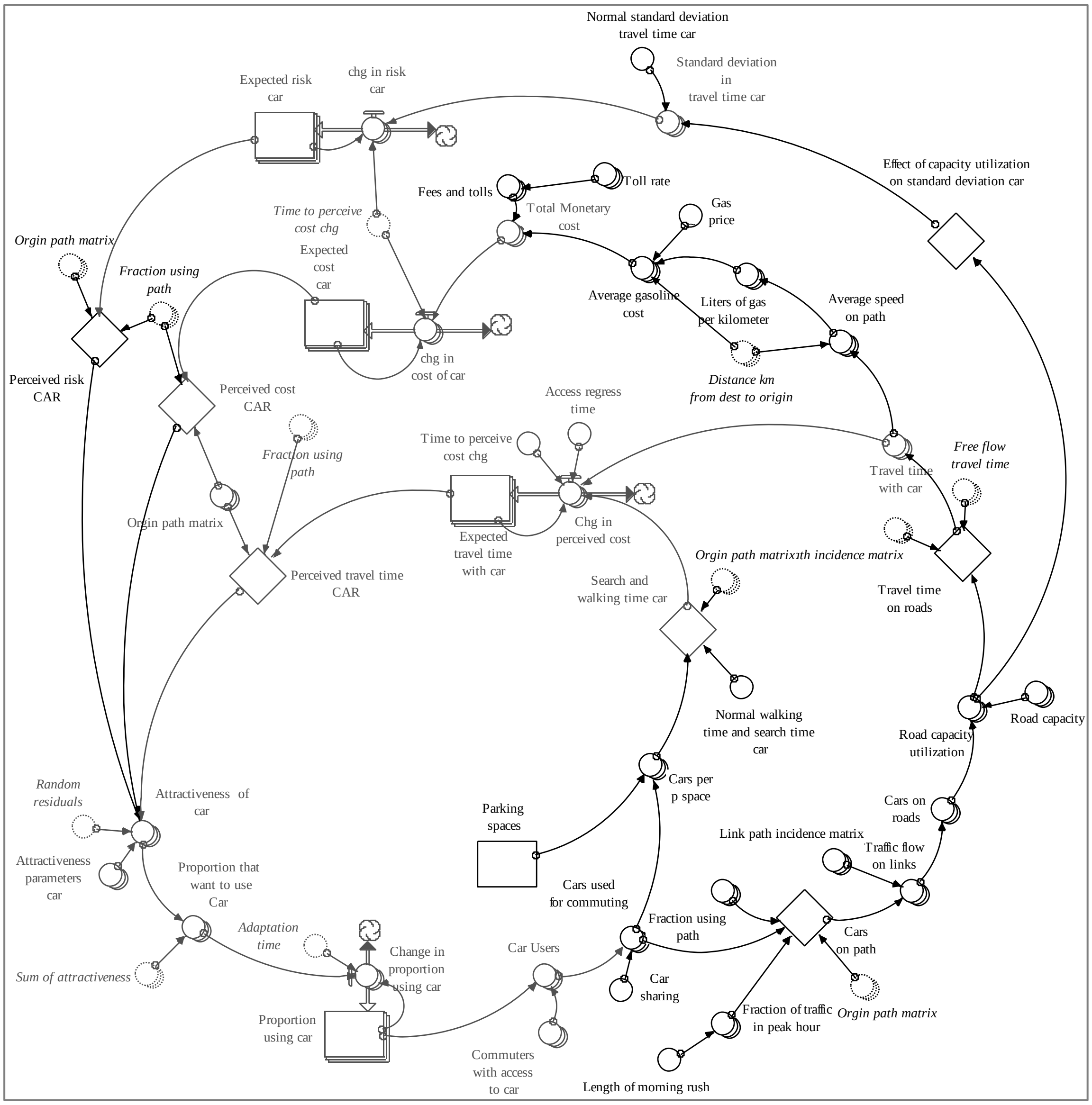


Figure 13 SFD of how expectations influences travel time, risk and monetary cost by affecting demand for car usage.

Commuters' expectation about monetary cost of using car depends on fees, tolls and gasoline cost. Gasoline cost increases as the speed becomes very high or low. A polynomial from Pfaffenbichler (2003) are used to model gasoline consumption and data from sentralbyrå (2013b) are used as the gasoline prices. This constitutes the feedback loop ide gas consumption shown in Figure 8.

This section explains how commuters' decide which transportation mode and how these choices affects the travel time, risk and monetary cost of using car. The expectations are the mental states that determine the commuters' transportation mode choice, but as shown in this section the choices feedback onto itself through the quality of the transportation mode.

Road quality improvement, parking spaces expansion and car acquisition

There are not only changes in demand, but also the supply of transportation services. The road network can be expanded, people can acquirer more cars and more parking spaces can be built to accommodate more traffic and car users. Such mechanisms makes the negative feedback loops discussed above weaker and can result in generating more car.

Figure 14 shows the road quality improvement. A higher traffic flow on the road links are measured by the public road authorities. After the data are compiled the desired number of (effective) lanes is calculated by multiplying the number of lanes needed to service the traffic at the lowest service level[10] by (100 + percent extra capacity)/100. There are two reasons why it is desirable with extra capacity: 1) lowest service level is not desirable since results in a very low average speed, and 2) too have a "safety margin" in case the traffic increases in the future. It is assume that it is desired to have the same number of lanes in both directions (because morning rush, becomes the evening rush) so therefore the direction with the highest traffic flow are used to calculate the desired number of effective lanes.

New lanes are desired constructed if there are a gap between the number of desired effective lanes and the number of effective lanes. The number of new lanes desired constructed are translated into desired change in road quality by multiplying the number of new lanes desired constructed by the length of the roads (in other words to increases the number of effective lanes with one for a 10 km long road requires more effort than doing the same for a 5 km long road). Desired change in road quality divided by the building time added with road maintenance gives the desired total road construction for one year. It is assumed that this desired total road construction is the actual road construction. As long as the road construction is greater than the road deterioration the road quality increases and the gap between the desired and the effective number of lanes is reduced. Road construction becomes smaller as the gap becomes smaller. This is the construction loop shown in Figure 14 Road quality construction and expansion. It improves road quality until the desired quality is reached. If the road quality is above the desired road quality then the desired total road construction is lower than the road maintenance. Hence road quality is reduced until the desired quality is reached.

[10] Traffic flow on a link divided by the ideal capacity of one lane

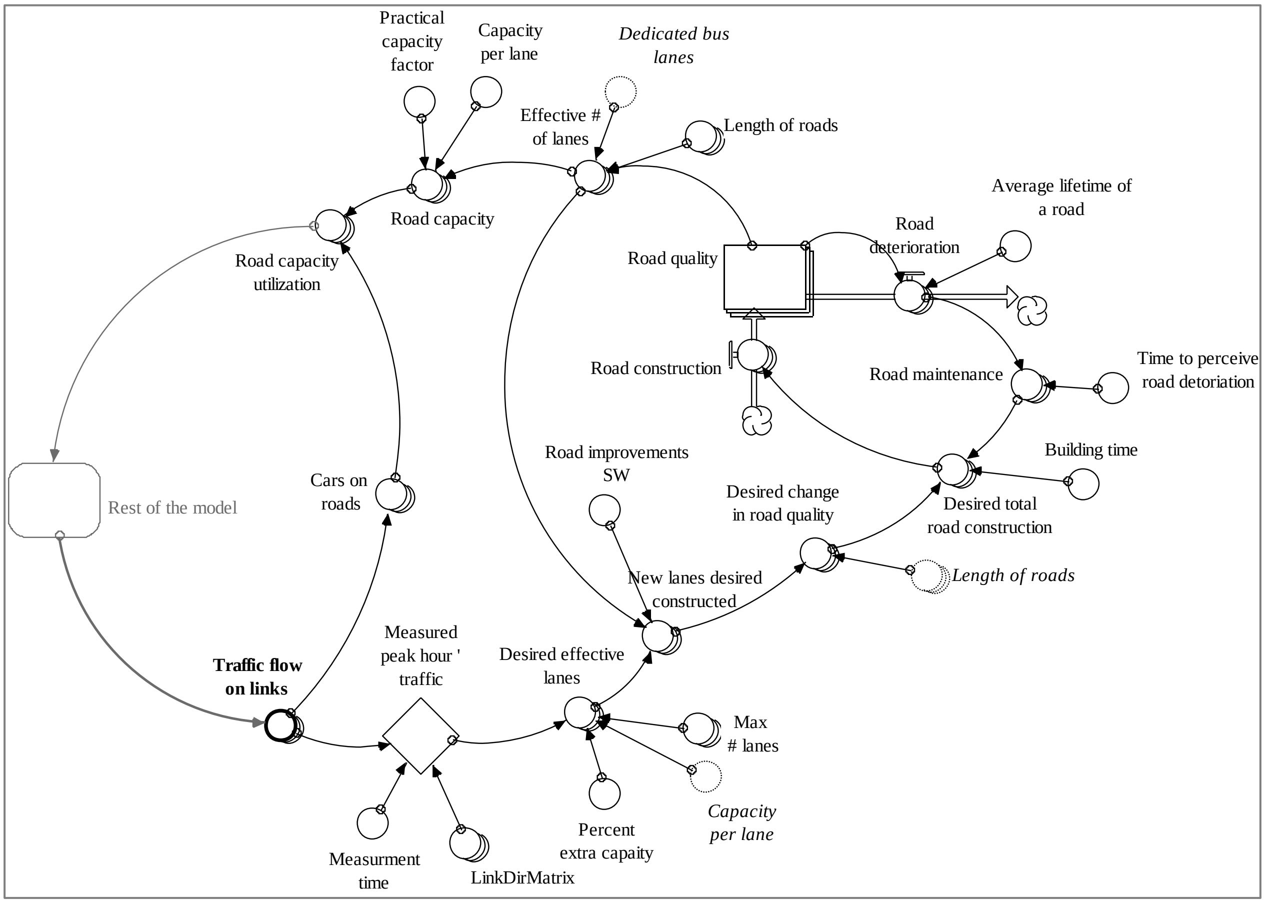


Figure 14 Road quality construction and expansion

As the effective number of lanes increases through road construction the road capacity[11] on the links increases. A higher road quality means that the road capacity utilization is reduced. Since the road can services a higher traffic flow the travel time decreases, which will cause an increase in the traffic flow on the road links. This is a positive loop that makes more commuters choose to use car. It is the same loop as the road expansion loop in Figure 8.

Figure 15 shows the sub-model for parking expansion. When more cars are used for commuting the demand for parking space increases. This increase in demand for parking spaced can be measured by the number of cars per parking space ratio. The desired number of parking spaces can be written as cars used for commuting times the desired parking space coverage since parking spaces are measured in the number of cars that can be accommodated. New parking space desired constructed equals the desired

[11] Practical road capacity are used following Kutz (2004), which is the maximum flow capacity (service level e) from Statens vegvesen (1990) multiplied with 0.8.

parking spaces delayed with the time it takes for the market and public administration to perceive changes in the desired number of parking spaces, minus the actual number of parking spaces.

This gap divided by the parking space building time is the parking space construction rate. As more parking spaces are constructed the gap between the desired and actual number of parking spaces closes, until there are no more unsatisfied demand. However parking space construction can be constrained by the available space for parking spaces, if there are no available space then the parking space construction stop and the gap remains.

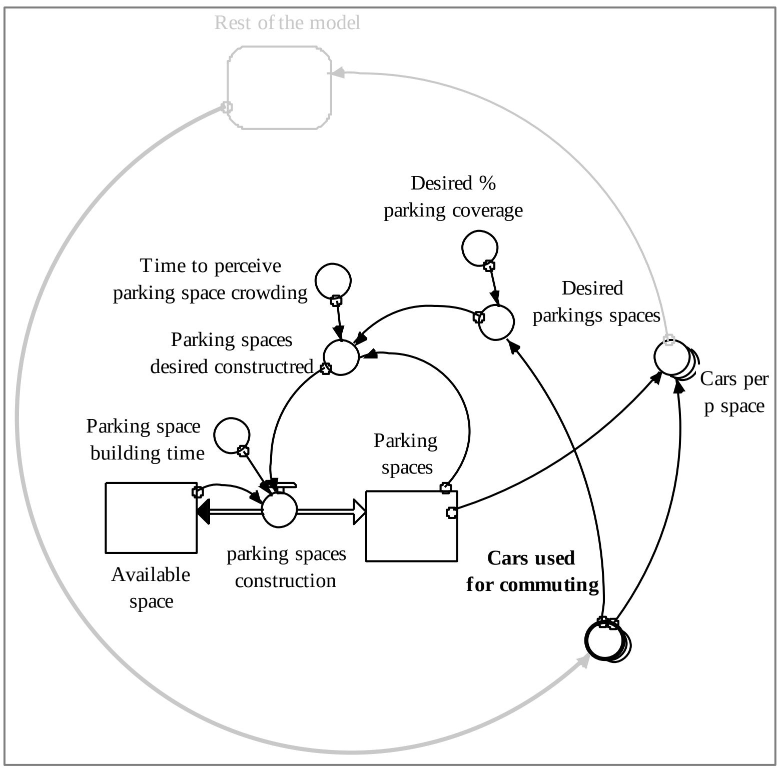


Figure 15 Parking space expansion

Another important reason why the traffic flow on the roads increases is that more and more people own a car. The number of car users (among commuters) increases if more commuters get access to a car. Figure 16 Car ownership sub-mode shows the car ownership sub-model[12] that explains how car ownership changes. The basic of the structure is very simple. The fraction of commuters desiring to acquire a car is the gap between the fraction of commuters that want a car and the fraction of commuter

[12] Somewhat simplified in the stock-and-flow diagram. Aging chain for car is not modeled explicitly, but captured with the iThinks softwares built-in function DELAY3(inflow, delaytime).

that have access to a car. The bigger the gap is the bigger is the car acquisition. Car acquisition increases the number of cars owned by the commuters until the fraction of people with access to cat equals the fraction that want's a car. This is

the same loop as B6 in Figure 8. Acquired cars enter the car stock. Over time cars rusts and breakdown, eventually they are scrapped. It is a higher order delay because cars goes through an aging chain from being a new car, couple of years old, old and ancient. In the reality the probability that the car is scrapped increases for each state as the car becomes older, but in the model we simplify it by using iThink software's DELAY3 function. However this gives a appropriate approximation (see J. D. Sterman, 2000, p. 421) where only few of the newly acquired cars are scrapped, most are scrapped at the (average) lifetime of the car and a few cars are kept for a long time before they are finally are scrapped. It is therefore assumed that the car goes through the phases new, old and ancient and finally is scrapped.

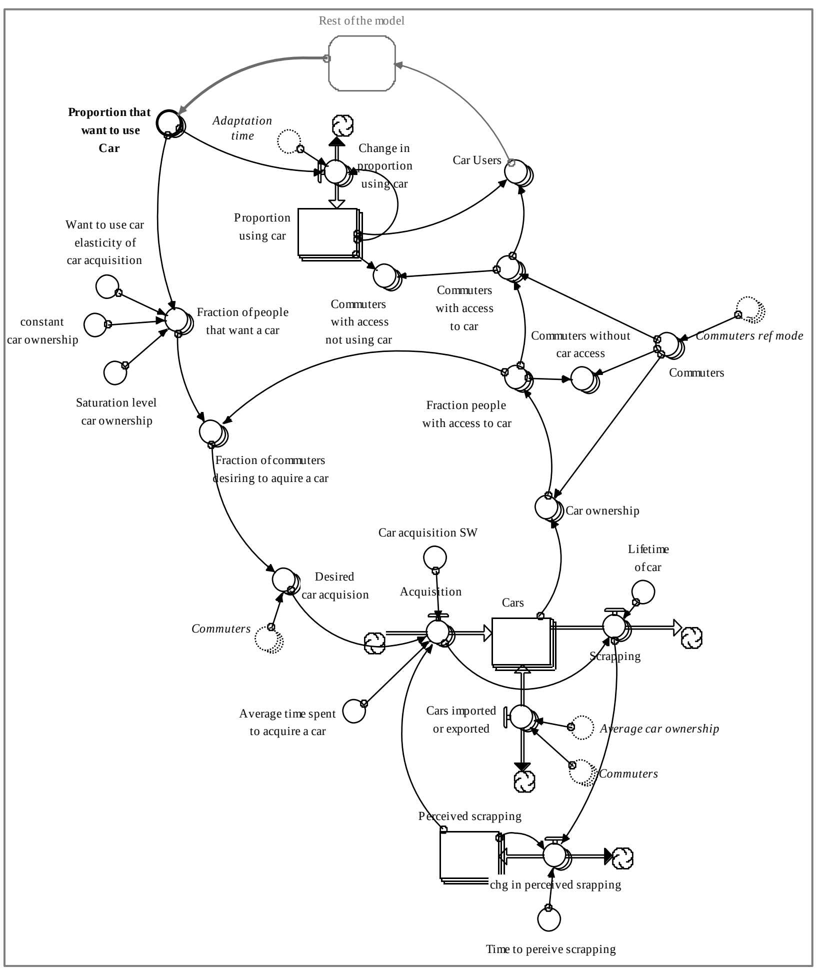


Figure 16 Car ownership sub-model

The commuters perceive that their cars deteriorate and finally are scrapped. It takes time for the commuters to adjust their expectation of the scrapping rate of cars. The commuters replace the scrapped cars based on their expectations about the scrapping rate. In addition they can either acquire more cars if the desire more cars, only replace the cars being scrap or not replace the scrapped cars if they desire fewer cars.

The most interesting aspect with Figure 16 Car ownership sub-mode is how the fraction of people that want car is determined in the model. Dargay and Gately (1999) studies aggregated data of average income and car ownership from many countries and argue that there is a s-shape relationship between income and car ownership. While the paper makes a convincing case based on is extensive data there still reasons to reject theirs' proposed model for car ownership given the purpose of this thesis. A very simple reason is that the model uses GDP as proxy for income. The problem is that GDP swallows expansion of road network, change in number of commuters and other factors influencing car acquisition. This may be fine when explaining and comparing changes in car ownership between different countries as done in the article. However it is quite useless in the practical management of traffic volume at the level where most transportation policies are implemented. Since many of these things swallowed by the GDP are exactly what are desirable to manipulate; therefore it is desirable to have a model that includes these factors. Instead in the model the fraction that wants to use car increases when more commuters want to use a car. The proportions that want to use car therefore affects the car ownership over time. A detailed discussion of the equation I made to model how car ownership is affected by the proportion that want to use car for commuting can be found in appendix 12.4.

Figure 17 illustrates the parts of the model discussed above (plus the path choice sub-model). Three important (arrays of) stocks that determined the demand already have been identified. These stocks are the commuters' expectation of risk, monetary cost and travel time when using a car. These stocks changes respectively when travel time, risk and monetary costs changes. Two stocks that determine the effect of changes in number of car users have on these expectation has also been identified. These two stocks are the road quality and the number of parking spaces. They function as the capacity of the transportation system in regard to road traffic. It has also been shown how this capacity can be increased to accommodate more demand. Lastly car acquisition was discussed and how the proportion of people that want to use car for commuting affects the number of cars, which in turn makes it possible for more people to use car. All of these are important for understanding commuters’ transportation mode choice, but what is lacking is how the other transportation mode are affected by these choices. To truly understand the commuters’ choice of transportation mode it is necessary to also understand what affects the attractiveness of the alternatives to car.   It is also important to investigate because some commuters’ choose other transportation modes than car if there are more alternative options or if they don’t have access to car.

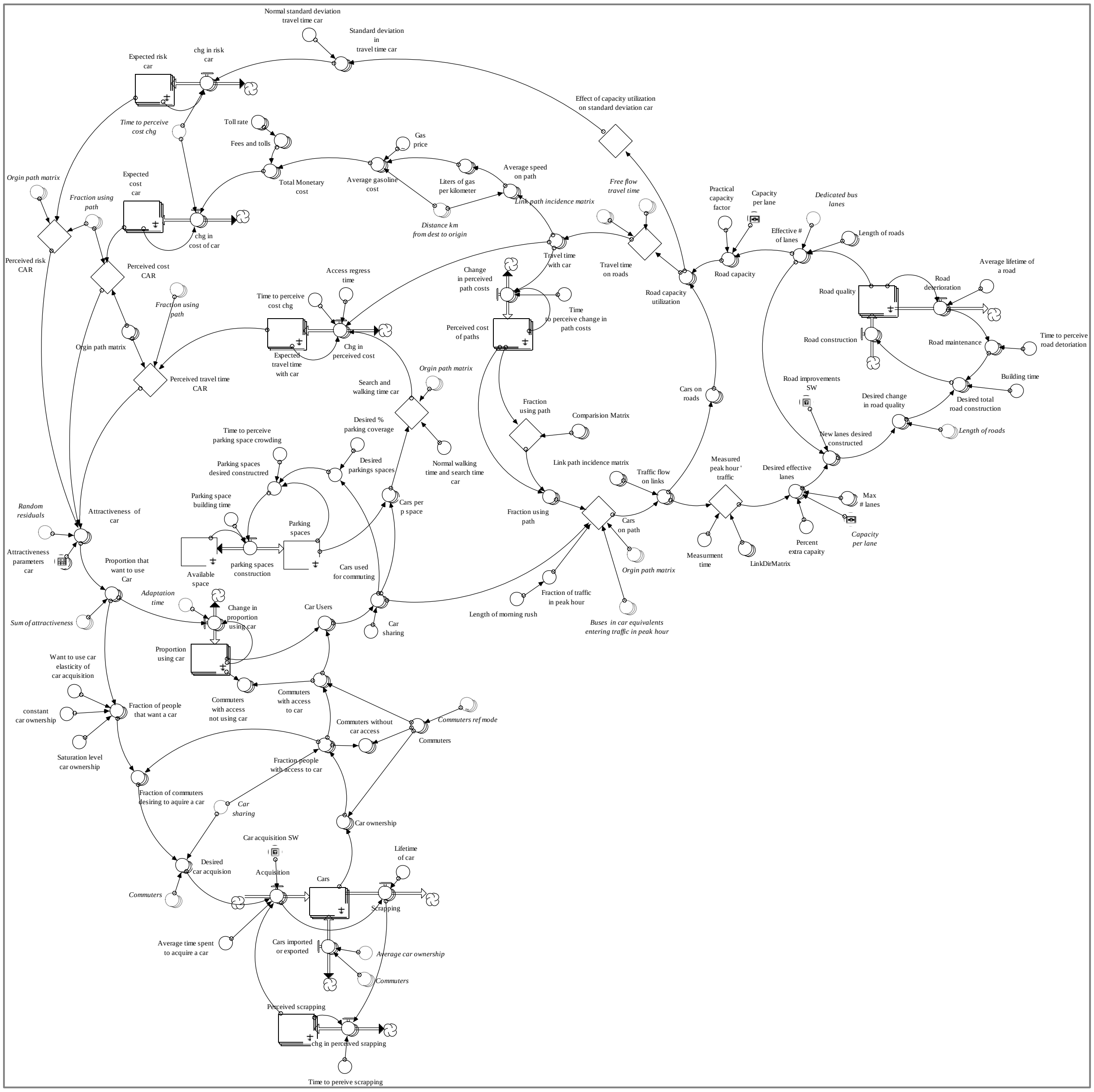


Figure 17 The whole car sector

Bus

Bus is the most common public transportation services in Bergen. Similar to car, the attractiveness of using bus is determined by the expected monetary cost, risk and travel time. The actual travel time with car is the time spent in traffic with bus, time used walking to the bus and time spent at bus stops. As shown in Figure 18 the travel time depends on the road capacity utilization multiplied with an additional factor. If this additional factor is higher than 1 then it means that an increase in travel time with car result in an even bigger increase in travel time with bus. If it equals one then the travel time with bus on the road equals the travel time with car on the road.   The diagram shows that the risk depends on the road capacity utilization of paths. If the normal standard deviation in travel time with bus is greater than that of car then an increase in capacity utilization increase the risk of using bus more than the risk of using car.

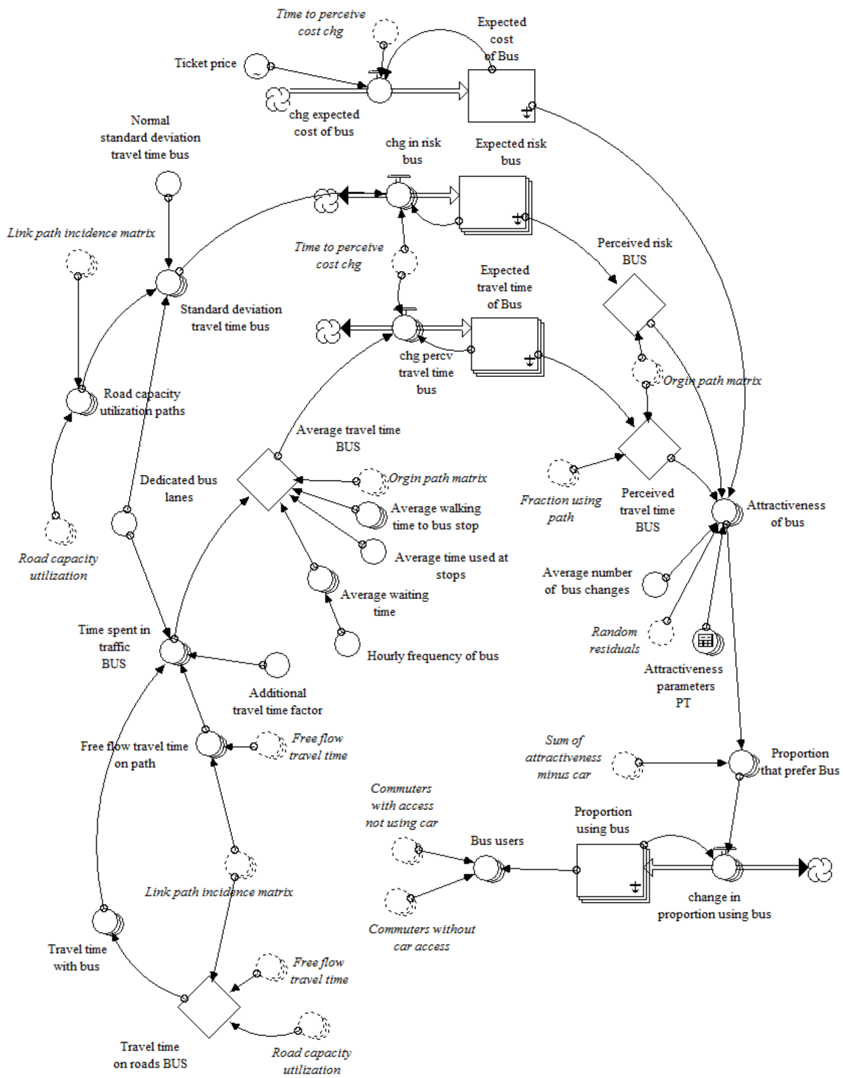


Figure 18 SFD of bus sub-model

The only monetary cost of using bus is the ticket price. Ticket price is assumed to be exogenous. There are system dynamics model that include it as an endogenous variable, however in the context of this model it seems more useful to treat it as a variable that can be controlled by the administrators and politicians at will. It is also not clear from data how the ticket price is decided or if it is in any way related to the number of PT users. Changes in ticket price are therefore outside the model's boundaries.

When the attractiveness of bus increases (decreases) the proportion using bus increases (decreases) and the proportion using the other transportation mode decreases (increases), everything else kept constant. This includes car and if there is a reduction in the traffic flow then the travel time of bus is reduced.

Consequently this can result in bus becoming even more attractive and result in even further decreases in the traffic flow. However this can easily go the other way, where attractiveness of bus decreases, more people uses car and traffic flow increases. Increased traffic flow leads to higher travel times which makes bud less attractive. As discussed in this section this is highly dependent on the additional factor which travel time with car is multiplied with to get the travel time with bus.

Boat

Figure 19 shows the boat sub-model. Boat can only be used to travel between Askøy and the city center in the model. The ticket price for using the boat is the same as bus. Unlike bus the capacity constraints are assumed to be much stricter than for bus, because it is much more costly to increase the number of boats than buses and therefore included in the model. Waiting time increases therefore as the number of users increases above the capacity (Cascetta, 2009). This is because some commuters' then must wait for the next boat. Otherwise it is modeled that the waiting time is higher when the hourly frequency low. This is because it is assumed that the time each commuter is supposed to arrive at their destination is uniformly distributed over the rush hour (Cascetta, 2009).

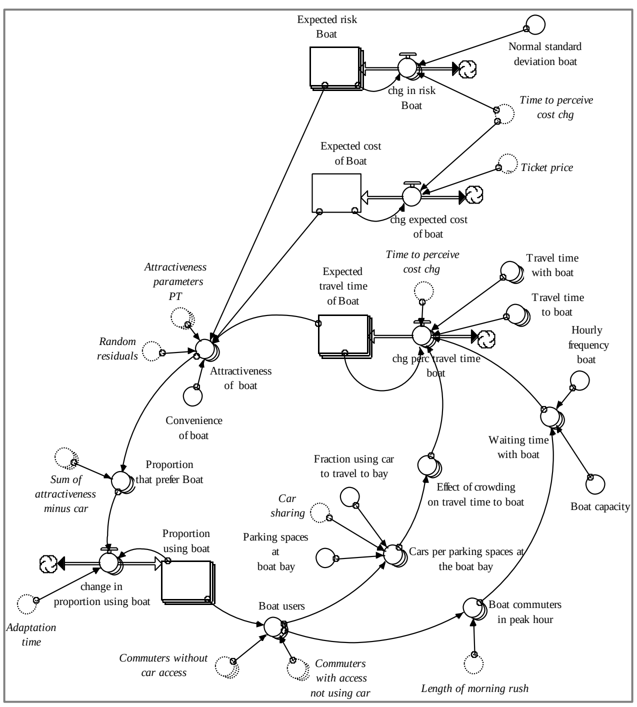


Figure 19 SFD of boat sub-model

Unlike bus the boat only have two stops, the boat bay at Askøy and the bay in city center. Average walk time to the boat bay is therefore higher than the average walk distance to the bus stops. However boat users can drive to parking space close to the boat bay and then take the boat. This reduces the average travelling time to the boat bay, but the parking space has a limited number of parking spaces. The more people use the boat and the higher fraction of these using cars to the boat bay the more of the parking spaces are used. This will cause an increase in the average time used to travel to the boat bay.

Tram

Tram, or as it is called in Bergen “Bybanen”, was opened in 2010 and it has currently only one line which connects the city center with Bergen south. Figure 20 is the structure used to model the tram and it is very similar to SFD for the bus. However there are one important distinction, the tram is unaffected by road traffic. This means that the travel time and risk stay the same.

Of course this is not true in extreme cases when the number of users is far beyond capacity and (dis)comfort effects kicks in decreasing the attractiveness, but this is kept out of the model to keep it simple.

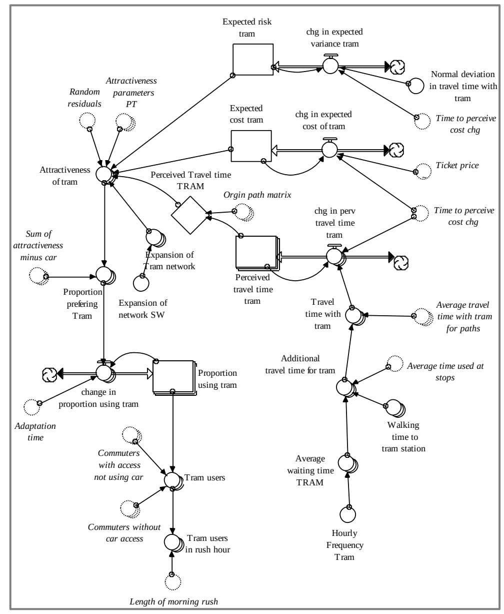


Figure 20 SFD of tram sub-model

Walking and bicycling

Walking and bicycling is modeled as shown in Figure 21. It is assumed that the expected risk, monetary costs and average travel time is constant. Since expected risk, travel time and monetary costs are constant they are represented in the diagram as auxiliary variables instead of stocks. Travel time is calculated by distance multiplied with a slow distance factor divided by the average walking and bicycling speed. The slow distance factor captures the fact that walkers and bicyclist have at average longer distances to traverse than cars. The road for cars cuts much more a straight line from A to B, while the road that can be used by bicyclists and walkers often is much less efficient. The proportions using bicycle and the proportions walking are models as stock. This means that it takes time for people to change from using car or another transport mode to begin to bicycle.

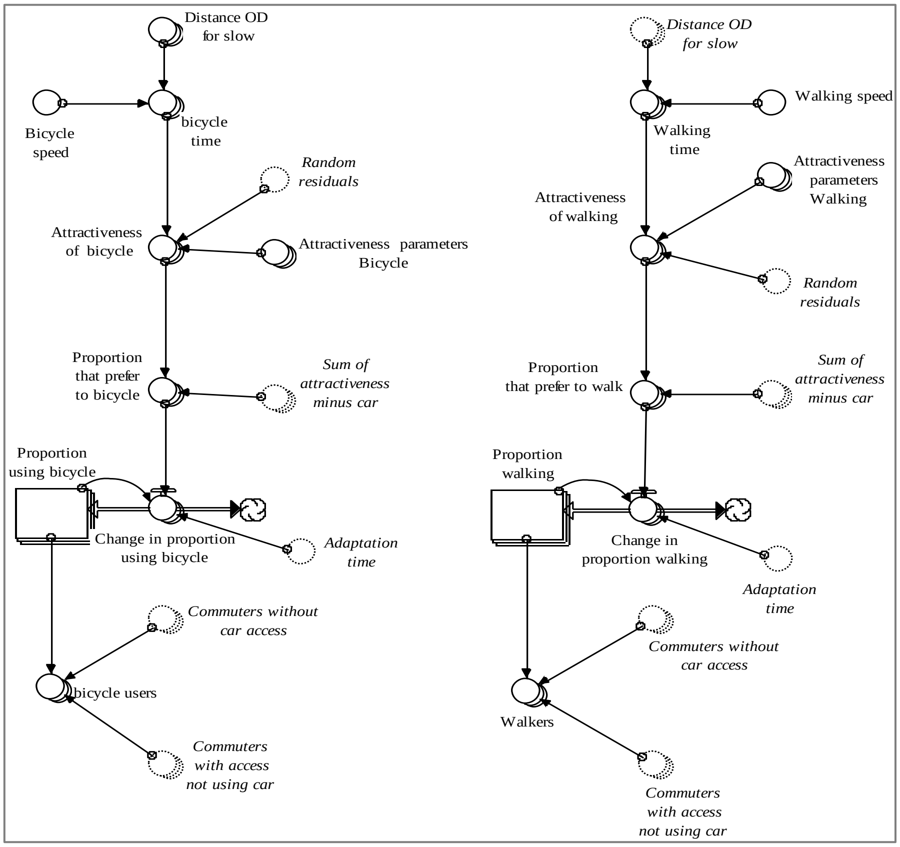


Figure 21 SDF of walking and bicycling

5 About the road network

The transportation model is spatial disaggregated into six zones and looks at the long term changes in the peak hour traffic. The long term perspective means that it cannot capture how the traffic distributes and flows through the road network over the duration of a day in detail. Nevertheless it is still desirable to capture to some extent how the traffic from Bergen west is influenced by traffic from Askøy or how the traffic going from Bergen north going to south through centrum is affected by traffic coming from the west going to south also through centrum that also goes through centrum and so on. This is captured in a very simple manner where the cars per hour on each road link is calculated by adding up all the cars that uses that road link in peak hour, as illustrated by Figure 22.

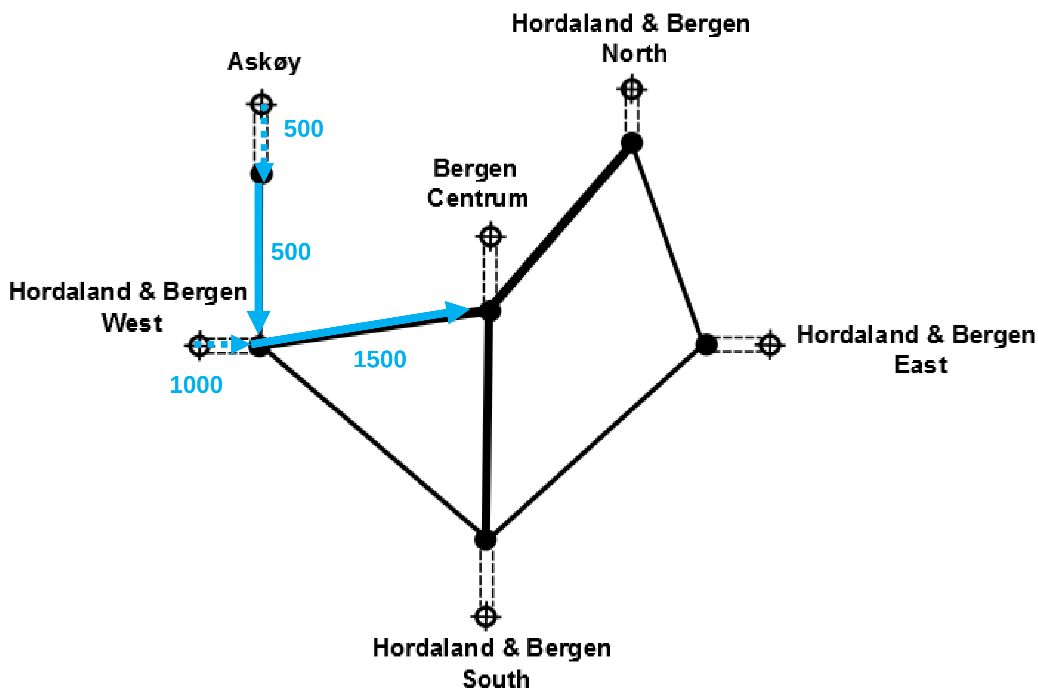


Figure 22 Road network

The 500 cars coming from Askøy joins the 1000 cars coming from Bergen West. This results in 1500 cars per hour flowing into the road link connecting Bergen West and Bergen centrum (RV555). The technical details regarding the network models are discussed in appendix 12.6.

6 Estimation of parameters

Parameter estimation in this thesis draws on a wide range of data sources. This chapter is divided after the sectors: car, bus, tram, boat, bicycling and walking. First the parameters relating to car usage are discussed, then bus, tram and so on. In addition there is an own section dedicated for the utility parameters because these parameters applies for all sectors and require special attention due to their nature. This parameters is the one used in the base run, however the more uncertain one will be changed in the process of calibration.

Ford (2010) place different data sources of information on a continuum ranging from hard to soft sources, with physical laws and personal intuition as the extremities of hard and soft data sources. It is often necessary to draw on both numerical, written and mental data since numerical data often only cover a tiny fraction of what is known about a system (J. D. Sterman, 2000, p. 853). It is therefore not only necessary because of limitation in numerical and statistical data to use a broader spectrum of the possible data sources, but also beneficial (J. D. Sterman, 2000). This applies for the case of the transport system of Bergen where most of the sources of information about the system lays on the softer side of the spectrum. However this also means there is great uncertainty about many of the parameters. Some however are taken from highway capacity manuals and can be treated as certain, because of the amount of research behind establishing these parameters makes it reasonable to treat them as certain.

Parameters in the car sector

Capacity per lane, practical capacity factor and the parameters used to *calculate liter of gas per kilometer* can all be looked up in highway capacity manuals (Statens vegvesen, 1990) and transportation engineering literature(Cascetta, 2009; Kutz, 2004; Pfaffenbichler, 2003). These parameters are treated as absolute certain and is set to 1200 and 0.8 for capacity per lane and practical capacity respectively. See the appendix with equation for the parameters value for the equation used to calculate liter of gas per kilometer. *Length of roads* can easily be looked up and calculated at Google maps (Google, 2013), of course an important issue when calculating length of roads between aggregated zones is which start and end points (called the zonal centroids) one chooses in the zones. For example when calculating the length of road from Fana to Askøy I can choose to calculate from the road patch closest to the geographical midpoint of the zones or I can choose any other point. The Transportation analysis literature says that the zones should be placed near the geographic “center of gravity” of the zone

(Cascetta, 2009), but without any geometrical definition of the center of gravity of a zone. I interpret this as meaning that the zonal centroid should be placed in the geometric midpoint of a zone if the population, shops, public buildings, workplaces and so on are uniformly distributed in the zone. However population and such are centralized and not uniformly distributed then the zonal centroid should be placed closer to where they are centralized. Calculation of length given zonal centroids are certain, however there are some arbitrary choice involved in setting this centroids. An areas center of gravity could of course easily have been calculated formally, but that would require detail data of how the population is distributed in the areas and such data does not exists or have at least not been made available for us (the participants in the project) in any useable form.

Access/regress time is the time car users spent on smaller roads to enter the highway. If the population density is high then these parameters should be lower than if the population was spread out, assuming there is an equal number of highways. This is arbitrary set to zero. However with better data this could be estimated and would improve the accuracy of the simulation. *Normal walking time and parking search time* is set to 5 minutes, this is arbitrary chosen value.

Walking time and parking search time is multiplied with *effect of search time on walking and search time* which is the effect parking space crowding has on the average time a commuter must use for finding a parking space and walking to and fro the parking space. If the travel time for the individual that arrive after the capacity have been reached increases is stepwise form of increase then the effect is close to linear. For example if the first 5 uses 5 minutes to find a parking space, the next five uses 10 minutes and so on. If the increases in the individual travel time is linear so that the first commuter uses 1 minutes, the next 2 minutes and so on then the effect should be approximately linear. If the travel time for each individual over the capacity increases exponentially then the effect should be exponential. For example if the first individuals travel time is 2.7 minutes, the next 7.3, 20, 40 and so on. This can be easily demonstrated mathematical, for example take the case of linear increase where travel time for a individual is the number of individuals, x, times A. Average travel time for N individuals can then be found solving the integration problem: $average\ travel\ time\ = \frac{1}{N}\int_0^N (A * x)dx$ with the solution $\frac{A}{2N}N^2$ assuming that the integration constant is zero. The one N in the denominator cancels the one in the nominator and gives $\frac{A}{2}N$, a linear expression. A graphical demonstration can be done with a very simple model that I have programmed to demonstrate these three cases numerically. Download[13] the whole folder since all three files are needed. It is assumed that the travel time either increases stepwise or linearly as the number of commuters increase since the assumption of exponential increase seems unlikely. Therefore the effect of search time on walking and search time is simply assumed to be the cars to parking space ratio.

Time to perceive cost changes is the time commuters uses to perceive changes in the cost, travel time or risk of using a transport mode and the time they use to change their behavior from using one mode of transportation to another.

Fees and tolls are typical for parking houses 73 NOK for two hours parking on the street *(Hansen, 2013)* in other words about 220 NOK the duration of a working day. However many people have free parking space, therefore the average fee becomes lower. To weight it appropriately 220 is multiplied with (1-fraction with free access to parking space), the fraction with free access to parking space are taken from Christiansen et al. (2010).

A dedicated bus lane is set to zero. Today there are only 7 km of lanes dedicated for public transportation and carpooling ("kollektivfelt") in Bergen (Statens vegvesen, 2011a). For all practical purposes this is the same as zero dedicated bus lanes. *Max number of lanes,* this parameter signifies that there are some limits to the number of new lanes on can desire built, either because of physical restriction such as the topography or a political policy. It is arbitrary set to three lanes (just counting on direction, six lanes counting both directions). Of course in practice this number can be changed, one could for example build a multilayered highway, but it seems reasonable to assume that it is three lanes in Bergen. It is assumed that the average *building time* of a road is about 3-4 years. *Measurement time* is the time the government uses to perceive changes in the traffic volume and act upon the change. *Average lifetime of road* is the average time it takes for a road to deteriorate. It is assumed to be 30 years. *Time to perceive road deterioration* is the time it takes for the public road authorities to perceive, register and maintain patches of roads that has deteriorated. It is assumed to be equal to be one year since road deterioration is not a big problem in the cities.

[13] Link to download: https://docs.google.com/folder/d/0B4tyscJZDJNQT2pOMTJUbDUxRkk/edit?usp=sharing

Desired car per parking space ratio is assumed to be 0.8. It is lower than 1, because it is desirable for the market and the public authorities to have some slack when it comes to capacity and some parking spaces are also not used by commuters if other alternatives are possible because they are inconvenient placed. *Time to perceive parking space crowding* is assumed to be 5 years. It takes some time for the government to compile, interpret and act upon traffic data. And it takes long time for actors in the private market to make expansion plans, financing, lobbying to politicians and so on before a building project starts (obviously getting smaller projects accepted take short time, while building a parking hours is assumed to at average take many years). *Parking space building time* parking space building time is assumed to be at average 0.5 years. *Normal standard deviation for car* is assumed to be 5 minutes.

Free flow speed is the average speed for a car when there are no or little traffic. It is assumed that this is close to the speed limit of 70 km/h, but 10 km/h lower because some stretches of road has a lower speed limit and a car cannot hold the speed limit at average since the speed must be reduced at intersections, curviness of the road and other obstacles that makes it necessary for the driver to slow down.

Car sharing ratio is the number of person per car, in other words how many people that can use each car, which is set to 1.05 persons per car. It is taken from Christiansen et al. (2010). If there are a population of 2 people, the number of cars is 1 and car sharing is 2 then every person in the population can use a car. However even if every person choose to use car in this population the number of car users will be two, but cars on the road will only be 1, because there are 0.5 car per car users (1/car sharing ratio).

Parameters in the bus sector

Hourly frequency of bus is approximately every 12 minutes. It is more frequent with the bus travelling within Bergen than the buses traveling from Bergen to the outlying communes (Skyss, 2013a). This means a frequency of 5 buses per hour, however some routes overlaps. Since most bus routes can to some degree be used interchangeable by the commuters this effectively increases the frequency. It is approximately 2 routes that overlap, more closer to Bergen centrum than further away(Skyss, 2013a). Therefore I set the frequency to about 10 buses per hour. *Average number of bus changes* is set to 0.25. Surveys show that around the bybanen (before it was build) that at 15 %of those who used bus had to change to another at some point to reach their destination (Christiansen et al., 2010). Taking into account that people who must change bus is less likely to take bus one can assume that this number should be higher than 0.15. *Average walking time* is assumed to be 8 minutes. It is assumed to be lower than tram since the bus stations are much more scattered around and have therefore bigger area coverage than the bus stops. *Average time used at bus stops* is assumed to be 1 minutes. *Normal standard deviation travel time bus* is assumed to be greater than the standard deviation in travel time for cars, because bus is less flexible when it comes to route choice, departure time and must enter and exit the highway at each bus stop. It is set arbitrary to 7 minutes. *Ticket price* is assumed to increase linearly from 22 to 28 NOK since 1999 to 2013.

Parameters in the tram sector

Normal deviation in travel time with tram is arbitrary set to 2 minutes. It is assumed to be smaller than both car and bus since tram uses track exclusively dedicated to it. Any deviation from the average travel time should be due to errors in traffic signal systems, accidents and similar uncommon incidents. *Hourly Frequency of tram* is 12 since it departs every 5 minutes from 6.30 to 9.10 in the morning (Skyss, 2013b). *Walking time to the tram station* is about 6 minutes in a survey conducted around the area where bybanen was build (Christiansen et al., 2010), however most people do not leave around this area, but are distributed in the city district. To reflect this the average travel time is set somewhat higher, to be 15 minutes. It is assumed that the *time spent at stops* with tram is equal the time bus uses which is 1 minutes. *Tram speed* is set to 45 km/h.

Parameters in the boat sector

Normal standard deviation in travel time with boat is assumed to be very low and constant. Boat may be affected by weather. It is assumed to be 2 minutes. *Travel time with boat* is 10 minutes from Askøy to Bergen. T*ravel time to boat* is assumed to be greater than travel time to tram since there only are one boat bay which everyone must travel to if they are going to use the boat. Ergo the area coverage of boat is very low. Travel time to boat is therefore set to 30 minutes. *Parking spaces at boat bay* is 450 based on counting of number of parking spaces at Kleppestø at Askøy using Google maps (Google, 2013). *Fraction using car to travel to bay* is set to 85 % which is the assumed fraction of the commuters at Askøy that live to far away from the boat bay to be willing to walk. *Hourly frequency* of boat is 2 (Bergen-

Nordhordland Rutelag, 2013).

Parameters in the bicycling and walking sector

Distance between origin and destinations for slow transport modes (bicycling and walking) is assumed to be two times longer than the distance for the other transport modes. This is because walkers and bicyclers often are forced to take detours because of roads, mountains and so on. Car roads on the other hand tend to be straighter and less “curvy”. *Bicycle speed* is assumed to be 12 km/h and w*alking speed* is assumed to be 5 km/h.

About parameters used in random utility theory

There are four utility/attractiveness parameters affecting the attractiveness of the different transportation modes: *Convenience factor, utility of travel time, utility of risk and utility of monetary costs.* Before talking about estimation of these parameters it is necessary to first discuss random utility theory to put these parameters in to a meaningful context and highlight some of the difficulties in estimating them. Convenience factor is specific to each transport mode. The other parameters are also specific to each transport mode, with exceptions of public transport which have the same parameters and the utility of monetary costs.

There are some utility variables, that is variables that determines the attractiveness of a transport mode, which is known and there are some random variables and factors that are unknown that varies from person to person. The known variables are called the systematic utility variables and when weighted on gets the systematic utility. The systematic utility is a function of all of these parameters and their respective variables (Cascetta, 2009):

$$Systematic\ utility = V =$$
$$utility\ of\ travel\ time * expected\ travel\ time + utility\ of\ risk\ and\ utility * expected\ risk +$$
$$utility\ of\ monetary\ costs * expected\ monetary\ costs + \text{convenience factor}$$

The parameters can be seen as a weighting of the different variables affecting the utility of the transport mode. If one hour travel time is more important than paying one crown in costs then the absolute value of the parameters for utility of travel time is greater than the absolute value of the parameter utility of monetary costs.

The utility parameters are referred to as specific if their respective variables are included in different form for different transport mode (for example perceived time is used as systematic utility variable in the form of t for car and as t squared for bus) or if the parameters are different for different transport modes (the utility of travel time for car is -1, but for bus it is -2) (Cascetta, 2009). If the parameters and their respective variables are similar for all transport mode then they are referred to as generic(Cascetta, 2009). Convenience factor is often called the modal preference attribute or alternative specific constant in the transport system engineering literature (Cascetta, 2009). It is a dummy variable specific for each transport mode. For example it can be -1.7 for car and -2 for bus, this means that there are some inherent properties with car (not captured by the utility variables risk, travel time an monetary costs) that makes car more attractive than bus. It can will reflect deficiencies and errors in the model (Cascetta, 2009; Moxnes, 1990), it can be seen as a measurement of the difference between the mean utility of a transport mode and the utility of transport mode captured by the model with the variables travel time, risk and monetary costs(Cascetta, 2009).

There is a fifth parameter called random residuals and it determines the steepness of substitution between the transport modes and tries to adjust for the unknown random variables that affect utility and variation between commuter to commuter in perception of utility of different transportation modes. Put in a very simplistic manner, if the spread of distribution of perceived costs (utility variables such as money, time and risk) among the commuters is wide then random residuals should be high (Cascetta, 2009). If there were no variation in the population then it would be possible to say that all commuters in the population will either use transport mode A or B. However because there are variation both at individual level in how people perceive the systemic utilities and variation in the actual cost on population level, the best thing one can do is to use a probabilistic model. In the probabilistic model a person choose A with a probability and B with a probability. At population level one gets a probability of people choosing transport mode A and a probability that people choose transport mode B. This probability then becomes the fraction of the commuters choosing a given transportation mode. Assuming that there are only two transportation modes, A and B, then **Feil! Fant ikke referansekilden.** shows the substitution between these two modes of transportation with a high and low random residuals.

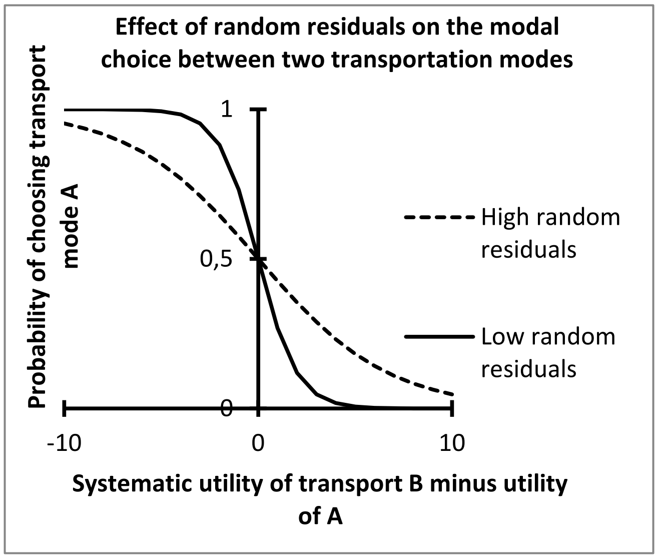


Figure 23 Effect of random residuals on probability of choosing a given transporation mode adapted from (Cascetta, 2009)

If the systematic utility of two transport modes are equal then the commuters should be indifferent whether they use A or B and the probability that the commuters choose either one should be equal, thus 0.5 since there only are two modes of transport. A small change in the systematic utility of A will cause more people to use transport mode A than transport mode B. Probability for using transport mode A becomes greater than 0.5 and the probability for using transport mote B becomes smaller than 0.5. However the change in probability is larger when the random residuals are low than if they are high.

Setting the random residuals to an extreme number means that the model mimics the behavior of a single person (Moxnes, 1990). The choice model then becomes more like a deterministic choice model where the commuters choose the transportation mode with highest utility (Cascetta, 2009). That is either A or B, and not A and B. Which is what one expect, because if there is very little variation in the costs inflicted on the population then the population as whole should act more uniformly, as one individual, than if there were a lot of variation in the costs. Random residuals should be quite large in this model because of the large zones used in the model. There are a lot of variations in walking time, time used to access the highway and so on within the population in the zones. Such “zoning errors” will lead to a higher random residuals (Cascetta, 2009, p. 95).

Two weak points using random utility theory is the uncertainty about the values of the parameters (Pfaffenbichler, 2003) and the difficulty of interpreting this kind of equation, but is very useful in choice models (Ford, 2010, p. 215). These parameters can be estimated using different survey approaches (Cascetta, 2009), but this also carries with it all sort of methodological problems. Articles and books where these parameters are estimated (Abdel-Aty & Abdelwahab, 2013; Bhat, 2013; Cascetta, 2009; Cherchi, 2008; Dai, Wu, & Lin, 2010; Enam, 2013; Groenhout, 1987; Markéta, 2013) does not necessary transfer to the case of Bergen or the model in this thesis. For example to bicycle in a city in southern Italy may be much more pleasant than bicycling in rainy Bergen, hence there should be some different in the utility parameters. The size of the cities, characteristic with geographical area and difference in economy and culture reduces the transferability of parameters from other studies.

Still, is there any pattern in the parameter values in these articles? Roughly the disutility of travel time for car is lower than for walking and bicycling, but not so different from bus. Costs of public transportation have a higher disutility than for car. This is no way conclusive or very robust in any way, but since it corresponds with intuition maybe intuition can help us to outline at least an hypothesis of the relation between this parameters. Firstly, walking and bicycling is energy consuming and by evolution human want to preserve energy. It also inflicted such inconveniences as the need for shower when the bicycler arrives at work and rain is certain an inconvenience for both walking and bicycling commuters. Car and public transportation on the other hand is unaffected. Car is maybe more comfortable than public transport, but on the other hand bus allow on to read, play with one's smart phone and so on. It is therefore reasonable to assume that the disutility of travel time should be greater when walking and bicycling than for car or public transportation. Car and public transportation should be more or less the same. Intuitively it seems reasonable that paying 30 NOK for using bus and 30 NOK for using car is the same and it is also supported by some parameters presented in Cascetta (2009). However in Markéta (2013) different parameters are used. I assume that the disutility of monetary costs should be the same for public transportation and car. Ramjerdi et al. (2010) is a stated preference study in Norway that can probably give better estimates for these parameters than the studies discussed above. The results from Ramjerdi et al. (2010) are shown in

Transportation mode	Utility variable	Utility parameter
Car	Travel time	-0.174
	Risk (travel time variability)	-0.42
Public transportation	Travel time	-0.146
	Risk (travel time variability)	-0.69
Walking	Travel time	-0.28188
Bicycling	Travel time	-0.251

Table 1 Utility parameters from time value study (Ramjerdi, Flügel, Samstad, & Killi, 2010)

The utility of travel time for people that walk and bicycle is calculated by taking cost in NOK of travel time when walking and bicycling reported in the study, dividing it by the cost in NOK of travel time with car then multiplying this ratio with the utility of travel time with car. By using the same assumption the utility of monetary costs is calculated to be -0.00193, which is derived by dividing 1 NOK by the estimated monetary cost of spending one hour in traffic and multiplying this ratio with the utility of travel time for car. Another way to think about the utility of monetary cost is that an hour of a commuters' time is worth what the commuters get paid per hour. If this is true then it I possible to find the utility per NOK in cost by dividing the utility of travel time by the commuters hourly wage. However in Statens vegvesen (2011a) they explain the increase of traffic on Askøy bridge as a result of the removal of the toll on the bridge, but if one assume this explanation is true then the commuters' in Bergen must be more sensitive to changes than this. Through model calibration (discussed later) the parameters is therefore set to -0.008 for bus and -0.005 for cars instead. The reason why the utility of monetary costs for bus is lower than car is because changes in ticket price is more salient for the bus users than changes in gasoline price for car users (of course one could argue that it should be the same for toll, however it is simplified by assigning same disutility to gasoline expenditures and tolls).

The actual parameter used in the model does however depart from those in . The utility of travel time for both public and car is set equal to 0.14. It is possible to make the argument that the disutility of time spent on public transport is less than the time spent driving a car because the commuter using public transportation can do other thing such as playing with their smartphone, reading a book, preparing for a meeting and so on. In model we however assume that this is offset by comfort factors. Time spent at the bus is perceived as more cumbersome and uncomfortable than the time spent in a private car. Also the utility of walking and bicycling seems very high compared to the value estimated in other studies. The utility of walking and bicycling is set much lower than the utility of travel time with other transport modes. In the end one must acknowledge the uncertainty when dealing with this kind of model trying to capture complex human decision-making.

Future trends: Commuters, gas price and ticket price

Detailed data about the pattern of commuting in Bergen is scarce. The data needed for this model is an origin-destination matrix where commuters are sorted into groups after work and living place. One such matrix can be found in Christiansen et al. (2010, p. 6). This shows the pattern, or network, of commuting between the city's districts, but only for year 2008. A matrix showing the change in the number of trips between Bergen's city districts from year 2000 to 2008 can be found in (Meland, 2009). However using this data Li (2013) derived an estimate for the number of commuters in the period 2000-2012. Number used for historical commuter origin-destination matrix can be found in the equations in the appendix. From 2012 and forth the model is fed with results from an urban migration developed by Li (2013). The models are tied together so that the travelling time in the transportation model affects the number of commuters and the number of commuters affects the travel time by increasing the total number of people commuting. This makes up a negative feedback loop where more commuters increase the travel times, which in turn reduces the number of commuters.

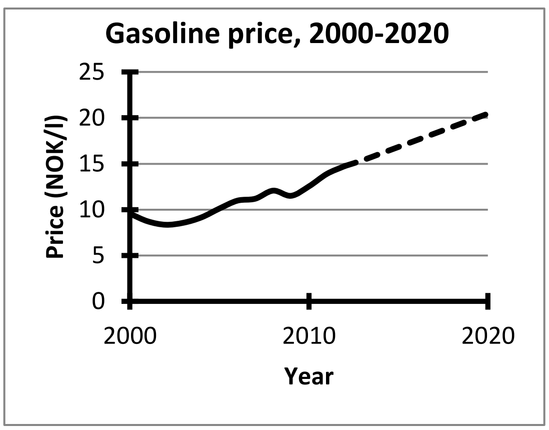


Figure 24 Gasoline price 2000-2020

Gasoline prices for 2000-2012 is calculated using current prices and consumer price index (CPI) for gasoline (95 octane) using data from sentralbyrå (2013b) and sentralbyrå (2013a). Gasoline prices is calculated by fitting a simple linear equation derived by regression analysis of the data from 2000-2012 and then using it to extrapolate a trend of what the gasoline price will be in year 2020 if the growth is linear and will continue to increase at the same pace as today . Figure 24 show that it then will hit 20.5 NOK per liter in 2020.

Ticket prices is assumed to have increased from 23 in 2000 to 27,5 in 2010 and then stay constant at 27,5.

7 Key insights from the model

Various tests were performed on the model. The tests had two purposes: to uncover flaws in the model and to analyze its behavior to gain insights to the system. The test shows that the model behaves appropriately and replicates the reference mode satisfactory. However this section is going to focus on the main insights gained from the model. In this section the key insights from the model is the focal point. For a detailed description of the tests see appendix 12.7. The three main insights from the model are that:

- Commuters are the main reason for the growth in traffic.

- Increased number of commuters causes a reduction in the proportion using bus, since a total increase in commuters increases the traffic volume. This makes car more attractive relative to bus because an increase in traffic volume has a more adverse effect on the attractiveness of using bus than it has on the attractiveness of car.

- Car acquisition is an important reason for the increasing road traffic. Car acquisition increases the car ownership. A higher car ownership results in more people being able to use car and consequently a key mechanism in causing the increase in road traffic in Bergen

The source of the increasing traffic problem is not located in the transportation sector, but rather caused by changes in the urban migration within the city. In other words the increase in traffic since year 2000 is not mainly due to changes in peoples' choices of transportation mode or in the transportation services, but to the increased number of people commuting. Nevertheless car acquisition is an important reason why the increase in commuting transforms into road traffic. Without car acquisition the road traffic would stabilize at a rate where further increases in number of commuters don't affect the traffic because it is constrained by the number of car available for commuting. Another important reason why increased commuting is transformed into road traffic is because of how the transportation system adapts to the increased number of commuters. The main mechanism is that increased road traffic has a more adverse effect on the attractiveness of bus than the attractiveness of using car. The policy implications of this are that policies aimed to decrease the negative impact of road traffic on the attractiveness of PT are important long term solutions to increased traffic. It also implies that keeping the road capacity high by building roads will decrease the road traffic, assuming that the total number of commuters is independent of travel time. However, as shown in a later chapter about BergenSim, the conclusion that road building keeps road traffic low is not true when the total number of commuters are made endogenous. In fact when commuters are made endogenous so that the total number of commuters increases if the travel time decreases; then road construction can cause the traffic volume to increase.

8 Policy Packages

Ten policy packages to reduce the peak hour traffic are tested. Each packages tested is constructed as a combination of seven policies in the list below:

- *Congestion pricing/tax.* Congestion pricing is essentially a time specific toll (OECD, 2010; Statens vegvesen, 2011a) that must be paid by those who travel with car through a toll booth at a certain time interval. This certain time interval is set to the peak hour. For example everyone travelling through a toll booth in the time interval 7.30 – 8.30 A.M. must pay a fee in addition to the normal toll. This is supposed to have two effects: reduce the number of car users and reduce the fraction of traffic occurring in rush hour. The first effect is that the monetary cost of using car for commuters increases, making car a less attractive transportation mode for the commuters. Consequently fewer people should choose car as their transportation mode. The second effect is time differentiating of when people choose to travel. Some people may have flexible work hours and therefore can opt for to travel before 7.30 or after 8.30, thus avoiding the congestion tax.

- *Expand tram network*. A policy with strong popular support is the expansion of the tram network to the north and west. An expansion will make the tram accessible for a much larger portion of Bergen's population. Since tram is unaffected by road traffic, unlike the bus, the number of car users are expected to drop as a large chunk of the previous car users will opt for using the tram.

- *Park and ride*. The idea of the park and ride policy is to reduce the travel time to the public transportation station by making it possible for people to drive to the PT station and change to the PT. This will reduce the average time people use to travel to the PT station.

- *Restrict car access.* With this policy only cars ending at certain numbers are allowed to travel on certain days. For example only cars with license plate ending on even numbers are allowed to travel through the toll booth on Mondays and Wednesdays; and only cars with license plates ending at od numbers are allowed to travel through the toll booths on Tuesdays and Thursdays (and everyone are allowed on Fridays). This effectively cut the number of people that can use car for commuting with 50 % the days the policy is in effect and consequently reduces the number of cars on the road.

- *Reduce parking spaces.* By reducing the number of parking spaces the total travelling time with car is increased. If there are fewer parking spaces the car users must use a lot of time to find a free parking space and probably travel a long way to and fro the parking space.

- *Dedicate lanes for buses.* By dedicating lanes exclusively to buses the (on road) travel time for bus becomes the same as the free flow travel time. The bus thus becomes unaffected by road traffic. This decrease the travel time with the bus a lot.

- *Carpooling program.* Carpooling programs aims to get more people to share car through changing their attitudes and facilitate car sharing. This reduces the traffic only if previous car users go from being car drivers to become car passengers. On the other hand if the effect is that people change from using PT to become car passengers then the car pooling program has no effect on the traffic.

Table 2 shows the 10 different policy packages and the 7 policies it contains. Each row represents one policy packages and each column one policy. A grey cell means that the policy package contains a policy. Policy packages zero has no grey cells, which means it contains no policies. It is therefore the "business as usual" scenario where no policy is adopted. Each policy packages from 0 to 7 contains only one of the seven policies. This policy packages represents the cases when only one policy is adopted.

Policy package 8 is a collection of the "non-intrusive" policies. That is policies that improves the current public transportation network by expanding it or otherwise improve it. It involves no tax, restriction or other kind of direct intrusion in everyday life of the people. In practice such policies cost money which is covered by taxes. This is however not a very visible connection and it is therefore improbable that these policies will generate a lot of resistance from the public. Most likely these policies (with exception of carpooling) will be perceived as improvement of public services.

Policy package 9 on the other hand includes the "intrusive" policies. They involve taxation, restricting people's freedom of movement and reducing current public goods (parking spaces), and restrict private market to provide such goods. These policies will probably generate resistance from the public or at least make the citizens of Bergen disgruntled. Such policies are also morally more questionable because they involve a certain degree for meddling with peoples' daily affairs. In this thesis the only consideration that will be done is the policies effect on the total traffic flow in peak hour. Moral considerations and cost-benefit analysis is beyond the scope of this thesis; however such consideration should be kept in mind and cost-benefit analysis is important extension of the policy evaluation.

Policies

Policy packages	Congestion pricing	Expand tram network	Park-and-ride	Restrict car access	Reduce parking spaces	Dedicate lanes for PT	Carpooling program
0							
1	■						
2		■					
3			■				
4				■			
5					■		
6						■	
7							■
8		■	■			■	■
9	■			■	■		
10	■	■	■	■	■	■	■

Table 2 Policy packages and policies

Policy package 10 is to adopt all seven policies. It includes both the intrusive and the non-intrusive policies. It is very useful to compare this policy package with policy 0 to 7. The total effect of all the policies can be evaluated by comparing policy package 10 with 0.

Congestion pricing

Congestion charges are determined dynamically in the proposed policy design. This is similar to the congestion pricing policy implemented in Singapore where:

"Rates are revised every three months in order to keep speeds between 45 and 65 km/h on the freeway links in the charged area. Rate changes respond to perceptible changes in congestion levels. " (OECD, 2010, p. 14)

I suggest a similar design for congestion charges in Bergen where congestion charge are increased if the average speed is lower than the desired speed and decreased if it is higher. The monthly increase in the congestion charge depends on gap between the desired speed and the average speed on the road link. Bigger the gap the bigger is the monthly increase in the congestion charge. Congestion charges are increased until the desired speed is reached.

Figure 25 illustrates how the congestion charge is adjusted until the desired speed on a road link is reached. Gap between desired and actual speed in percent is the desired speed minus average speed on the road link divided by the desired speed. It measures the gap between the desired speed on a road link and the actual speed on a dimensionless scale. Increased percent deviation in speed form desired speed results in an increased congestion charge. Over time increased congestion charges will lead to less cars on the road as the commuter adapts. A lower number of cars on the road cause the average speed on the road links to increase, reducing the gap between the desired speed and actual speed. If the actual speed is higher than the desired speed then the congestion charges is decreased to zero or until the gap between desired and actual speed in percent is zero. The equation for the policies and how they ties into the model is shown in appendix 12.15.

The (minimum) desired speed is set to 50 km/h in the simulation. A higher desired speed results in a more aggressive use of congestion pricing and a stronger effect of the policy on reducing the rush hour traffic.

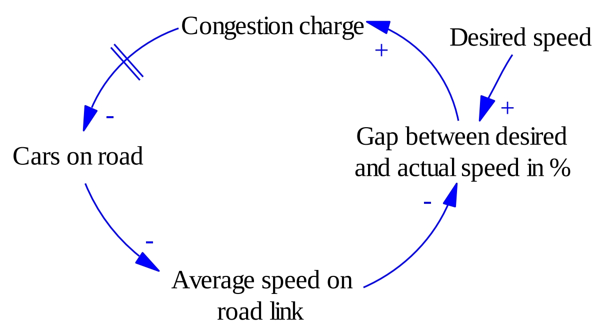


Figure 25 Congestion charge policy

Congestion pricing can have also a second effect not included in the model. The congestion charge may affect commuters' choice of departure time. Commuters can avoid the congestion charge by either travelling before or after the peak hour traffic. This is an option for commuters with flexible work hours, but also commuters with inflexible work hours may opt for travelling before or after peak hour if the cost of arriving early or late is smaller than the cost of the congestion charge. The relationship between the congestion tax and the fraction of commuters travelling in peak hour is not well known. There are game theoretical studies shows that congestion pricing changes when people departs so that peak hour traffic is reduced (Levinson, 2005). Anyhow the effect of congestion charge can be ignored in the model since choice of travel/departure time is not included and it is assumed that the traffic is evenly distributed over the three hours of the morning rush. A possible Extension of the model where this assumption is relaxed is discussed under the chapter about limitations.

Expand tram network

Expansion of the tram network is modeled by opening closed links in the tram network. Closed tram links are modeled by setting the attractiveness of using tram equal to zero by subtracting a sufficient big constant from the systemic utilities. Opening up the link is modeled by adding an equal big number to the systemic utilities, zeroing out the constant used to setting the attractiveness to zero. Doing this changes the attractiveness from being constant zero to depend on the distance between the areas, cost of the tram ticket and so on. In the simulation the tram network is assumed fully build out in 2014 to allow for comparing the effect of the expansion of the tram network to the other policies.

Park-and-ride

Park-and-ride policy is simply modeled by reducing the value of the "walking time" parameters. Park-and-ride policy involves building parking spaces close to public transportation stops. This allows people to drive to the parking space and then ride the public transportation to their destination. This is effectively the same as a reduction in the average walking time to the public transportation stop. In reality the parking space can only hold limited number of cars. This is not considered in the model and only a simple change in the parameter is used. There are however some problems related to simulating change in the public transportation coverage like this. It is likely to underestimate the effect of a park-and-ride policy[14].

Restrict car access

Restrict car access policy is modeled by multiplying the fraction of commuters with car access with 0.5. Since this policy is the same as reducing the number of people with access to a car with 50 %. In other words only people with a car with a license plate number ending on an odd number are allowed to drive on Monday, Wednesdays, Fridays and those with a number ending on an even number can use the car on Tuesdays and Thursdays. Obviously the days must be rotated between cars with even and odd numbers on a weekly basis. If not then the policy will favor people with a car ending on an odd numbers.

Reduce parking spaces

Reduction of parking spaces policy can be simulated by reducing the "Desired % parking spaces coverage" in the model. This parameter is the goal for the number of parking spaces in the region. Reducing this number would mean less construction of public parking spaces and stricter regulation of

[14] Whether it overestimates or underestimates depends on the shape of the probability function, that is the multi nominal logit model used in random utility theory. See Cascetta (2009, pp. 148-153)for discussion.

private parking space construction. The policy simulated involves a 50 % reduction of the desired percent parking space coverage. This means that the parking spaces coverage is reduced from 110 % to 55 % after the policy is implemented.

Dedicate lanes for PT

Dedicated lanes are defined between 0 and 1. If set to 1 then 100 % of the roads have one dedicated lane for public transportation. There are two variations of the dedicating lanes to PT policy: 1) dedicate lane to public transport by building a new lane (or replacing the dedicated lane) and 2) dedicating a lane to public transportation without replacing it thus reducing the number of lanes that can be used by car users.

Carpooling program

Carpooling program is simulated by dividing the number of cars used for commuting with a fraction. This fraction is the effectiveness of the carpooling program. A fraction of 0.01 means that half of the people that normally would opt for driving a car themselves instead rides as passengers. Changing the fraction from 1 to 0.99 therefore means that 1 % of the people that used to drive their own car become passengers.

Comparison of the result of the policy packages

Table 3 shows the peak hour traffic in 2020 between the six zones in the model for the 11 policy packages (plus the two versions of the dedicated lane policy). It is assumed that the policies are implemented instantaneous in year 2014 and with their intended effect which is described above. The number of commuters used is imported from the base run in BergenSim, shown in appendix 12.9.

Figure 8 also shows a very rough estimate of the daily cost inflicted by traffic congestion (in the end of the simulation which is year 2020). This is calculated by taking the number of car user for each path, multiply with the travel time minus the free flow travel time, and multiply with the hourly average wage[15] which gives a cost of 248 NOK per hour per car user. Policy papers focusing on estimating the social cost of time spent in traffic is estimated to be 280 NOK per hour for car users (Norheim, Ruud, Haug, Nesse, & Frizen, 2011), showing that 248 NOK per hour per car user is not that far from numbers used by other analysts . The idea is that the cost of congestion is the time spent in traffic by the commuter that could have been avoided by reducing the traffic. The value of this time is assumed to be

[15] Daily cost of congestion = car users*average wage*(travel time –free flow travel time)

the average wage in Bergen, because the time spent in traffic could be used at working instead being wasted sitting in traffic. This is of course a very rough estimate, in reality there are many other costs such as accident, pollution and noise costs. There may also be costs related to increased use of public transportation. To consider all these costs is beyond the scope of this thesis. However this will at least provide a rough estimate of the daily cost of the peak hour congestion and daily benefit of the policies aimed at changing the peak hour traffic.

Policy package	Total traffic flow peak hour (cars/hr)
Business as usual	20410
Congestion pricing*	19670
Expand tram network	11980
Park and ride[16]	19300
Restrict car access	10820
Reduce parking spaces	20320
Dedicate lanes for PT without replacements	17610
Dedicate lanes for PT with replacements	18470
Carpooling program	20170
Non-intrusive policies	5370
Intrusive policies	10210
All policies	2945

Table 3 Peak hour traffic with policy packages instantaneous implemented, year 2020 (* it is assumed that there are no transaction cost and that a crown in the communal/state coffers is worth equal a crown in a citizen's wallet).

The table shows that the policy that reduces the car traffic most is the restrict car access policy, which reduces the peak hour traffic to 10 820 cars per hour. The policy with the smallest effect is the reduction of parking space coverage. Reduction in parking spaces only increases the travel time with car in the model from about 5 minutes to 10. There are many parking spaces on the street, private parking spaces or places where people can park illegally, so the effect of reducing parking spaces is linear on the walking time and time used searching for parking space. Whether this structure really captures the reality is hard to say because of the lack of data. If parking space is modeled as a constraint the effect of reducing parking spaces would be bigger. If parking space is constraining then only people with a reserved parking space can use car. In the model it is assumed that people are creative (meaning that they eventually find somewhere to park, it only takes more time) and that reducing parking space therefore have much

[16] While it is not very effective at aggregated level it is very effective in Bergen South where it decreases the peak hour traffic with 79 %.

smaller effect. However it is not obvious which the right way to model this behavior is. If parking space is really a prerequisite for using car then the model should be changed.

Congestion pricing reduces the peak hour traffic to 19 670 cars per hour. This is when the desired speed is set at 50 km/h which is 10 km/h below the assumed free flow speed. Carpooling programs reduces the traffic flow to only 20 170 cars per hour, assuming that it has an impact/efficiency of 1%. Dedicating lanes to PT without replacing them reduces the traffic flow to 17 610.

Dedicating lanes to PT becomes less efficient when they are replaced with new lanes. This is because dedicating lanes to PT causes a big decrease in travel time and risk of using bus, but also decreasing the time and risk of car. If the dedicated lanes are replaced with new ones then only the favorable effect of dedicating PT lanes on travel time with bus remains. The unfavorable effect on travel time and risk with car disappear. This is why dedicating PT lanes without replacing the lanes causes a bigger decrease in road traffic.

The table shows that the policies that directly affect the number of cars that are entering the road are the most efficient. Restricting car access reduces traffic directly by respectively forcing people to use other transportation modes than car and reducing cars entering the road by making previous car drivers ride as passengers. The reason why restricting car access with 50 % doesn't have the effect of reducing the traffic flow with 50 % in the long run is because people acquirer more cars (the policy is that car ending in even and odd numbers in the register plate can only drive at certain days assigned to even and odd numbered cars. However by owning two cars, one with register plate number ending in an even number and one in odd, one is unaffected by the policy). Figure 26 show a simulation without any policies (continuous line) and a simulation with the restricted car access policy (discontinuous line), using commuter number from BergenSim.

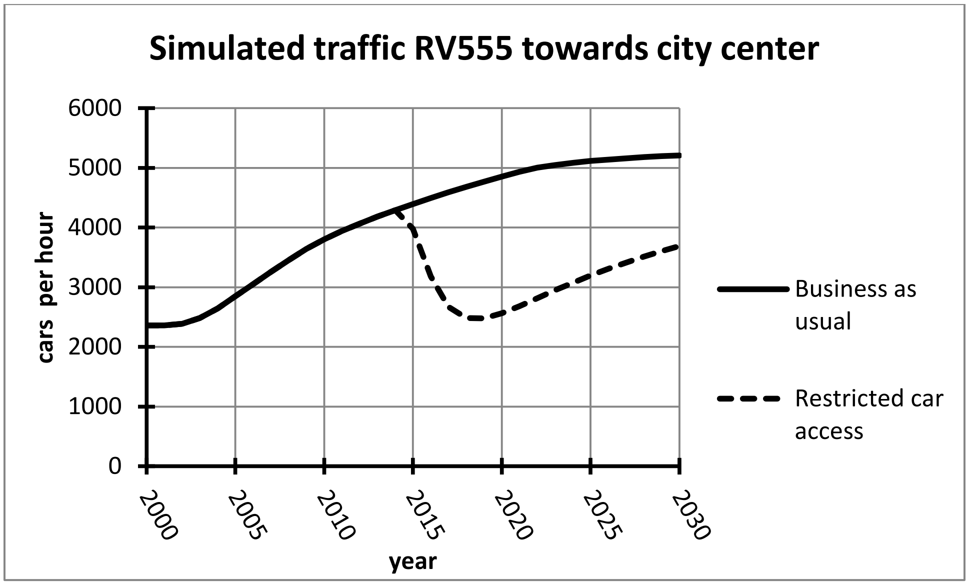


Figure 26 Effect of restricted car access simulated traffic RV555 towards city center

The simulation shows that the restricted car access causes a sudden drop in the traffic flow on the road RV555 in 2014. However over time the traffic flow increases towards its former level. In the simulation the number of commuters is kept constant after 2020. Therefore the increase after 2020 is not because of more commuters, but because the commuters acquires more cars to circumvent the restricted car access policy. Nevertheless the traffic flow is much lower with the restricted car access policy than without it.

Park-and-ride policy seems to be not very effective. Park-and-ride policy aims to reduces the travel time to the public transport stop., but the time the commuter uses to walk to the stop is only a small part of the total time used when travelling with public transport and the policy is therefore not very effective. However walking time to public transport may be underestimated in the model since the estimate is a rough guess based on available datasets and studying the maps. Furthermore the simulation shows that the park-and-ride policy is extremely effective in reducing the peak hour traffic on the road connecting Bergen South and centrum. This is because of the tram network connecting Bergen centrum and south, which is in accordance with other policy studies that concludes that the park-and-ride policy only is effective combined with other policies like improved public transportation (Bergensprogrammet, 2008, p. 65).

Implementing all policies (replacement of dedicated lanes not included) decreases the 2 945 cars per hour. However this scenario would be very hard to achieve. As already mentioned, it assumes the policies are instantaneously implemented and 100 % successful in achieving their desired effect in 2014. It also means making Bergen a city with a highly reduced number of parking spaces, a build fully build tram network connecting every city district, dedicated lanes for public transportation on every expressway (for some road links this means having lanes only dedicated for PT and no possibility of using car in rush hour), a congestion pricing system in place, a carpool system that get 50 % of current drivers to carpool and restrictions on car users so that only allow 50 % of the cars be used every day; which is difficult from both a construction, political and financial perspective.

As indicated in the last paragraph, the total cost of policies and their total benefits (for example expanding the tram network has more benefits than just reducing the peak hour traffic) is beyond the scope of this thesis, however by assuming that the benefit of reduced peak hour traffic only occurs on workdays, that there are 230 workdays per year and using the assumptions above; the benefit of reduced peak hour traffic for a six year period (2014-2020) can be calculated. Table 4 shows the cumulative benefit of the policies over a six years period discounted at a yearly rate of 7%. If the implementation cost of a policy is equal or less than the cumulative benefit in the table then the reduction in the morning peak hour traffic caused by policy is enough to justify adoption of the policy. Otherwise one cannot say with certainty whether the benefits of policy outweighs the costs without making a cost-benefit analysis that includes a wider specter of costs and benefits.

Policy	Present partial benefit (million NOK)
Carpooling	71
Expansion of tram network	930
Congestion pricing	193
Parking space reduction	10
Park and ride policy	23
Restricted car access	1240
Dedicated PT lanes	-2333
Dedicated PT lanes with replacement	483
Non-intrusive	1061
Intrusive	971
All	1285

Table 4 Cumulative partial benefit of three policies

The three most beneficial policies is restricted car access, expansion of the tram network and dedicating PT lanes with replacements. Even though restricted car access is the most beneficial policy in the analysis it is very probable that there are big costs of the policy not captured by the model. Some people lives far away from PT and don't have many other options than car. If these people are affected equally as people living close to PT then this policy will inflicts some unintended costs. Congestion pricing may therefore be better since it gives people the option to pay for using the car. Hence if the peoples' benefit of using a car is greater than the congestion charge then they will pay the charge. This is more efficient than just indiscriminately forbid people using car which is implied by the restricted car access policy. When only considering the partial benefit of price congestion then the present value of the policy is 94 million NOK over the six year period. This assumes no cost in collecting the congestion charge.

The estimated cost of the expansion of the tram network to north and to the west is 6 500 million NOK (Statens vegvesen, 2011a, p. 83). Over 6 years the social benefit (calculate above) by reducing the travel time in the morning peak hour will alone cover about 14 % of the investment cost. Assuming that the traffic is distributed uniformly over the 3 morning hours and that the evening rush is symmetric with the morning rush, then the total partial cumulative benefit of the expansion for a six year period equals 5580 million NOK, thus covering about 86% of the initial investment. There are also many other benefits of tram besides just reducing the peak hour traffic. School children may use the tram, people may use it to and from the city for recreational purposes and there are environmental benefits of having a tram network and the benefits of the tram network continue beyond the six year time horizon of this analysis. This analysis shows that these other benefits, or the continued benefit of reduced peak hour traffic beyond the six years, must amount to 14% of the investment cost of building out the tram network if the policy is "going to pay itself".

Carpooling has a present partial benefit of 71 million NOK over six years when the effectiveness of the policy is set to 1 % (meaning that 1 % of previous drivers become passengers). There is therefore a lot to be gained from getting people to carpool instead of each driving their separate cars. The problem is how to make people carpool and what is the cost of a car pooling policy.

Dedicate lanes inflicts a cost of 2 333 million NOK on the car users over six years, only the morning peak hour considered. This is because in many cases dedicating a lane to PT involves removing the only expressway available for the car users. This inflicts large costs. The benefit of such a policy for the bus users is not included in this analysis, but it must be larger than 2 333 million NOK to justify the policy. Or at least it should not be implemented where there are few lanes or low capacity.

The partial benefit of introducing the intrusive policies are 971 million NOK and the partial benefit of introducing non-intrusive policies are 1061 million NOK. This means that the non-intrusive policies obtain a better result than the intrusive policies. Introducing all the policies has no additional benefits than introducing only the non-intrusive policies. Ergo there are diminishing marginal returns of the policies. The diminishing returns arise from the fact that there always some people that prefer car for unknown reasons and to sway this people to becoming bus users are difficult.

Strong policy recommendations cannot be given without a more detailed model of the implementation of the different structures (especially regarding how to best model the effect of parking space crowding) and their costs and benefits. There are also uncertainty in the explanatory model that need to be clarified through further research (for example data to determine the best way to model the effect of parking space crowding on transportation mode choice and parameter values). An uncertainty analysis and a detailed discussion of uncertainties are included in appendix 12.8.

9 Limitations

9.1 Assumptions

Every model must be based on some assumptions. The usefulness of the insights of the model provides us about the reality is limited by how sound these assumptions are. The less sound the assumptions are the more likely are it that the model results depart from the reality. However assumptions are necessary for limited the model to a manageable size. As follows are the main assumptions made in the model, the consequences and a discussion of how to slack these assumptions:

1. Close to homogenous commuters. If there are very big variation in the commuters' attributes problems with aggregation arises which leads to a bias towards overestimation or underestimation depending on the shape of the probability function for how people make choices (Cascetta, 2009). A way to slacken this assumption is to divide the commuters into more classes of similar agents (Cascetta, 2009). For example in the model people are divided in after which zone they live in. One could divide this groups further after how far people lives from the public transportation stations, from zonal centroids, socioeconomic groups, age groups and so on. This would give more precise simulation of the effect of increasing the public transportation coverage. Simulating change in coverage by just change "walking time" is likely to underestimate the effect of changed coverage. Of course this results in increasingly complex model which is harder to understand and would require more data and more computational power.

2. No trip-chaining. It is assumed that people only travel directly to and from jobs. Meaning that people travel from home to job and from job to home. Commuting trips that combines commuting trips with trips with other purposes is not modeled. Meaning that people don't drop by the kindergarten, school, food store or other places when they commute. The main problem with including trip chaining is the time perspective of the model. Different type of trips occurs on different times. A way to solve this is to introduce new network paths that captures the travel pattern of trip-chaining and make a model of hourly travel behavior. Alternatively to keep a long term perspective is to make a 2 dimensional model. That is a model like the one in this thesis combined with a model of the hourly traffic. Such model will use two timestep to "gearshift"

between the short term and the long term model (or a shift between a time perspective and a spatial perspective). First the hours of a "typical" day is simulated with the initial number of car users, road quality and so on. This allows for inclusion of all kind of activities that occurs over the duration of 24 hours, after for example 24 time steps (representing hours) the average travel times from the hourly traffic is fed into the more aggregated model and the simulation is advanced one month. The 24 hours simulation is then repeated and the process are repeated.

3. Choice of travel time is exogenous. When the commuters choose to travel is exogenously determined in the model. An improvement would be to make departure time endogenous in the model. However this would require either use of matrices with more than 3 dimension which is not supported by iThink 9.1.4 or by making a 2 dimensional model with two timesteps as discussed above. This is not been done because that would cause problems when integrating the model with other land use and demographical models.

4. No advanced multi-modal trips. It is assumed that people don't use advanced combinations of transportation modes. That is people don't changes transportation mode in the simulation with expectation from walking to and from car and public transportation. The model allow for people to change transportation mode within a zone, so people can drive to the tram and then change to tram, but they cannot change transport mode as they travel across zones. Consequently people will not have the option of using the tram form Bergen south to the Bergen center and then change to bus in the city center. This assumption can be loosen by including more paths. The problem is that the number of links in the network model will be more than 4 times bigger, because each link in the network must be defined for each transportation mode so that multi-mode trips can be modeled as combination of these different links.

5. Commuters must commute in the model. Meaning that commuters cannot choose to stay home and miss work. This assumption should be unproblematic for Bergen, because travel time in general is low. Another way to frame this is as follows: the travel time cost is always assumed to be lower than the cost of missing work. This means that the model does not cover cases where travel time reaches so extreme heights that people choose to skip work.

6. Simplistic road network. Bottlenecks and influence of more advanced road structure on travel time is not included, which is not so much a problem since we are mostly interested in the average travel time. This assumption will however be slacken if one implemented a 2 dimensional model as described above. One could also make an agent-based model of the hourly traffic; however such model is not useful to evaluate long term effect of different policies on the traffic congestion.

7. *No constraints on PT, comfort factors or downgrading of PT (infinity capacity assumption)*. In the simulation the public transportation service is assumed to stay be sufficient and have a capacity always above the demand. Experience from America after 1940 do however suggest that there exists mechanisms where a decrease in number of PT users causes an increase in fares and cuts in quality which leads to even fewer PT users, resulting in a vicious circle where fewer and fewer uses PT (J. D. Sterman, 2000). Available literature and the datasets do not indicate that this is the case for Bergen the last ten year and is therefore not included in the model. There is also possibly feedback related to comfort (Cascetta, 2009). When the bus becomes crowded the passengers' comfort level drops. There is though little information about how important this is in peoples' choice of transportation mode and the literature does not put a lot weight on comfort factors. Feedback loops related to comfort for the passengers is therefore not included in the model.

8. *Constant utility parameter*. Utility parameters don't change. The populations' valuation of time, monetary costs and risk could change over time. However in the model it is assumed that they stay constant.

9.2 Boundaries Adequacy Test

Some important model assumptions have been discussed above and some of these assumptions stipulate some borders around the model. It is important to reflect around the boundary of the model and assess whether it is adequate for the purpose of the model and to explain the model structure (Cascetta, 2009; J. D. Sterman, 2000). The purpose of the model was to answer the question "How much of the increase in the peak hour traffic from 2000-2010 is caused by commuters' choice of transportation mode and changes in the supply of transportation services?" and what can be done with the transportation services to reduce the growth in traffic.

Table 5 is three lists of selected variables from the model. The table has three columns: 1) the variables that are excluded, 2) the variables that are exogenous, and 3) variables that are endogenous in the model. The table is in no way exhaustive. Only variables that are deemed useful in assessing the boundary adequacy are included. The variables are included in discussion which is meant to answer whether the model variables important to explain the problematic behavior are endogenous, whether the model behavior will change significantly if the boundary of the model is expanded and whether policy recommendations changes when the model boundary is changed (afterJ. D. Sterman, 2000, p. 859).

Excluded	Exogenous	Endogenous
Non-commuting trips	Commuters	Car, bus, boat and tram users, an bicyclists and walkers
Trip chaining	Ticket price on public transportation	Road quality
Discomfort	Gasoline price	Car Ownership
Crowding of public transportation	Hourly frequency of bus	Travel time
Tram network construction		

Table 5 Model boundaries

Non-commuting (not work-home or home-work trips) trips were excluded to ensure that the model was kept small. The purpose of the model is to evaluate a policy that reduces the peak hour traffic. Most of the trips that occurs in the peak hour is people commuting to and from, shopping trips and other trips than work related tends to occur outside the peak hours (Christiansen et al., 2010).

Trip-chaining is when people combines different trips together into one chain, like home-kindergarten-work or work-shopping-home (Cascetta, 2009). This is not modeled, because it is most likely that these additional trips in the chain occur inside the zones and not between them. This kind of behavior will therefore not affect the traffic on the highways significantly, but more the traffic on the smaller roads within the zones which is beyond the scope of this model.

Discomfort and crowding occurs when the number of users of a transportation mode on a line is greater than the capacity of the transportation mode at that particular line (Cascetta, 2009, p. 87). Discomfort is the unpleasant feeling the commuters get when the bus, tram or subway is overcrowded. If the discomfort increases then the attractiveness of the transportation mode decreases. Discomfort must be measured in different units than risk, travel time and monetary costs. Crowding on the other hand just adds to the travel time. Crowding refers to when the bus or tram is so full that the boarding passengers have to wait for the next bus or tram. Not including discomfort or crowding is the same as assuming that the public transportation has unlimited capacity. This assumption becomes problematic when the demand is close to the capacity.

Tram network construction is not included in the model. It is just assumed that the tram network suddenly appears. Adaption rate and effectiveness of carpooling program is also not included. These variables deal with the implementation and the effectiveness of the policies. It is necessary to expand the model to include such variables that can uncover implementation problems and the policies real effectiveness if one is going to provide strong policy recommendations.

One of the model specifications was that the model can be integrated with an urban migration and land use model. To fulfill this specification number of commuters had to be made exogenous. An important positive feedback that generates more traffic is lost by making commuters exogenous. This positive feedback loop is that road expansion (that is improvement of the roads connecting the zones in the model), and other improvements of the transportation system, leads to lower commuting time between the zones which makes it more attractive to commute. When it is more attractive to commute more people choose a job where they need to commute and consequently the traffic increases and more roads must be building. Leaving out this loop has implications on the policy recommendations since the creation of new commuters caused by road expansion is ignored. Luckily the model is designed to be easily integrated with other models by providing and accepting input without any overlapping structures to other sectors than transportation. This loop is explored in the chapter about BergenSim.

Ticket price on public transportation is modeled as an exogenous variable since ticket price can be controlled by the politicians of Bergen. It could be modeled endogenous and has been in some system dynamics models (see J. D. Sterman, 2000), but in this case it seems little to be gained by explaining why the ticket price changes since the bus company is controlled by the local government. Thereby the ticket price is also controlled by the government. Changing the ticket price without backing up with other financing of the public transportation will have adverse effects for the public transportation system. Such effects cannot be captured in the model when the ticket price and the bus company are made exogenous.

Gasoline price is made exogenous since the contribution to the world demand for gasoline by the peak hour traffic in Bergen is so small that its effect on the gasoline price that it can be treated as exogenous.

Hourly frequency of bus (and the other transportation modes) is treated as an exogenous variable. This means that the model does not capture changes in the hourly frequency that may occur to increase the capacity on the lines.

The focal point of the model is the number of car, bus, boat and tram users, and bicyclists and walkers which is all model as endogenous variables, this constitute the commuters' transportation choice or the demand side of the transportation system. Road quality and car ownership is also made endogenous. Road quality can be interpreted as the supply of transportation services in the model. It seems crucial to make these endogenous since much of the literature put a lot of weight on these variables. By making these variables endogenous the model can explain the change in traffic that occurs as a result of changes in road quality, road capacity and how this affects the usage of the other transportation modes, which is the main purpose of this thesis.

9.3 Lack of data

A model is a theory, a hypothesis reflecting our current understanding of how something is build up and function. However data is needed to test and uncover flaws so that the model can be improved and made more useful. By making a model one also learns a lot about what data is important both in managing the system and to improve our understanding of it (i.e. our model). So what is the crucial data when managing the peak hour congestion in Bergen? To some extent this are given by the sensitivity analysis and uncertainty analysis in chapter 12.7 and, but this is only within the context of the model and does not reflect the need for more information to improve the structure of the model. However working with building the model has revealed some of these uncertainties. Based on the sensitivity analysis, uncertainty analysis and overall work with the model I have decided that the following four datasets should be prioritized:

- *Disaggregated detailed road traffic data*. It is important to know the traffic on the different roads sorted after the direction of the traffic. This means that data for the traffic flow on E39 should consist of two vectors, the traffic towards centrum and the traffic from centrum. The data should also show the hourly traffic over decades. There are two reasons why this is important: 1) it is a big difference between having 2000 cars on one lanes going towards centrum and having 2000 cars distributed on two lanes going opposite direction (the first case would lead to more congestion than the second), 2) traffic at different hours of the day has usually different purpose, what reduces commuting may have little or no effect on shopping trips, and 3) a clear picture of the problem one are trying solve is important. By the nature of the collection of this data, using cables in the road that measures when the car passes (Kutz, 2004), this data should be easily collected or even be available. However in the published dataset this is not the case (Statens vegvesen, 2011b). It is possible to derive some estimates from this dataset, which have been done in this thesis, but these estimates are bound to be rough and better traffic data is really needed for a more rigorous model tests. Road quality is also important. Dataset about the current road quality/capacity of the roads is needed. Luckily this can be derived using detailed traffic data (Statens vegvesen, 1990).

- *Public transportation users*. Detailed dataset for the number of public transportation users on the different bus routes would help immensely. I have talked to people at the bus company (Skyss). They said that these data do exist, but nobody has thought them important enough to make an available datasets from the databases, or prioritize to retrieve the data from their database, due to a big workload. Such data is very important to evaluate how the transportation system works. It makes it possible to determine where and why the public transportation usage is and such datasets should therefore be made available for the public (or at least the decision-makers).

- *Experimental data about how reduction in parking spaces affects people transportation mode choice.* Is it just causing an increase in travel time for the car users or is parking space a necessary prerequisite when commuters choose to use car?

- *Detailed data about commuters.* Where do they live and where do they work in form of a origin-destination matrix. This determines after all the total demand and as the sensitivity analysis shows it is a crucial variable to explain the change in the traffic over the last ten years.

Ideally there is no end to the information one could wish for, but collecting data is usually an expensive and tedious endeavor. Of this reason I have chosen four datasets above which I consider the most important ones. Some of these datasets may already exist, but is not available to my knowledge. If this is the case then making them available would be very beneficial for city planners.

10 BergenSim

BergenSim is the name of an integrated Land Use, Transportation and Urban Migration Model. It combines three models covering the subjects of transportation (the model developed in this paper), land use (Schulze, 2013) and urban migration(Li, 2013). Right from the get go one of the specification of the transportation model developed in this paper was to make it compatible with an urban migration and a land use model. This chapter will revisit the question about the road expansion impacts on the peak hour traffic by using BergenSim. The difference from the tests done in the isolated transportation model is that in BergenSim the number of commuters is affected by the travel times and the travel time is affected by the number of commuters, thus making the number of commuters endogenous.

Figure 27 shows the traffic flow on Harafjellstunnelen for two simulation runs in BergenSim. The continuous line is the traffic flow in the simulation run with road expansion (that is expansion of the highway between the zones) and the discontinuous line is the simulation run without road expansion.

In both cases the traffic flow increases, but the increase is steeper when road expansion is included. By 2020 the traffic flow at Harafjellstunnelen is 1200 car per hour higher in the case where road expansion is included in the model. Removing car expansion has more effect on the peak hour traffic in the BergenSim model than in the isolated transportation model. This is because removing road expansion increases the total commuting time. In the isolated model this only result in more commuters choosing car over bus, but in BergenSim it also cause the number of commuters to become lower than what it otherwise would have been. Some people simple stop commuting by either moving or changing to a job closer to their home. This explanation was confirmed by studying the simulated number of commuters from Askøy to centrum (commuters that uses

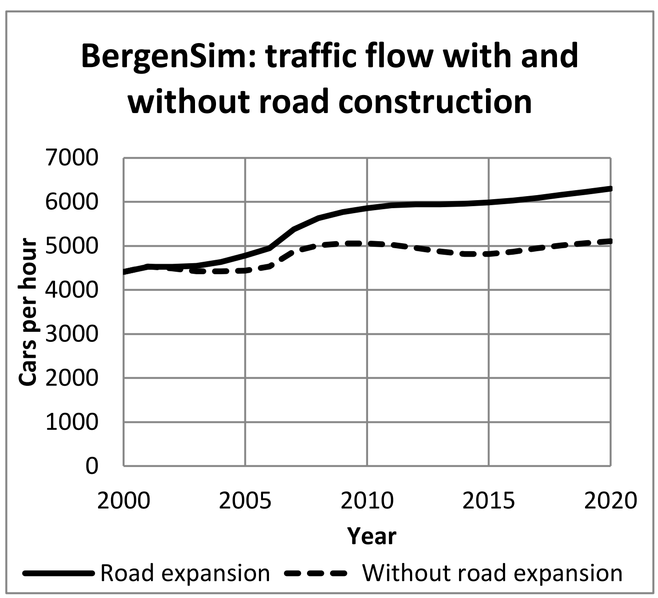


Figure 27 BergenSim: traffic flow Harafjellstunnelen

Harafjellstunnelen) which is smaller in the simulation run without road expansion.

Simulation runs in BergenSim also shows that by building out the tram network in only one zone may cause a big influx of people to that zone (south Bergen) and an increase in commuters, if the tram significantly reduces the average commuting time. The consequence is that the number of commuters in South Bergen increases. The simulation shows that the traffic still is reduced after the build out, but this is under the assumption that the tram network must be able to handle the increasingly larger amount of commuters every day.

BergenSim shows the importance of combining urban migration and transportation models. By not combining urban migration and transportation one loose important feedback between these two sectors that have policy implications. One such implication is that one can expect an increase in the increase in commuters from/to Bergen South and that the tram network must have a capacity to handle the increase in commuter. This can however be adverted by building out a tram network to all parts of Bergen.   As demonstrated above the road expansions effect on the total number of car users becomes much stronger when travel time affects the total number of commuters and not only the distribution of commuters over the different transportation modes.

In conclusion there are important effects and feedback between transportation and the urban migration sector. The feedback between the sectors going through the number of commuters and travel time has considerable policy implications that should be kept in mind.

11 Conclusions

Risk, monetary cost and travel time have been postulated as the essential characteristics explaining the commuters' choice of transportation mode. These three characteristics are used by the commuters to decide which transportation mode to use. The more commuters there are the more cars enter the roads and the more of the road network capacity is utilized. This causes an increase in travel time and risk for both bus and car users. If the increase in travel time and risk is greater for bus than car then the proportion using bus will decrease and the proportion using car increase, as the total number of commuters increases. Hence more and more of the increase in the total number of commuters will be transformed into car users rather than bus users. There are however considerable delays involved. People use time to change from one transportation mode to another and it takes time for the commuters to acquire a car. The more people that own a car the more people can use car for commuting. Car ownership is therefore a key factor in constraining the number of car users in the short run, but a weak one in the long runs as the constraint loosens as car ownership increases.

As the number of car users increases, the market and public road authority construct new parking spaces, build new lanes and other road improvements. The analysis shows that this however cannot alone explain the growth in the traffic. In isolation (i.e. only looking at the transportation system) road improvements and expansion makes bus a more attractive option for commuter, and can in fact reduce the car traffic because it makes bus a much more practical and less risky choice. But this conclusion is not necessary true if the number of commuters depends on the travel time. By combining a transportation model, urban migration and land use model the simulation runs shows that building roads help keeping travel times down, thus facilitating more commuting between the city districts. Road expansion therefore makes it more attractive for people to commute between the city districts and increases the total traffic. This was investigated by combining the transportation model developed in this thesis with an urban migration model and land use model. Simulation runs on these three combined models (BergenSim) show that another effect of expansion of the tram network is an increase of population and commuting in the area the tram network is expanded into.

Restricted car access, expanded tram network, dedicated PT lanes without replacements, dedicatde lanes with replacements, park-and-ride, congestion pricing, carpooling program and reduce parking spaces are all policies that reduce the peak hour traffic. Policy analysis shows that their relative effectiveness is in the specified order where restrict car access is the most effective policy and reduce parking spaces the least effective.   The present benefit of the reduction in commuting time for car users caused by the policies was calculated in the policy analysis. The policies ranked in the following order from the most beneficial to the least: restrict car access, expansion of tram network, dedicate PT lanes with replacement, congestion pricing, carpooling program, park-and-ride, parking reduction and dedicated PT lanes without replacements. However many costs of the policies were not included. This means that the ranking of policies is not necessarily in the same order as the policies total present value. For example restricting car access may inflict immense costs on the commuters not captured in the analysis that can outweigh the benefits of the policy. Similarly there are many benefits not captured in the analysis. But the analysis does tell part of the story which is the benefit of the policies in regard to reduced peak hour and what the analysis tells is that the six years benefit of a built out tram network in year 2014 would cover 86% of the initial investment needed to build out the tram network to North and South Bergen.

It would however not be wise to give strong policy recommendations without a more detailed cost-benefit analysis and an implementation model. The value of the different policies with regard to reduced peak hour traffic has been shown. This shows part of the policies' value, but the policies total value remains uncertain without a more exhaustive cost-benefit analysis. There are also uncertainties in the model both in regards to structure and parameter values that cast a shadow of uncertainty over the policy conclusion. Further research is especially needed to determine the best way to model the effect of parking space crowding, future importance of crowding of PT, whether the public transportation services are significantly affected by the commuters' choices on transportation mode and how. Further work should also look into the appropriateness of the aggregation level of the model.

12 Appendix

12.1 Description of the equation used to model the commuters' choice of transportation mode

The simplest random utility model is the multinomial logit model in Equation 1 (Cascetta, 2009, p. 97; Kutz, 2004 l. 6175; Pfaffenbichler, 2003, p. 14). In the case of choice of transportation mode the probability of choosing car can be expressed as:

$$p_c = \frac{e^{(V_c/\theta)}}{\sum_{i=1}^{m} e^{(V_i/\theta)}}$$

Equation 1 A multinominal logit model of transportation mode choice

p_c…… is the probability for choosing car.

V_i….. is the (dis)utility of transport mode i.

m...... is the number of transport mode in the choice set of a user.

θ…… is a scaling parameter called random residuals.

V_i is usually a linear equation with variables for the different characteristics of a given transportation mode (travel time, monetary costs and so on) and with parameters for each variables giving the utility per unit of each variable (utility per travel time, utility per NOK and so on). The multinomial model is possible to estimate with survey data where participants must rank different mode of transportation based on some given scenarios (Cascetta, 2009, p. 539; Pfaffenbichler, 2003). In the scenarios the transportation modes are given different values in regard to relevant model variables such as time, monetary costs and so on. The estimation techniques are described in Cascetta (2009) and Croissant (2012) explains how to do the estimations using the package "mlogit" for the statistical programming environment R. These parameter values are very uncertain since they relates to peoples subjective valuation of time, monetary costs and so on. There exist however a useful study from Norway that estimates these parameters (see Ramjerdi et al., 2010).

12.2 Description of travel time on road link as function of traffic volume and road capacity

The following equation is often used to calculate travel time as a function of traffic flow (Kutz, 2004 l.6270):

$$t = t_0 \left(1 + a \left(\frac{V}{C}\right)^b\right)$$

Equation 2 Travel time as a function of traffic flow

t….. is the travel time over one road segment/link

t_0…. is the free flow travel time.

V….. is the assigned volume, the number of cars entering the road segment per hour.

C … is the capacity on a given road segment/link.

a, b…. are parameters to be estimated

(USA) State official highway manuals has set the convention of assuming that $a = 0.15$ and $b = 4$ (Kutz, 2004 l. 6200)

12.3 Note on risk

Risk has been mentioned as one of the important factors in peoples' choice of transportation mode, but what is exactly meant by risk? Simply put, two transportation modes may have the same average travel time, but with different variation in travel from trip to trip. Let's assume that bus have greater risk than car, but at average uses the same time to travel between two points. If someone measured the travel time for each and every trip over the course of a year on would find that there would be some variation in the data around an average. If one then divided all the commuting trips over a year into infinitesimal categories after travel time and then calculated the percent of the trips that where in each category one is very likely to get a graph (a histogram) that looks like Figure 28.

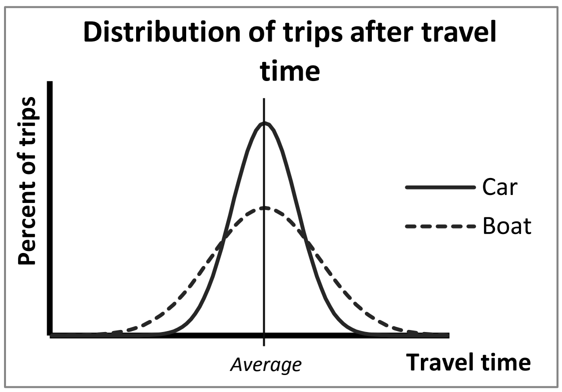


Figure 28 Stylized graph showing difference in risk for two transportation modes

At average the travel time for car and boat is the same, hence the travel time expected by commuters for these two transportation mode is the same. However, in this fictive dataset, when using boat there is a greater probability to either arrive to early or too late. Even though the expected travel time is the same. Boat involves therefore more risk than car. A commuter may say that he prefer car over boat because "the boat is less reliable than car". The level of risk for a transport mode can be measured by recording data showing the time used at each trip over the course of a year and then calculate the variance or standard deviation.

It seems reasonable to assume that there always are some risks involved in commuting. There are always something that can disturb the transportation process. These risks can be caused by variations in weather, the sea, temperature, pedestrians, and commuters' behavior and other random factors. Normal standard deviation is the risk the commuters are exposed to when there are few or none other cars on the road. If the number of cars on the road increases then the consequences of variations in weather, temperature and the individual car drivers' behavior increases. Partly because more traffic in itself increases risk, but also because it enhances the magnitude of existing risk. A single car driving on an icy road is affected by the risk weather variations and therefore arrives 20 minutes later than expected. A car has a higher probability to be involved in a chain collision when there are many cars on the road than if there are few.

12.4 Equation for the fraction of commuters that want a car

I have chosen to make a very simple equation for the fraction of commuters that want to own a car:

$$F = (\delta - k) * \alpha^{\beta} + k$$

Equation 3 Fraction of commuters that want a car

F ... is the fraction of commuters that want to own a car.

α... is the proportion that want to use a car for commuting.

δ... is the saturation level for car ownership.

k... is the constant car ownership.

β... is a scaling coefficient.

This fraction is defined in the interval 0 to 1, assuming that there are never more cars than there are commuters. This means that α, δ and k are only defined in the interval 0 to 1. If one believed that the only reason that a person would require a car was the purpose of using that car for commuting then $k = 0$. A higher k means that commuting are less important in the decision of acquire a car. If k is set equal to δ then the proportion that want to use car for commuting have no effect on car acquisition, meaning that the attractiveness of using a car for commuting has nothing to do with the decision of buying a car. k can be interpreted as the importance of the other reasons for people want to own a car. δ is the saturation level. Saturation level is likely to depend on the purchasing power of the commuters and a series of other unknown factors. The effect of an increase in the proportion that wants to use a for commuting is $(\delta - k)$. This goes back to what have already been said that the stronger the other reasons (than commuting) for owning a car are the weaker is the effect of an increase of people that want to use car for commuting on the fraction that want to own a car. β decide the shape of the function. It is assumed the fraction of commuters that want to have car increases as more people want to use car, however these effect becomes smaller as more and more people owns a car and the car ownership reach a saturation level. Therefore β should be smaller than. It is arbitrary set to 0.2.

12.5 Some notes on the equations

The previous chapter aims to give an explanation for the increasing traffic in Bergen and therefore used number of cars or travel time as starting point. This chapter however is meant to describe the model on a technical level and therefore starts not with the conceptual interesting variable, but with the state-variables of the system. However the section does not give and exhaustive representation of the model (this will be given in the appendix), only some of the basic equations are shown and discussed. This section also clarify some of the equations that are difficult to understand in iThink's representation of the equations (the one shown in the appendix), but which is quite easy to represent with normal linear algebra.

One of the model's features is that it is geographical disaggregated so that different important zones of Bergen is represented. In the case of the transport system this means that one introduces a transportation network structure to the model. This has some consequences for the structure, but as the following shows the causal structure remains quite similar.

Whether people choose car is governed by three mental states: expected travel time with car, $\boldsymbol{E}(\boldsymbol{T}_{car}) = \{E(T_{car})_i\}$, expected risk using car, $\boldsymbol{E}(\boldsymbol{R}_{car}) = \{E(R_{car})_i\}$, and the expected monetary cost of car, $\boldsymbol{E}(\boldsymbol{M}_{car}) = \{E(M_{car})_i\}$. Here i denote the expected risk, travel time or monetary cost for one certain path. For example $E(T_{car})_i$ is the expected travel time for link i and $\boldsymbol{E}(\boldsymbol{T}_{car})$ is the vector consisting of all the paths.

These mental states are line vectors of the order $1 * n$, where each element is the expected travel time cost, expected risk or expected monetary cost of using a certain path in the road network. E(x) denotes an information delay and **E(x)** denotes a vector of such functions, often referred to as exponential smoothing function in the system dynamics literature (see J. D. Sterman, 2000, p. 428). In our case they can be written as following differential equations, where t denotes time and D_{cost} is the time the commuters use to update their expectations:

$$\frac{d\boldsymbol{E}(\boldsymbol{T}_{car})}{dt} = \begin{bmatrix} \frac{dE(T_{car})_1}{dt} & \cdots & \frac{dE(T_{car})_n}{dt} \end{bmatrix} = \left\{ \frac{T_{car,\ i} - E(T_{car})_i}{D_{cost}} \right\}$$

Equation 4 Equation for expected travel time for car

$$\frac{d\boldsymbol{E}(\boldsymbol{R}_{car})}{dt} = \begin{bmatrix} \frac{dE(R_{car})_1}{dt} & \cdots & \frac{dE(R_{car})_n}{dt} \end{bmatrix} = \left\{ \frac{R_{car,i} - E(R_{car})_i}{D_{cost}} \right\}$$

Equation 5 Equation for expected risk of car

$$\frac{d\boldsymbol{E}(\boldsymbol{M}_{car})}{dt} = \left[\frac{dE(M_{car})_1}{dt} \quad \cdots \quad \frac{dE(M_{car})_n}{dt}\right] = \left\{\frac{M_{car,\ i} - E(M_{car})_i}{D_{cost}}\right\}$$

Equation 6 Equation for monetary cost for using car

$T_{car,\ i}$………… is travel time with car using path i.

$E(T_{car})_i$ ……..is the expected travel time with car using path i.

D_{cost} ……..is the adjustment time for commuters to perceive changes in the actual travel time and updating their expectations.

This structure is similar for boat, bus and tram. In some cases the states are constant over time (for example the risk of using boat is unaffected by the number of boat users) and consequently can be treated as constants instead of stocks in the model. What this illustrates is that the overall causal structure is quite similar as if it was an highly aggregated model treating Bergen and Hordaland as one big zone. The difference is that there are more copies of the same structure for each zone.

12.6 About the network model

The tricky part when dealing with networks is when different parts of the network interacts. It is desirable that traffic going from Askøy to Bergen is influenced by traffic going from Fjell to Bergen in the mode, because they share much of the same road. Section 5 explains how this is done. However cross multiplication is not included in iThink, but this can be worked around. As following is an example of a work around.

In the following equation I want to calculate the travel time on the different paths. I know two things, the travel time on each road link and the path-link incidence matrix (a matrix showing which links belongs to which path). Normally one can simply achieve the travel time for each path by cross multiplying the vector with travel time on each road link with the path-link incidence matrix:

$\boldsymbol{Travel\ time\ on\ paths\ with\ car} =$

$$(\,travel\ time\ on\ road\ 1 \quad travel\ time\ on\ path\ 2 \quad \cdots \quad travel\ time\ on\ road\ m)\begin{pmatrix} \delta_{11} & \cdots & \delta_{1n} \\ \vdots & \ddots & \vdots \\ \delta_{m1} & \cdots & \delta_{mn} \end{pmatrix}$$

= $(\,travel\ time\ on\ path\ 1 \quad travel\ time\ on\ path\ 2 \quad \cdots \quad ravel\ time\ on\ path\ n)$

Here δ_{ij} equals 1 if link i is in path j, otherwise it equals 0. In other words what this simple calculation does for each path is to sum up the travel time on every road link included in the given paths. To do this in iThink however two equations are needed and the built-in function ARRAYSUM:

Travel_time_on_roads_matrix[Paths,Links] = Travel_time_on_road[Links]*Link_path__incidence_matrix[Links,Paths]

```
Travel_time_with_car = ARRAYSUM(Travel_time_on_roads_matrix[Paths,*])
```

What this really does however is just cross multiplication of the vector "Travel_time_on_road[Links]" with the matrix "Link_path__incidence_matrix[Links,Paths]" as shown above.

This section explains the network sub model and how it ties in to the rest of the model. The destinations and origins in the network graph are represented with the symbol⊕. Origins are points or areas where the traffic enters the road network and destinations are areas or points where traffic leaves the road network.

Fictitious road nodes • are nodes representing intersections or the starting/ending point of a road segment. They connect different road segments and create waiting links. Intersections cause the traffic from more than one road segment to enter the same road segments or split traffic from one road segment onto multiple road segments (Cascetta, 2009). For example to divide a road segment into a running link and a waiting link that precedes an intersection, or to divide road segments into smaller bits to get more accurate calculations. A road segment (running link) shown with a line **−**. It represent spatial finite road segment with a certain length.

Figure 29 shows a network graph of the Bergen road network and Bybanen using the symbols described above. A thicker black line signifies a road with four or more lanes, while a thin black line is a road with two lanes. The network was derived from a road map in the policy paper Statens vegvesen (2011a, p. 20).

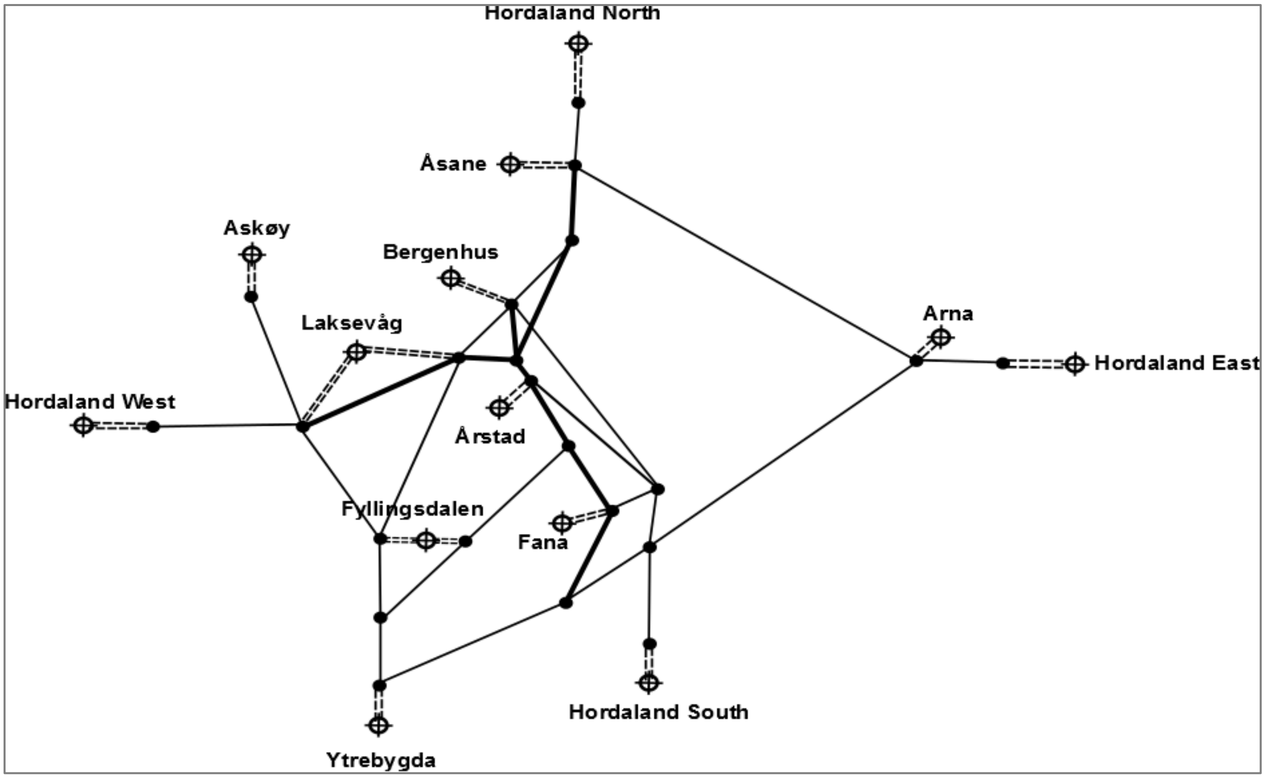


Figure 29 Road Network Bergen I

A computer program was written in PYTHON 1.6 to analyze this network. First the computer program finds the optimal path for the 210 origin-destination pair (from Bergenhus to Laksevåg, from Fana to Åsane, and so on). Next it calculates feasible alternative routes, which is the second and third fastest route between two points in the network. Alternative routes with a travel time longer than 50 % of the fastest travel route was excluded. A total of ~390 routes was identified. Finally, the program writes matrices in a CSV format that can be fed into iThink. However there where technical problems when trying to feed iThink with these matrices, because the iThink software crashed every time when dimensional matrices of a 100x100 order or larger was created. Consequently a simplified network sub model was needed. Figure 30 shows this graph of the simplified network submodel.

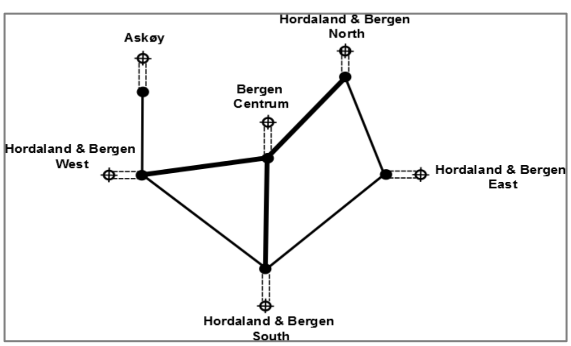


Figure 30 Simplified network submodel of Bergen

Since an essential part of modeling is in fact simplification a reduction from 210 to 30 origin-destination (OD) pairs may be seen as a vast improvement of the model. A smaller network makes it easier to understand the model. Of course very detailed policy consideration regarding road expansion would no longer be possible, but the model can still be used for evaluating bigger road expansion plans. Feasible paths for this network were determined manually.

The tram network consist currently of only one link, but gray dashed line - - - shows the planned tram lines that are going to be built if the tram network is expanded. In the case of the tram network there are not path options, hence it is sufficient to just state the average travel time between OD pairs.

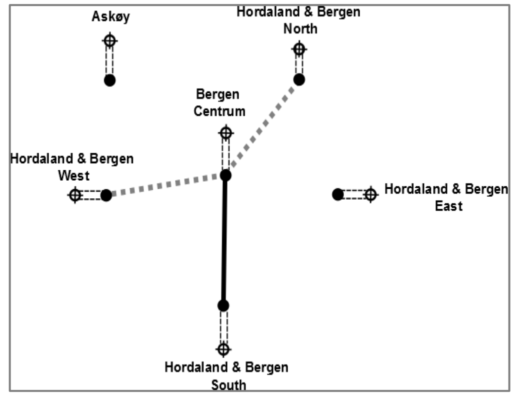


Figure 31 Tram network in Bergen

Path choice model: How people choose which path to take

The purpose of the path choice model is to calculate which path people will choose, how this affect travel time and how this feeds back to peoples path choice behavior. Network modeling techniques outlined in Cascetta (2009) are used in this chapter, but the modeling of the feedback from path choice behavior, to travel cost and back to path choice behavior, is based on SD modeling principles.

How many people that chooses a given path depends on the path cost. Equation 7 gives the equation for the vector of path costs (Cascetta, 2009, p. 52).

$$\boldsymbol{g} = \boldsymbol{\Delta}\mathbf{c}$$

Equation 7 Vector for path costs

The vector $\boldsymbol{g}$ consists of the elements$\{g_i\}$, where g_i refers to the path cost of path *i*. In our case $i \in [0, 37]$ since there are 28 possible paths indexed from 0 to 27 (the paths are described in appendix 12.10). $\boldsymbol{\Delta}$ is an link-path incidence matrix. A link-path incidence matrix is a matrix showing the different paths and which links that is a part of the path (Cascetta, 2009, p. 49). The concept of link-path incidence matrix is explained in more detail later, but simply put it consist of the elements $\{\delta_{ij}\}$, where $\delta_{ij} = 1$ if transportation link *j* is in path *i*. $\mathbf{c}$ is a vector of the transportation link costs consisting of the elements $\{c_j\}$, where c_j is the cost of transportation link j. It is the disutility experienced by the user when using the transportation link, which is determined by a link performance function (Cascetta, 2009). mAs mentioned in the literature review, the travel is a function of the traffic flow. At the same time the users' choice of path is dependent on the travel time, hence there are feedback as shown in the CLD in . The more people using a path the higher is the travel time on the links in the path. Consequently fewer people want to use that path and people begin to use other paths. Thus travel time becomes lower than what it otherwise would have been. This is a negative feedback loop and the number of people using a loops goal-seeks the number of users where the cost is consistent with the number of users. This is of course a rough simplification of the model, because when the link costs on one path increases this also affects other path which also partly consists of the same links. However to capture this feedback mechanism one must calculate $\boldsymbol{g}$, which requires $\boldsymbol{\Delta}$ and $\mathbf{c}$.

Origin-destination pairs

Before establishing $\boldsymbol{\Delta}$ and $\mathbf{c}$ one must first determine which places people travel from (origins) and to which places they travel to (destinations). A origin-destination (OD) matrix is typically the preferred representation. The OD pairs are (Bergen centrum, Bergen West), (Askøy, Bergen centrum) and so on. The relevant OD pairs for the network shown in Figure 30 are listed in a table in the appendix, section 12.10. The pairs are indexed with numbers from zero to thirty. Henceforth in this thesis an OD pair will be referred to using its index number. Identification number (ID) correspond to their placement in the matrices and which element in the origin dimension that represents a given OD pair in the *iThink* modeling software.

The paths in the Car Network

Next step in constructing a path choice model is to make the paths that are to be included. Since the number of possible paths is low because of the relative low number of OD pairs and the low density of the transportation network of Bergen. The identified paths are shown in a table in the appendix, section 12.10.

The table gives in the first column a sequence of links represented as vector with two nodes which is connected by the link (see appendix 12.11 for the index used for the nodes) that the path consist of. The second column shows the paths corresponding OD paths (in essence this shows who this path is relevant for) and finally an identification number for the path. The identification number corresponds to the element that represents a given path in a link path incidence matrix.

A list of identification numbers is also needed for each link in the network for assigning link-path incidence matrix and other matrices elements to the links. The table and graph in the appendix 12.11

shows the links, which nodes they connect and the links ID numbers. For example link 1 connects node 1 to node 2. This connection is denoted [1, 2]. Link 2 connects node 2 to node 1, therefore [2, 1]- This means that there are roads between “Bergen centrum” and “Hordaland & Bergen North” in both directions. At the chosen aggregation level all the roads within the boundaries of the network sub model will be bidirectional. In the case of link 11 and 12 the link refers to the road RV562 and the bridge connecting Askøy with the mainland. However in some cases the link may refer to a set of roads connecting two zonal centroids/areas. If this is the case then it still is treated as only one link, but with more lanes. For example if there are 2 roads connecting area A and B, and each road has 2 lanes going in direction of B (from A) then the link connecting A and B will have 4 lanes. Lanes of the roads connecting two areas are in other words added and the resulting sum assigned as the number of lanes for a given link.

Link-path incidence matrix for Car Network

The link-path incidence matrix, $\mathbf{\Delta} = \{\delta_{ij}\}$, is derived from the list of paths in appendix 12.10 which shows the paths included and the links that constitutes the path and the list of links in appendix 12.11. The ID-number of the paths is used as index for the columns in the matrix and the rows uses the links ID-numbers. If a link in a row *j* is in path *i* then δ_{ij} is set equal to 1, otherwise 0. By doing this for every path a link in the network one gets the matrix shown in Table 6.

The purpose of the link-path matrix is to keep track of which links are in which paths, which is useful when simulating traffic in a road network because traffic from Askøy flows through many of the same roads as traffic from Fjell. It is obvious that this is captured by the matrix if one compare path 25 with path 31. Both paths include the link 13, but path 31 also includes link 12. Link 12 is the bridge from Askøy and the subsequent road (RV562) that intersects with the freeway RV555. Commuters from Fjell, Bergen west and Askøy must use this road when traveling to the city center of Bergen, which means that commuting time from Askøy is affected by the traffic from Fjell and likewise is commuting time from Fjell affected by the traffic from Askøy.

Paths	Links 1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	1	0	0	0	0	0	0	0	0	0	0	0	0	0
2	1	0	1	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	1	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0	0	1
5	0	0	0	0	0	0	0	0	0	0	1	0	0	1
6	0	1	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	1	0	0	0	0	0	0	0	0	0	0	0
8	0	1	0	0	0	0	0	1	0	0	0	0	0	0
9	0	1	0	0	0	0	0	0	0	0	0	0	0	1
10	0	1	0	0	0	0	0	0	0	0	1	0	0	1
11	0	1	0	1	0	0	0	0	0	0	0	0	0	0
12	0	0	0	1	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	1	0	0	0	0	0	0	0	0	0
14	0	1	0	1	0	0	0	0	0	0	0	0	0	1
15	0	0	0	0	1	0	0	0	1	0	0	0	0	0
16	0	1	0	1	0	0	0	0	0	0	1	0	0	1
17	0	0	0	0	0	0	0	1	0	0	0	0	1	0
18	0	0	0	0	1	0	0	0	1	0	1	0	0	0
19	0	0	0	0	0	0	1	0	0	0	0	0	0	0
20	1	0	0	0	0	0	1	0	0	0	0	0	0	0
21	0	0	0	0	0	1	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	1	0	0	0	0	0
23	0	0	0	0	0	0	1	0	0	0	1	0	0	1
24	0	0	0	0	0	0	0	0	1	0	1	0	0	0
25	0	0	0	0	0	0	0	0	0	0	0	0	1	0
26	1	0	0	0	0	0	0	0	0	0	0	0	1	0
27	1	0	1	0	0	0	0	0	0	0	0	0	1	0
28	0	0	0	0	0	1	0	0	0	1	0	0	0	0
29	0	0	0	0	0	0	0	0	0	1	0	0	0	0
30	0	0	0	0	0	0	0	0	0	0	1	0	0	0
31	0	0	0	0	0	0	0	0	0	0	0	1	1	0
32	1	0	0	0	0	0	0	0	0	0	0	1	1	0
33	1	0	1	0	0	0	0	0	0	0	0	1	1	0
34	0	0	0	0	0	0	1	0	0	0	0	0	0	1
35	0	0	0	0	0	1	0	0	0	1	0	1	0	0
36	0	0	0	0	0	0	0	1	0	0	0	1	1	0
37	0	0	0	0	0	0	0	0	0	1	0	1	0	0
38	0	0	0	0	0	0	0	0	0	0	0	1	0	0

Table 6 Link-path incidence matrix

By cross multiplying the vector with number of people using each path with the the link-path incidence matrix one gets the total number of cars on each link:

$$\boldsymbol{f} = \Delta * (\boldsymbol{K} \circ \boldsymbol{A})$$

Equation 8 vector of flow on links

$\boldsymbol{f}$…. is a vector with the flow on each and every link in the network. $\boldsymbol{f} = \{f_i\}$ where f_i is the traffic on link i.

Δ… is the link-path incidence matrix.

$\boldsymbol{K} \circ \boldsymbol{A}$…. Is the Hadamard/entrywise product of vector K and vector A, which gives the number of people that uses each path.

$\boldsymbol{K}$… is a column vector where the entry is the maximum people that can uses a given path. In other words $\boldsymbol{K} = \{k_i\}$ where k_i is the number of people that chooses path i if everyone that travels between the path i's origin and destination choose to use path i and no other path.

$\boldsymbol{A}$… is the column vector with fraction of people choosing each path. $\boldsymbol{A} = \{a_i\}$ where a_i is the fraction of people that chooses path i.

$\boldsymbol{f}$ Gives the number of cars on each road segment/link in the road network and is used to calculate the average speed on the road with Equation 2. Using this function one can derive a new vector, **c**, with the travel time cost on each and every road link. **c** is used to calculate the path costs, **g**, as shown in Equation 7, which is the path incidence matrix multiplied with the link costs or more simply put: the sum of the travel time on each and every road link in a given path. The path costs are then used to determine how many people that chooses a given path. $\boldsymbol{A}$, the vector with the fraction of people choosing a given path, can therefore be written as a function of the flow on each link in the network, $\boldsymbol{A}(\boldsymbol{f})$. Ergo this is the feedback discussed above with causal-loop and stock-and-flow diagrams

Feedback from path choice, path cost vector and path choice

Given $\boldsymbol{f} = \{f_i\}$ then **c** =$\{c_i\}$= $\{\mathrm{t}(f_i)\}$, where t(f_i) is the travel time at road link i calculated using Equation 2 with traffic volume set equal to f_i. Path costs, **g**, are derived by setting in **c** in Equation 7. $\boldsymbol{A}$ can now be calculated:

$$\boldsymbol{A} = \{a_{\boldsymbol{i}}\} = \left\{\frac{e^{(g_i/\theta)}}{\sum_{j\in\mathbf{P}} e^{(g_j/\theta)}}\right\}$$

Equation 9 Fraction choosing a given path

g_i… is the path cost at path i.

θ… is the random residuals.

$\mathbf{P}$… is a set of path costs for all paths leading from a given origin to a given destination. For example if path 1 and path 2 leads has the same origin and destination then both are in $\mathbf{P}$ otherwise they are in different sets.

In practice this is done using a “comparison matrix”, where element i, j equals 1 if path i and j has the same origin and destination, otherwise it is zero. Notice that the element i, i always will equal 1 because a path should always be compared to itself. If this is not the case then the fraction of people using paths leading between a origin-destination pair would sum up to more than 1, meaning that people materialize from thin air which does not make sense.

Origin-destination path incidence matrix

The origin-destination matrix is a device in the model used to convert values relating to paths into values relating to origin-destination pairs. Given the origin-destination matrix **M** = $\{m_{ij}\}$ the m_{ij} equals 1 if path i correspond to origin-destination pair j, otherwise it is 0. In other m_{ij} equals 1 for the paths that match a given OD pair. This is useful for example when calculating the average travel time between two areas.

12.7 Model Analysis and Testing

One of the biggest advantages of using a formal model is that it is possible to perform various tests to determine the models usefulness (Ford, 2010). The purposes of these tests are both to uncover flaws in the model and build understanding of how the system works. This chapter will go through some of the tests done on the model.

Loop knockout analysis

Loop knockout analysis is a method where loops are deleted from the system (J. D. Sterman, 2000). This makes it possible to determine the importance of a loop by comparing the simulation results before and after the deletion.

Figure 32 shows the effect of removing road expansion from the model. Removal of road expansion means that the road quality stays constant at its' initial value. The discontinuous line is the simulation run used to simulate the historical data and includes road expansion. The continuous black line is the simulation results without road expansion. As the figure shows the effect of removing road expansion is quite small, but increases somewhat over time. An explanation for the surprisingly little importance of the road expansion loop is that the road network already is built out to handle the current traffic flow fairly well. Studying the simulation results shows that explanation is that the roads already have the maximum number of lanes and therefore cannot be improved. The reasons why the number of car users do increase is that the overall road network is improved (more lanes added to other road links than Nye Nygårdsbro shown in the graph) so that some traffic flows through other paths in the road network. However the effect of removing the road expansion loop is also small on the roads which don't have the maximum number of lanes. This may be explained by the initial values of road being quite high for the roads so that they can handle the traffic.

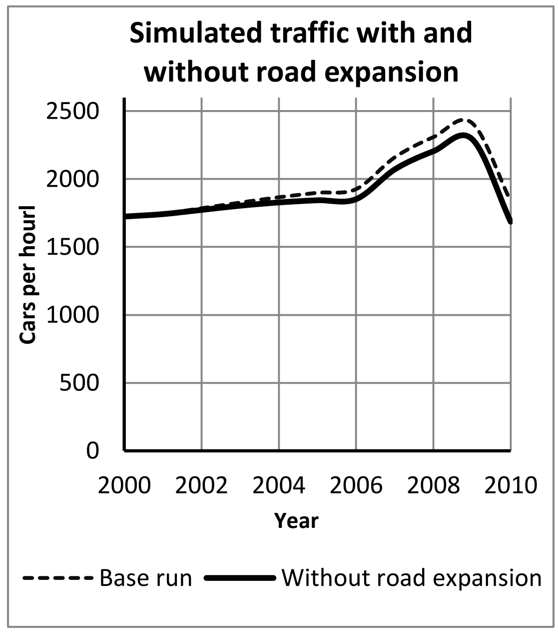


Figure 32 N. Simulated traffic with and without road expansion loop, N. Nygårdsbro, 2000-2010

This explanation is explored further in section 0 where knockout analysis are performed with different initial values for the stocks to investigate how this affect the importance of some of the loops in the model.

Removing the congestion loop from the model by setting the road capacities to infinity has a big effect on the traffic flow. A somewhat counterintuitive result in contradiction with common knowledge is that the car flow decreases when congestion are removed, as shown in Figure 33. The discontinuous line is the base run and the continuous line is the simulation run when the road capacity is set to infinity. Studying the simulation results however reveals that this is because the risk of taking bus is much more affected by an increase in traffic than car. Bus is the only available option to car (it is assumed that few people are willing to bicycle or walk) so removing congestion therefore makes bus more attractive, consequently reducing the number of car users.

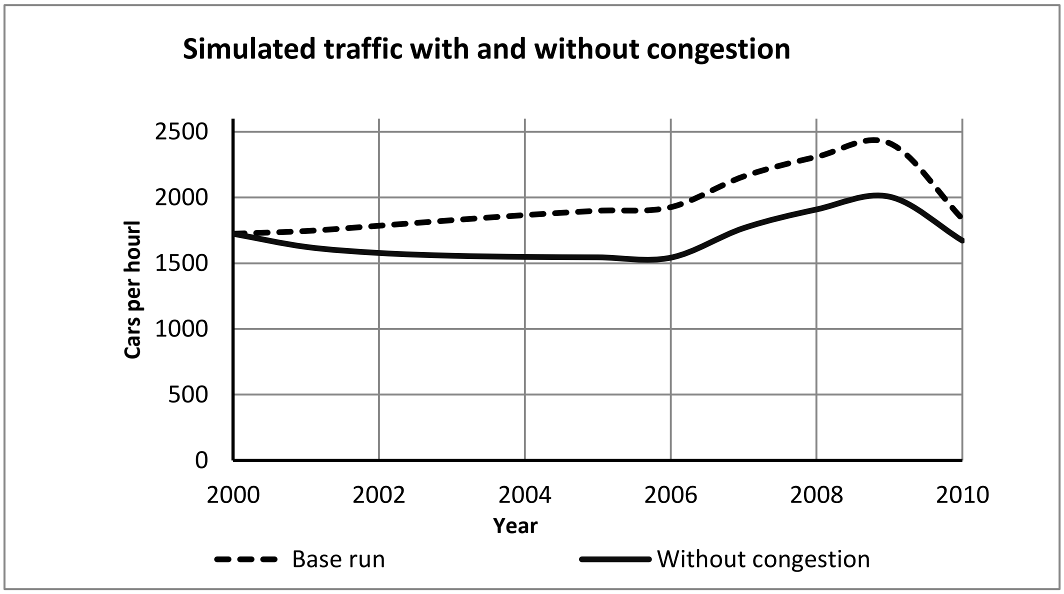


Figure 33 Simulated traffic N. Nygårdsbro with and without congestion, 2000-2010

Figure 34 illustrates the effect of knocking out the car acquisition loop in the model has on the traffic flow at Harafjellstunnelen. The continuous line is the simulation run with car acquisition and the discontinuous line the run without road acquisition. As the figure illustrates the effect of removing car acquisition from the model reduces the traffic flow. Without car acquisition the car ownership stays constant in the model, the consequence is that the number of cars users reach a celling where it don't increase anymore. This celling is determined by the car access. After 2011 in the simulation the numbers of commuters are kept constant and the traffic flow stop increasing. Without car acquisition the traffic flow stabilize at a lower traffic flow.

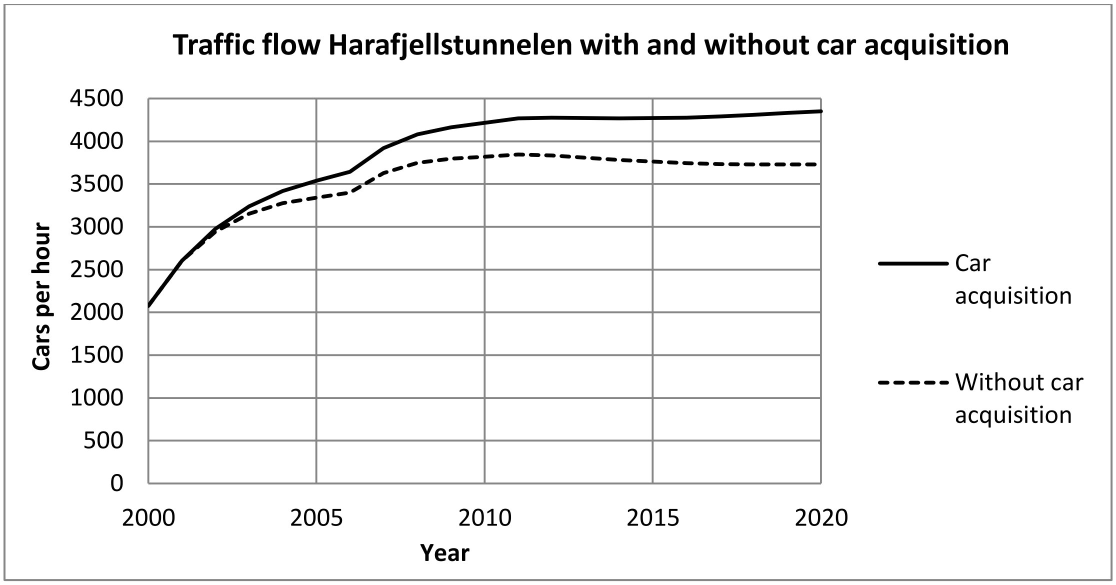


Figure 34 Traffic flow Harafjellstunnelen with and without car acquisition, 2000-2020

Car acquisition is therefore an important reason for the growth in the traffic flow. There are two reasons why. First when commuters' increases they acquire cars to use it for commuting and secondly the car ownership is increasing, meaning that not only the absolute number of people using car increases, but also the proportion of people that can use car increases. Increasing car ownership is therefore important to explain the increasing traffic flow in Bergen.

Only a selection of the loop knockout tests has been documented above. However they are representative for the main finding. It seems to indicate that the model behave appropriately, however that less road construction leads to more car users are somewhat surprising. The tests also indicate that the loops are not the main causes for the increasing traffic. This section suggest that the reason why road expansion, parking space expansion and so on are not the main mechanisms causing the increase in traffic is because the parking space constructed, road quality and number of cars owned already are at level where they satisfied the current demand and only small adjustment are needed to meet the new demand. This small adjustment does however not affect the commuters' transportation mode in such a way that it has a big impact on the traffic flow. In other words they may have been important to reach the current state and traffic volume. For example increased car ownership may have been an important driving force expanding the use of car 60 years ago, but now most families own at least one car and further increase have little effect. The next section explores this future by performing a loop knockout analysis with a lower initial value for car ownership than the one used in the base run.

Loop knockout analysis and extreme condition tests

It is fruitful to combine loop knockout analysis with extreme condition tests. Often the loops are not active under normal conditions (J. D. Sterman, 2000). This is the case in the historical run for the model, because the model starts out close to equilibrium and the changes caused by the loops are just small changes as reactions to the changing number of commuters. The real potential of the loops are therefore not shown in the historical case. By setting for example the initial value of road quality to 1 for all roads one reveals the real importance of road expansion loop. This section complements the previous loop knockout analysis and also performs some new tests to investigate the models behavior.

Previous section seems to indicate that the “car acquisition loop” and other loops included in the model is not so important in determine the changes in number of car users. That the main cause is the changes in number of commuters, while road expansion, car acquisition loop, road quality and parking space expansion only makes small adjustments to adapt to changes in the number of commuters. However this does not mean that this loops hasn’t been important in the past or that they are not going to be important again in the future. The future importance of car ownership will be discussed in the chapter about “BergenSim”, which is this model combined with an urban migration model (provides origin destination matrix with commuters) and a land use model. Here the historical importance of increased car ownership is tested. This is done by assuming: 1) the number of commuters for each origin destination pair start at 500 people and increase to 7000 by year 2010, and 2) set the stocks of cars owned by the commuters to 100 (in other words assuming 20% of the commuters own a car). These assumptions are in no way meant to be accurate and neither are the resulting simulation result in Figure 35, but they are meant to show what happens if the number of commuters increased steadily since 1950 and if the car ownership start out low. The qualitative scenario itself are close to the reality and by having two simulation runs, one with the car acquisition loop and one without, one can illustrate the importance of car acquisition in a longer time perspective.

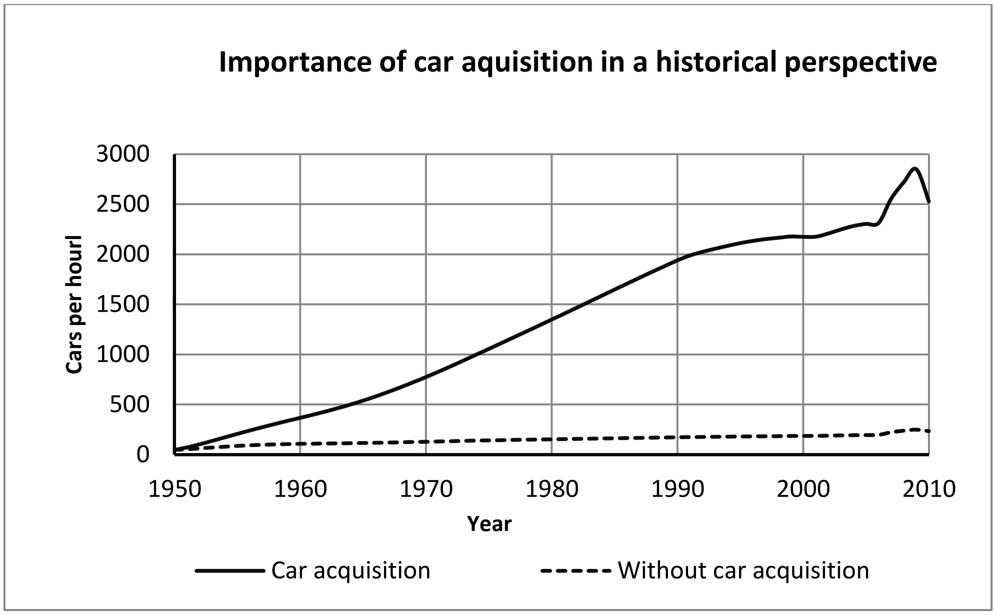


Figure 35 Importance of car acquisition in a historical perspective

As Figure 35 shows car acquisition is important for the increase of traffic in the long run, as one would expect. If the number of cars stayed constant then the traffic flow would increase very little. This shows that the model generates respond realistic to changes in the structure in regard to car ownership and that car acquisition is important in the long run.

Figure 36 shows simulated traffic flow at a road under the assumptions that: 1) the number of commuters for each origin destination pair increases from 500 in 1950 to 7000 in 2010 (then kept constant), 2) equilibrium amount of car ownership in 1950, 3) an undeveloped road network with only 1 lane in each direction, 4) the only alternatives to car is bus, walking or bicycling (not historical true, since there did existed a tram network in Bergen prior to “bybanen” that was removed). The continuous line in Figure 36 is the simulation run without road expansion and the discontinuous line is the simulation run with road expansion.

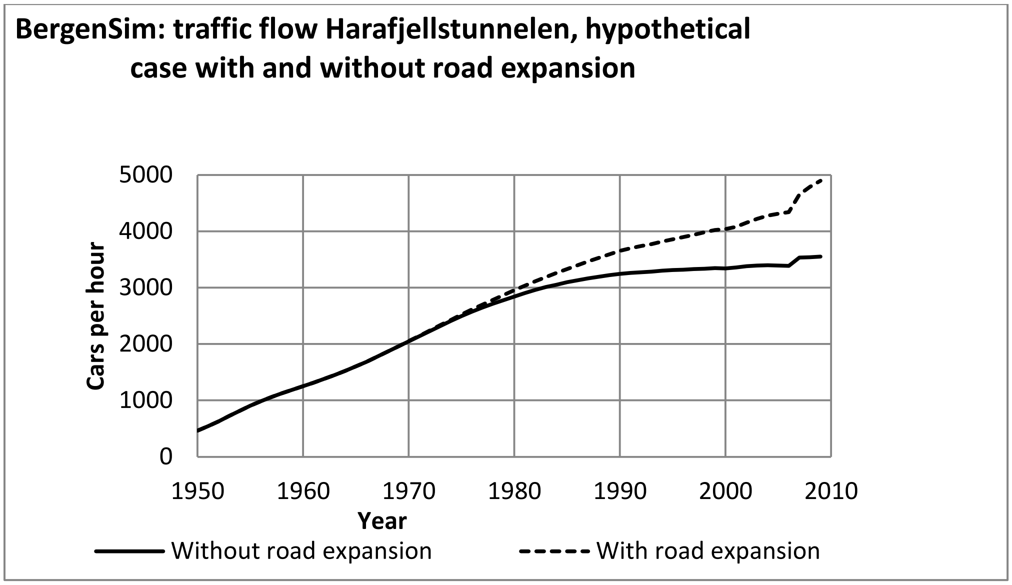


Figure 36 Importance of road construction in a historical perspective

The traffic flow is quite similar in both simulation runs, but after 1970 the traffic flow in the simulation run with road expansion increases faster. It seems that the traffic flow in both simulations saturates, but at a higher level in the simulation with road expansion. This is because road expansion increases the total capacity of the road network and therefore allows for more traffic. Without road expansion more people rely on walking and bicycling as their means of transportation. Traffic expansion loop weakens the congestion loop and thereby allows for growth in traffic. Without it many people will switch to other transportation modes unaffected by the car traffic, such as bicycling.

However a limitation that should be mention is that in the model only captures transportation mode choices and quality of the transportation services, but not the effect of travel on urban migration (total number of commuters). Consequently road expansion may lead to more commuters because it makes it easier (take less time) to commute between zones. A lower travel time between zones may therefore make it easier to commute and consequently in the long run increase the total number of commuters. The chapter BergenSim tests the hypothesis that more roads can lead to more traffic by making commuting more attractive. This is also discussed further in the chapter about model limitations.

The purpose of this test is to test if the model behaves realistic in regard to peoples' mode choice. This part of the model simulates the demand for different transportation modes and tries to answer the question "How does a change in the costs or travel time change peoples' choice of transportation mode?”. An increase in cost of a transport mode should be followed by a decrease in number of people using the transportation mode. These people changes to other modes of transportation and therefore one would also expect to see an increase in people using the other transportation modes.

To remove any influence from other variables the supply side of the system is kept constant (i.e. no road or parking space expansion, changes in ticket or gas prices or total number of commuters). It is also necessary to remove the road network effect so that traffic from other areas does not affect the travel costs. In other words everything is kept constant and then at time T the road toll is reduced by 50%. This is done by using a step function. The result is shown in Figure 37.

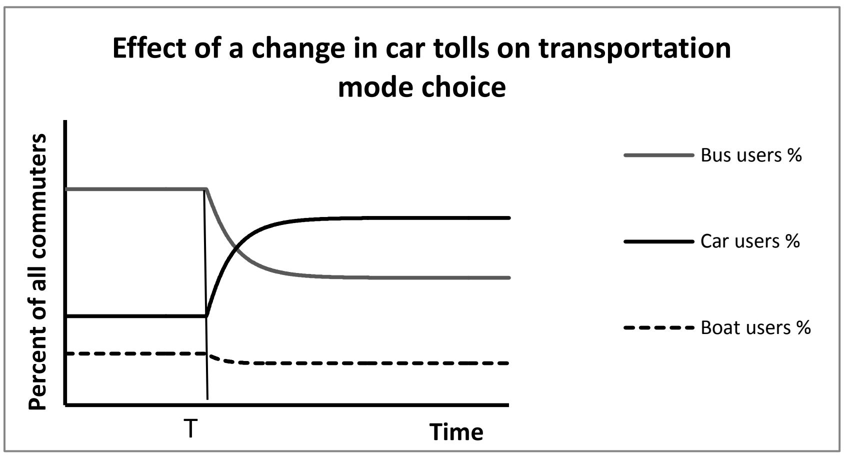


Figure 37 Effect of a change in car tolls on transportation mode choice

The cut in road tolls causes the percent of car users to exponentially decay towards a higher equilibrium level. Percent of bus and boat users exponentially decays to a lower level. This result seems reasonable. When the cost of some transportation mode is decreased, then the number of people using it increases, which means that some people switch mode of transportation. One would maybe think that the decrease in bus users a boat users where equal. However there are several reasons why this is not the case. The main reason is that increased car users influences the travel time with bus. More car drivers means more traffic and congestion, thus longer travel time when using bus. Travel time for boat, tram, pedestrian and bicyclers are unaffected by the number of car users.

It is fair to say that the model give a sound simulation of how people choose transportation mode and reacts to changes in the attractiveness of the transportation modes.

By setting cars used for commuting constant and setting parking spaces equal to the number of cars used for commuting the parking space construction sub model is isolated and set in equilibrium. By introducing a sudden increase in the number of cars on road the number of parking spaces also increases as shown in Figure 38, with some oscillations around its goal cars used for commuting road.

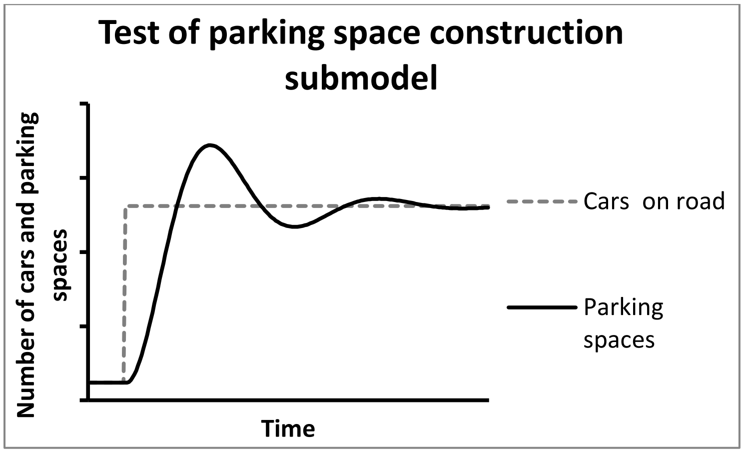


Figure 38 Shock test of parking space construction submodel

Several other parameters where also tested and the model behavior where appropriate in all cases. For example at high values for road construction times or when time to perceive parking space crowding is set very high.

Sensitivity Analysis

Sensitivity analysis is useful to understand how uncertainty of model assumptions affects the conclusion and insights drawn from the model (J. D. Sterman, 2000, p. 883). It reveals how sensitive some model variable interest is to changes in the models parameter. The parameters are changed systematically within a range of plausible values(Railsback & Grimm, 2012; J. D. Sterman, 2000), starting from the lowest probable value to the highest. Therefore the width of this range depends on the uncertainty of the parameter being tested. Sensitivity is here defined as the effect a change of parameter values has on the number of car users in year 2020 in the simulation, assuming external influences on the system is assumed to stay constant from 2012 and out.

In each simulation run the parameter tested is varied incrementally over a range of plausible values using the "sensi specs" functionality in the *iThink* software. Sensitivity, S, is measured by calculating the sensitivity of the parameter above and below its reference value, C, which is the number of car users in

2020 in the simulation run where the estimated parameter values are used. The sensitivity of above the parameters reference value are defined as $S^{+} \equiv (C^{+} - C)/(dP/P)$, where C^{+} is the number of car user simulated when dP is greater than zero, dP is the change in the parameter being tested and P is the reference value for the parameter being tested (Railsback & Grimm, 2012). That dP is greater than zero means that the tested parameter is increased. If dP is less than zero then the tested parameters is decreased. The reference value for the parameter is the estimated parameter value. The sensitivity below the parameters reference value is defined as $S^{-} \equiv (C - C^{-})/(dP/P)$, where C^{-} is the lowest number of car users simulated when dP is less than zero (the change in the parameter is negative) and P is the reference value for the parameter being tested (Railsback & Grimm, 2012). Notice that dP/P is the percentage change in the parameter value, therefore the sensitivity of different parameters can be compared since the change in the parameter is made dimensionless. The interpretation of S^{-} and S^{+} is the marginal change in the end number of cars (in year 2020) that occurs per percentage change in the parameter. For example if S^{+} for some parameter equals 100 then a 50 percentage change in that parameter increases the end number of cars with 50 (100 cars per percentage change *0.5 fractional change). Notice that one must use the percentage as a fraction or divide S^{+} by 100.

Some parameters are vectors, describing a set of parameters for different zones, paths and roads. In these cases the parameters is assumed to be equal for all the different areas so that sensitivity analysis can be done on one parameter instead of many. The sensitivity of these parameters describes the situation where the parameter changes for all the zones, paths and roads. Changes all parameters in a vector have of course a bigger effect on the system than just changing one of the parameters in the vector. Therefore the reported sensitivity is expected to higher than if only one of the parameters in the vector where changed. In cases where the parameter tested is really a vector the parameters is denoted with a star as superscript (parameter*).

Not all of the parameters tests are shown in the following section. Only those parameters which value are deemed very uncertain or are interesting to change in policies are analyzed. Table 7 shows the distribution used, the best estimate of the parameter's value[17], the standard deviation the upper and lower sensitivity for each parameter tested in the sensitivity analysis. If $S^{-} < S^{+}$ then the relationship between the parameter and the end number of car users is positive. Meaning that if the parameter

[17] Disclaimer: The best estimate values in the table may have small deviations from the values used in the simulation attached.

increases then the number of car users in year 2020 increases. If $S^{-} > S^{+}$ then the relationship between the parameter and the end number of car users is negative. Therefore if the parameter increases then the end number of car users in year 2020 decreases.

Parameter name	Distribution	Best estimate	Standard deviation	S-	S+
Access regress time	Incremental(0, 0.5)	0,25	2606	772	-781
Adaptation time	Incremental(0.25, 2)	1	25	-32	52
Additional travel time factor	Incremental(0.25, 2)	1	152	-462	454
Attractiveness bicyle[Convenience]	Incremental(-0.5, -0.1)	-0,30	5956	4969	-24289
Attractiveness bicyle[Travel time]	Incremental(-0.35, -0.15)	-0,25	3488	4150	-13357
Attractiveness car[monetary cost}	Incremental(-0.001, -0.009)	-0,005	6190	-15479	8589
Attractiveness car[Standard devation]	Incremental(-0.82, -0.02)	-0,42	6329	-15012	6603
Attractiveness car[Travel time]	Incremental(-0.04, -0.24)	-0,14	1226	-2989	2678
Attractiveness PT [Changes]	Incremental(-0.001, -0.01)	-0,01	2681	176	-7875
Attractiveness PT [Travel Time]	Incremental(-0.29, -0.1)	-0,14	2681	1475	-7632
Attractiveness PT[Monetary cost]	Incremental(-0.009, -0.001)	-0,005	2681	1976	-8859
Attractiveness Walking[Convenience]	Incremental(-1, 0)	-0,100	491	64	-1480
Attractiveness walking[Travel Time]	Incremental(-0.48, -0.08)	-0,28	6524	785	-32416
Available Space	Incremental(1, 160000)	80000,00	182	-680	0
Average lifetime of a road	Incremental(1, 21)	10,00	69	-345	6
Average number of bus changes	Incremental(0, 4)	0,25	111	-99	50
Average time spent at bus stops	Incremental(0.01, 0.05)	0,03	47	-132	126
Average time to acquire a car	Incremental(1.7, 14.7)	7,70	1018	688	-2827
Bicycle speed	Incremental(6, 18)	12,00	197	854	-467
Building time	Incremental(1, 20)	5,00	170	50	-409
Capacity per lane	Incremental(800,1600)	1200,00	3544	-23504	11929
Car sharing	Incremental(1, 2)	1,05	2201	-18596	7178
Constant car ownership	Incremental(0.1, 0.6)	0,3	395	-1709	167
Dedicated bus lanes	Incremental(0, 1)	0,01	1689	47	-52
Desired % parking space coverage	Incremental(10, 200)	120,00	13905	-3247	101
Free flow speed	Incremental(50, 70)	60,00	721	-8040	6291
Hourly frequency of boat	Incremental(1, 4)	2,00	24	108	-30
Hourly frequency of bus	Incremental(1, 12)	6,00	1254	-168	344
Importance of commuting in car acquisition decision	Incremental(0,1)	0,50	1286	-36261	0
Max # of lanes	Incremental(2,6)	3,00	3890	-21192	5674
Normal standard deviation boat	Incremental(0.01, 1)	0,05	18	-7325	312
Normal standard deviation Bus	Incremental(0.1, 1)	0,50	2143	-11362	565
Normal standard deviation car	Incremental(0.1, 1)	0,25	6433	7181	-15170
Parking spaces	Incremental(5000, 40000)	20000	0	0	0

Percent extra capacity[18]	Incremental(0, 20)	10	17	-38	-49
Random residuals	Incremental(0.1, 1)	0,32	16416	26334	-17192
Replacement time	Incremental(0.1, 5)	0,50	1016	532	-334
Saturation level	Incremental(0.1, 1)	1	14844	-54290	43305
Slow distance factor	Incremental(1, 6)	1,00	6313	NA	2887
Toll	Incremental(0, 30)	30,00	14498	11	-65536
Walking speed	Incremental(1, 6)	5,00	447	719	-4850

Table 7 Sensitivity analysis. (PT includes boat, bus and tram.)

The relation between the absolute value of the upper sensitivity, $|S^{+}|$, and the absolute value of the lower sensitivity, $|S^{-}|$, indicates the shape of the relationship between the parameter and the number of car users. If $|S^{-}| < |S^{+}|$ then an increase in the parameter has a larger effect on the number of commuters than a decrease. This means that the effect of an increase in the parameter has an increasing rate. If $|S^{-}| > |S^{+}|$ then a decrease in the parameter has a larger effect on the number of commuters than an increase. This means that the effect of an increase in the parameter decreases at higher parameter values. Of course one can only say this for certain within the range of parameter value tested. It could also be highly nonlinear, however none of the parameter tested shows such relationships with the number of cars. $|S^{-}| \cong |S^{+}|$ indicates an approximately linear relationship between the parameter and the number of cars.

The most sensitive parameters are as follows:

- The saturation level for car ownership, which is the maximum fraction of the commuters that own car. The saturation level set the maximum cap on the number of people that have access to a car. Reduction of people with access to car reduces the number of people that can use car and therefore is the number of car users very sensitive to the saturation level.

- Toll, which is how much the driver must pay at tool booths and at parking houses.

Number of car users are also very sensitive to most of the attractiveness parameters, max # of lanes, capacity per lanes, car sharing and the importance of commuting in car acquisition (however only whether it equals zero or not). The attractiveness parameters and the max # lanes parameter are the most uncertain of all these parameters. The attractiveness parameters are only supported by a stated preference study (see Ramjerdi et al., 2010) and the max number of lanes is assumed. These parameters

[18] Concave shape, consequently $0 > S^{-} and\ \ 0 > S^{+}$.

are therefore the prime candidates for the uncertainty analysis. The high sensitivity to toll indicates that policies involving imposing monetary costs on car users have a big impact on the number of car users in the long run.

Some variables are external time series. It is also of interest to test how sensitive the model is to assumptions one make about future trends. The time series in the base run is assumed to stay constant from 2012 and out at the level they were at in the end of 2012. Scenarios are constructed by assuming a linear trend of how the variable develops from year 2012 to year 2020. This trend is specified in Table 8 as yearly change in the parameter. For example id gas price parameter is set to 5 then it means that the gas price increases yearly by 5 NOK. The sensitivities can then be calculated similarly to the other parameters, but with dP and P defined respectively as the yearly change in the parameter and value of the parameter in 2012. In cases of vectors the change in the parameters is for every element in the vector. If commuters are changed yearly by 100 then this means that the number of commuters is assumed to increase with 100 for every origin and destination pair.

Trends for four variables are tested: number of commuters, ticket price for public transport, gasoline price and income level. When a trend is tested the other trends are kept at a constant level from 2012 to 2020.

Table 8 shows the result from the sensitivity analysis of the time series.

Variable name	Distribution	Best estimate	Standard deviation	S-	S+
Commuters[OD]	Incremental(-100, 2000)	100	5988,02039	-3241	13173
Ticket price	Incremental(-2,2)	1	284,7261245	-219	295
Gas price	Incremental(-5,5)	1	2752,161525	363	-7739

Table 8 Sensitivity analysis of timeseries and future trends

The number of car users is very sensitive to all four variables. Ticket price is the parameter the system is least sensitive. The system is most sensitive to the number of commuters is the variable it is most sensitive to. This is can be explained by the fact that the number of commuters determines the total demand for transportation in the morning rush, while ticket price only changes the fraction using the different transportation modes.

The table shows that an increase in the trend for number of yearly increase in commuters will cause an increase of car traffic that is greater than the reduction in traffic that occurs when the increase in number of commuters is decreased. Increase in ticket price has almost the same effects as a decrease on the number of car users. An increase in the yearly change in gas prices causes a greater decrease in the number of car users than the effect of a reduction.

Number of car users is very insensitive to some parameters. However in some cases it seems likely that there is important interaction effects lost in the analysis above. The initial number of parking spaces is unimportant as long as there are available spaces for new parking spaces and market/political mechanisms that ensure that the demand for parking spaces is met. This is shown in Figure 39, where the initial number of parking spaces and available space to builds parking spaces is shown at the axis and the color shows number of car in the end year of the simulation.

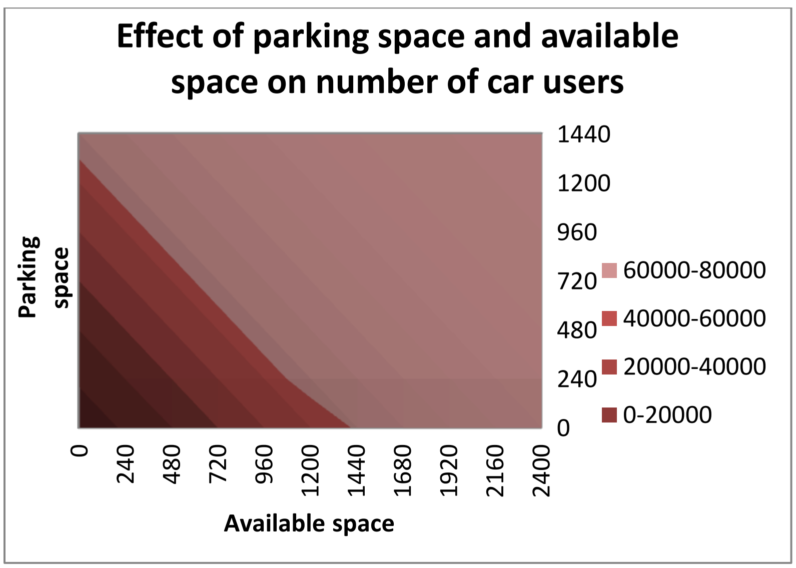


Figure 39 Contour plot effect of parking space and available number of car users

The contour plot shows that the effect (on the end number of car users in 2020) of a change in parking space decreases as the number of available space increases. It can also be interpreted as the effect of a change in available space decreases as the initial value for number of parking spaces is increased.

This means that the effect of parking spaces must be understood in the market context. If there is available space for new parking spaces and market mechanisms than ensure that the demand is met then it doesn’t matter in the long run how many parking space there are today. Therefore if one wants to decrease the number of car users through parking space policies then on must reduce available space and parking spaces. Most of the variables analyzed showed similar results as parking space and available space. None of them really stand out by showing highly nonlinear behavior or other surprising behavior that makes decision-making difficult.

Behavior Reproduction Tests

Behavior reproduction tests assess the models ability to replicate historical data. In these tests the point-to-point correspondence between a simulated variable and numerical data for that variable is compared (John D Sterman, 1984; J. D. Sterman, 2000). Discrepancy between the model's behavior and historical data are useful to uncover flaws in the model (J. D. Sterman, 2000). To evaluate how well the model reproduces historical data several formal measures for goodness-of-fit are used. The advantage of using formal measures is to give the discussion of how the model behavior compares to historical data a concrete foundation. Before using and discussing these measures the simulated variables and historical data are plotted into one graph for comparison.

Figure 40 compares the simulated number of cars on three roads in peak hour with estimates from available datasets, for year 2000 to 2010[19]. Estimated data is shown as continuous lines and simulated as discontinuous line. It is easy to conclude just by eyeballing it that the model behavior resembles the behavior seen in the data, but some discrepancies are also obvious. Simulated traffic at Nye Nygårdsbro have a so good fit with the data that it are nothing to gain by discussing it. Simulated traffic on Sandviken is too low in the period 2000 to 2008, but grows until it reached the same traffic flow as in the data. This also means that the relative growth simulated is too strong. A possible explanation is that the initial number of cars and the proportion of car users are two low for Bergen north in the simulation, but that the acquisition rate is too fast. Traffic flow simulated for Askøy bridge have a good fit with the data, but it don't show the same jump in the traffic flow after 2006. The literature explains this growth in traffic as a result of removing the toll on the bridge (Statens vegvesen, 2011a). This may suggest that commuters' reaction to change in monetary costs are too weak in the model and that the utility of money in the attractiveness parameters should have a lower value.

[19] The tram was opened in Bergen in 2010.

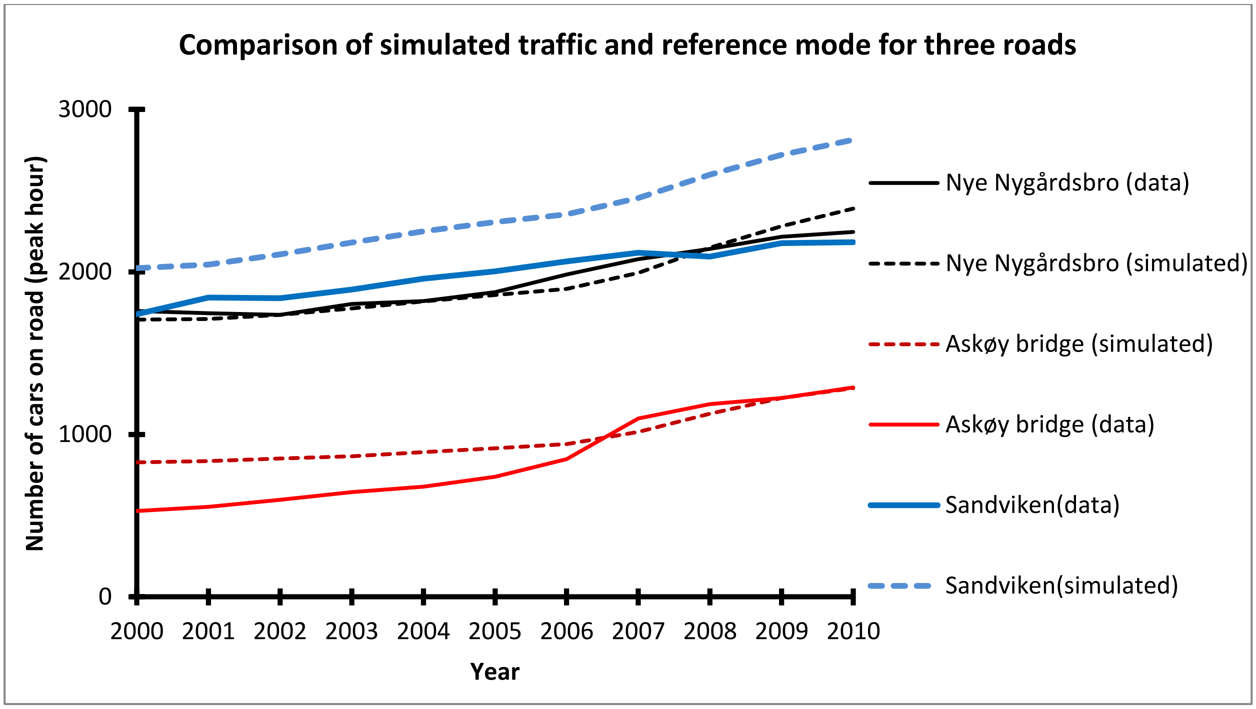


Figure 40 Comparison of simulated traffic and reference mode for three roads.

Discrepancies between the simulation result and the data shown above are useful because they may indicate that there are flaws and errors in the model (J. D. Sterman, 2000, p. 879). A potential problem in the transportation model is how the Bergen region is divided in to different zones. Wrong level of disaggregation could easily lead to bad simulation results. For example if a zone had two equally sized groups of people, those who live within spitting distance of a public transportation stop and those who live many kilometers away from it, then it is probable that the model will underestimate the number of public transportation users.

An interesting question is therefore whether the model generates better results for certain roads. Eyeballing goes a long way when just judging the fit between the data points and the simulation result. However it is harder to eyeball how well the fit is between the data and simulation results for Askøy Bridge compared to the fit between the data and simulation results for Sandviken. Therefore it is necessary to use some quantitative measurement of how well simulation results fit the data. Several such measures exists (see J. D. Sterman, 2000, p. 875). I choose to use Mean Absolut Percent Error (MAPE) and Theil's inequality statistics[20] (TIS).

[20] Equations for Theil's statistics printed in Morecroft (2013, p. 399) and John D Sterman (1984) are used since there are typos in the equations printed in J. D. Sterman (2000).

MAPE is a dimensionless measure of the point-by-point correspondence of the model and the data and can be interpreted as percent error when multiplied with 100 (J. D. Sterman, 2000). The closer MAPE is to zero the better is the correspondence of the model simulations and the data. TIS has another purpose than MAPE. It measures the nature of the error by decomposing Mean Square Error into three components: bias, unequal variation and unequal covariation (John D Sterman, 1984; J. D. Sterman, 2000, p. 875). A high MAPE (or MSE) indicates that the correspondence of the simulated variable and the data for a variable is low, but nothing more. However it is possible by using TIS to ascertain whether this error is systematic or unsystematic; if the model parameters should be adjusted and more (Morecroft, 2013; John D Sterman, 1984; J. D. Sterman, 2000 is used for interpretating the results of TIS below). Table 9 shows MAPE and TIS for the three roads in Figure 40. Each measurement is given one row and each road is given a column. MAPE is reported as percent in the table.

		Nye Nygårdsbro	Askøy Bridge	Sandviken
MAPE (%)		1	8	6
Theil's inequality statistics	*Bias*	0,43	0	0,52
	Unequal variation	0,02	0,65	0,26
	Unequal covariation	0,55	0,35	0,21

Table 9 MAPE and TIS for four roads

MAPE is low for Nye Nygårdsbro, but high for Askøy bridge and Sandviken. Nye Nygårdsbro shows a quite good fit which is confirmed by the low MAPE. Simulated traffic on Sandvikens shows a large bias which is dominating the TIS. This indicates that there is a substantial systematic error and that the mean differs (J. D. Sterman, 2000). This can easily be seen from Figure 40 where the simulated number of cars always is a little higher than the data. Askøy bridge shows a particularly bad fit. To investigate this further simulated number of users for each transportation mode is compared to data.

Figure 41 shows the number of persons commuting from Askøy to the other zones sorted after transportation mode (walkers and bicyclists excluded). Number of car users and bus users has a pattern similar to the data, but simulated car users is at average too high and simulated bus users is at average too low. The car users don’t show any jump in the growth after 2006 when the toll on the Askøy bridge where removed.

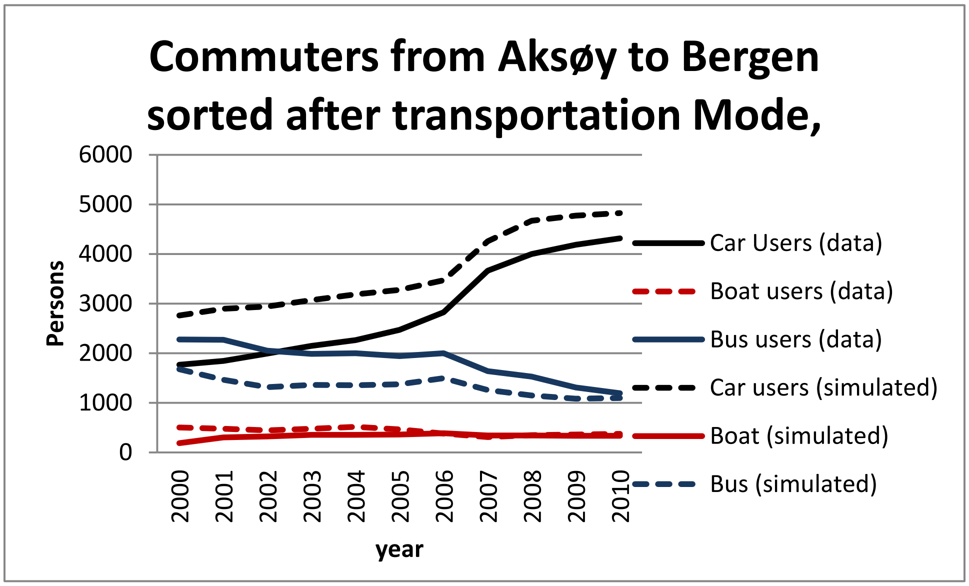


Figure 41 Commuters from Aksøy to Bergen sorted after transportation Mode, year 2000-2010

Calculating the difference between the number of commuters in the simulation and the number of commuters in the data shows an average discrepancy of ~190 persons. This is not very high and cannot be the main cause for the difference between the simulation result and the data. Theil’s inequality Statistics is again used to further investigate the goodness-of-fit of the model.

		Car users	**Bus users**	**Boat users**
MAPE (%)		18	28	35
Theil's inequality statistics	*Bias*	0,86	0,87	0,41
	Unequal variation	0,02	0	0,02
	Unequal covariation	0,12	0,12	0,57

Table 10 MAPE and TIS for transportation mode users in Askøy

MAPE is 18, 28 and 35 for the three transportation modes shown in Figure 41. Results for both simulated car and bus users have a high bias, indicating that some parameters are off. In the case of Boat users there is a high Bias and a high unequal covariation. This indicates random noise, however since very few uses boat in the model this is not explored further and focus is rather turned towards car and bus users. By adjusting the "random residuals" parameter in the model the fit can be improved for the simulated car and bus users, however at expense of reduced fit for the other references modes previously discussed. It could be possible that the random residuals differ from zone to zone. For example it could be that the distribution of average travel time with car, bus, walking time to the bus and so on has a higher variance. This would mean a higher value for the random residuals parameter.

In the extreme case, if zone A is the whole Bergen region minus one household and zone B is the one household, then the random residual parameter must be very high for zone A and very low for zone B. There are for example a lot of variations in the average walking distance from a bus stop in zone A, because people live quite different places in the region, from an isolated island to the city center of Bergen. Therefore a lot of people will still live close to a bus stop even if the average distance from a bus stop is very high, which implies a high random residuals parameter. For zone B the average travel time is the travel time for all persons in zone B. In other words there are no variations in the systemic utilities for the persons in the zone. Everyone would choose the transport mode with the average highest systemic utility. Following this argument it could be argued that the random residual parameters should be different for different zones, due to different topography, how the population are spatially distributed in the zone and other sources for random variation in peoples systemic utilities of transportation mode. Alternatively would be to use smaller zones. Disaggregating the model further would reduce the variation in the systemic utilities used for each zone. Another possible source for error is that in many cases the same parameters are used for all the zones. Improving the parameter estimation could also reduce the error.

The tables show that bias is a consistent issue. Overall the model does replicate the behavior of the reference modes, but leaves a lot to be wanted when it comes to accuracy. In the defense of the model it should be noted that the data have a very low quality. Several variables are confounded in the data (the available road data shows the total traffic on the road instead of dividing into direction) and estimations assumes that some variables are constant (car, boat and bus users estimates in Figure 41 assumes that the proportion of commuting trips remains constant) Therefore there is some ambiguity to which extent a lack of good fit between simulation results indicates flaws in the model.

All in all, the conclusion is that the model should be useful to evaluate different policies and strategies, which is the purpose of this model. The question about the accuracy of the model remains open until better data can be acquired. However for evaluating the long term effect of policies this accuracy is not crucial.

12.8 Uncertainty

To acknowledge uncertainty is important in any kind of scientific endeavor, because this makes it possible to identify its magnitude and sources. Measuring the magnitude is important because it affects the confidence that should be ascribed to the insights and the policy recommendations derived from the model. Higher uncertainty means that the results derived from the model should be given less weight. Identifying the sources of uncertainty is maybe even more important since it is the first step in eliminating, or at least reducing, the uncertainty by focusing future research towards the where it is really needed.

Uncertainty analysis is one way to quantify the uncertainty. It involves several simulations where a selected set of parameter values are drawn randomly in the beginning of the simulation(Ford, 2010; Railsback & Grimm, 2012; J. D. Sterman, 2000). These values should be drawn from a range of probable values, which means setting a probable minimum and maximum value around the estimated value. The most uncertain variables in the transportation model are the convenience coefficients (the alternative specific constants) and the random residuals parameter since there are no real data available to back up these values. I have therefore chosen to draw randomly variables for the convenience factor for car, convenience factor for public transport and the random residuals parameter. The parameter values are drawn from a normal distribution. Table 11 shows the setup for each of the three variables. Mean is the mean of the standard deviation the parameter values are drawn from. It is set equal to the baseline value of the parameter and standard deviation is set equal to the baseline/estimate parameter value times 0.25. This means that at 95 % of the drawn values should be $\pm$ 50% of the baseline parameter value.

Parameter	Mean	Standard deviation
Convenience factor car	-0.18	0.045
Convenience factor PT	-0.4	0.1
Random residuals parameter	0.45	0.1125

Table 11 Uncertainty analysis setup, normal distribution with seed = 1, 500 simulations.

The drawing of random numbers is done by using the “*sensi specs”* functionality to the *iThink 9.1.4* software. The seed for the random number generator is set to 1 for all of the parameters. Five hundred simulations were performed and the distribution of the total peak hour traffic in the simulations end year (2020) is shown as kernel density by the black line Figure 42. The horizontal axis is intervals of the total peak hour traffic in the end of the simulations and the vertical axis is the proportion of the simulations that fall within the intervals.

So what is the magnitude of the uncertainty? Simply put, the wider the distribution of simulation results the higher is the uncertainty (Railsback & Grimm, 2012). The simulations follow a distribution that is very close to a normal distribution. This is illustrated by adding a normal distribution with the same mean (15948) and standard deviation (2440) as the simulated peak hour traffic. Assuming that this normal distribution is a good approximation then one can conclude that 95 % of the simulations have a total traffic flow in the end year 2020 that fall in the interval 15948 $\pm$ 4880 cars per hour. This interval is indicated by the gray area in the Figure 42.

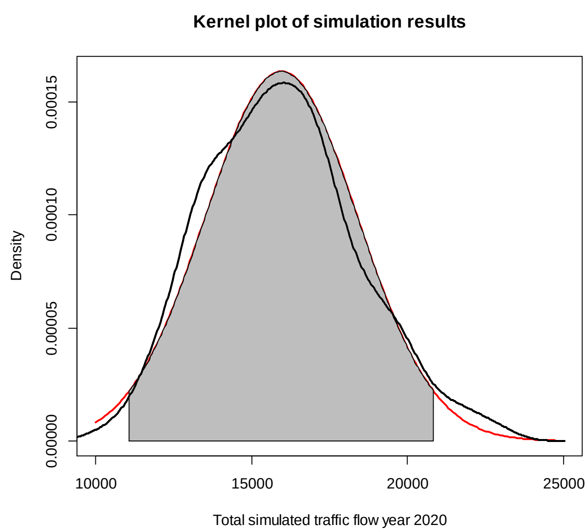


Figure 42 Kernel plot (black line) of simulated total peak hour traffic in 2020, normal distribution with same mean and standard deviation as simulation results (red line).

The conclusion is that given a random variation where 95% of the drawn values falls $\pm$50 % from the uncertain parameters baseline values; then 95% of the total simulated traffic flow in year 2020 falls only $\pm$30.6 % from the average of these simulations. The distribution is somewhat wide, but not terrible so taking into consideration of the width the uncertain parameters where varied. An interpretation of this is that one can still be confident on the model, but the uncertainty should be taken into consideration.

The uncertainty discussed above is not so important necessary when it comes to evaluate differences in the effectiveness of the policies. Absolute simulation results is often not the main interest and the difference between scenarios (Railsback & Grimm, 2012) and policies. Studying the simulation runs shows that changes in the value of the three parameters have little effect on the mode of behavior. It mostly causes an upwards/downwards shift in the total peak hour traffic flow. The behaviors for more disaggregated variables tend to change more mode of behavior when the random residuals parameter is changed then the total peak hour traffic flow. This seems to suggest that the changes in behavior mode at disaggregated level don't cause that big difference in the aggregated variables.

Structural uncertainty is another kind of uncertainty than the uncertainty in parameter values discussed above. Structural uncertainty refers to the fundamental structure of the model, which feedback loops are included and so on(Ford, 2010, p. 299). The main structural uncertainty in the transportation model is the formulation of how parking space crowding affects the transportation mode choice. It is modeled that the expected travel time increases when the car per parking space ratio increases. However an alternative formulation is that only people with access to parking space can use car for commuting (or a combination of these two model formulations). With the first formulation the effect of parking space crowding is weak and with the second formulation it becomes strong. It is not obvious what the best formulation is. Further research could however give an answer. For example a pilot study of two similar, but independent, areas, where a parking space policy was introduced in one of the areas. The study areas must of course be applicable to the case of Bergen/Norway.

12.9 Simulated commuters in BergenSim

Years	BergenC to BergenN	BergenC to BergenE	BergenC to BergenS	BergenC to BergenW	BergenC to Askoy	BergenN to BergenC	BergenN to BergenE	BergenN to BergenS	BergenN to BergenW
2000	1390	444	4341	3017	74	8390	441	1758	1232
2001	1430	426	4252	2831	201	8698	470	1801	1194
2002	1563	433	4161	2768	333	9031	525	1857	1228
2003	1672	443	4050	2748	430	9361	570	1897	1277
2004	1744	450	3899	2743	502	9634	607	1904	1328
2005	1805	458	3758	2755	557	9708	635	1886	1369
2006	1857	466	3637	2766	599	9778	658	1868	1403

2007	1907	476	3539	2779	629	9886	678	1855	1434
2008	1957	488	3470	2795	650	10028	700	1852	1462
2009	2005	502	3414	2804	666	10175	721	1850	1483
2010	2051	516	3358	2803	677	10340	741	1845	1497
2011	2099	533	3167	2804	688	10540	760	1847	1502
2012	2147	550	3021	2815	700	10782	780	1862	1512
2013	2193	563	2913	2831	711	11034	795	1884	1525
2014	2234	575	2833	2852	722	11283	810	1911	1541
2015	2272	586	2777	2876	734	11527	826	1941	1559
2016	2306	595	2740	2903	746	11764	842	1972	1577
2017	2337	602	2722	2932	759	11990	857	2004	1596
2018	2367	609	2725	2965	772	12205	874	2037	1615
2019	2396	615	2751	3000	785	12403	892	2072	1634
2020	2426	621	2797	3039	798	12586	912	2108	1651

Years	BergenN to Askoy	BergenE to BergenC	BergenE to BergenN	BergenE to BergenS	BergenE to BergenW	BergenE to Askoy	BergenS to BergenC	BergenS to BergenN	BergenS to BergenE
2000	30	2178	452	669	138	3	9607	419	372
2001	59	2412	513	807	164	9	9825	495	380
2002	104	2556	587	959	203	19	9763	598	411
2003	144	2543	617	1042	228	29	9612	669	434
2004	181	2531	634	1109	250	37	9462	717	453
2005	213	2521	648	1169	269	44	9311	757	469
2006	240	2515	658	1221	286	50	9167	788	484
2007	262	2519	666	1266	300	55	9038	815	499
2008	278	2527	674	1308	313	59	8932	840	517
2009	292	2536	681	1343	322	62	8882	864	536
2010	302	2551	688	1368	328	64	8918	888	557
2011	309	2576	692	1394	331	66	8609	918	583
2012	315	2613	697	1424	335	67	8384	946	605
2013	321	2654	703	1457	339	68	8222	971	621
2014	327	2694	709	1492	342	69	8114	993	635
2015	333	2732	715	1529	346	70	8049	1013	646
2016	340	2769	723	1570	350	71	8021	1030	655
2017	346	2804	731	1614	353	72	8031	1044	661
2018	352	2835	740	1662	356	73	8076	1057	667
2019	358	2861	750	1716	358	74	8153	1068	671
2020	363	2882	760	1773	359	74	8260	1078	675

Years	BergenS to BergenW	BergenS to Askoy	BergenW to BergenC	BergenW to BergenN	BergenW to BergenE	BergenW to BergenS	BergenW to Askoy	Askoy to BergenC	Askoy to BergenN
2000	2096	51	12987	625	108	4292	181	2322	112
2001	1914	81	12481	665	121	3914	331	2536	145
2002	1785	123	11964	760	149	3556	540	2670	199
2003	1683	157	11777	848	175	3296	692	2788	248

2004	1600	187	11905	931	200	3089	812	2919	293
2005	1537	213	12239	1019	225	2942	909	3050	337
2006	1482	235	12673	1105	250	2840	991	3167	377
2007	1438	254	13079	1186	273	2766	1061	3254	412
2008	1403	269	13330	1252	294	2702	1125	3290	437
2009	1373	281	13490	1305	312	2639	1187	3292	454
2010	1348	291	13655	1351	329	2579	1244	3288	464
2011	1334	302	13913	1390	343	2543	1293	3298	471
2012	1326	311	14090	1419	355	2513	1338	3291	473
2013	1323	319	14227	1443	364	2492	1379	3279	473
2014	1324	325	14367	1464	372	2483	1417	3272	473
2015	1327	332	14527	1484	379	2483	1453	3273	473
2016	1333	338	14700	1503	385	2492	1487	3281	472
2017	1341	343	14872	1519	389	2506	1520	3292	471
2018	1349	349	15022	1532	393	2520	1553	3302	468
2019	1358	353	15141	1541	396	2538	1585	3308	463
2020	1367	358	15225	1547	398	2554	1618	3309	457

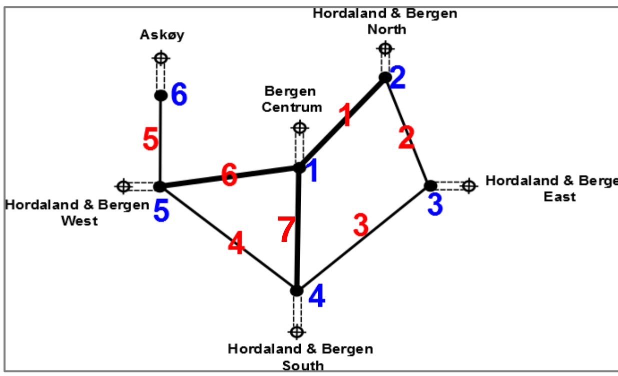
Years	Askoy to BergenE	Askoy to BergenS	Askoy to BergenW
2000	19	767	1318
2001	26	922	1389
2002	40	1116	1535
2003	52	1268	1652
2004	65	1378	1752
2005	76	1465	1841
2006	87	1532	1907
2007	97	1584	1960
2008	105	1625	2000
2009	111	1656	2028
2010	115	1681	2047
2011	119	1709	2056
2012	121	1730	2058
2013	122	1747	2058
2014	123	1761	2057
2015	123	1773	2056
2016	123	1783	2054
2017	123	1791	2052
2018	122	1796	2049
2019	121	1802	2044
2020	120	1806	2038

12.10 Table with Origin-Destinations pairs and Paths

Origin	Destination	ID
Bergen Centrum	Hordaland & Bergen North	1
Bergen Centrum	Hordaland & Bergen East	2
Bergen Centrum	Hordaland & Bergen South	3
Bergen Centrum	Hordaland & Bergen West	4
Bergen Centrum	Askøy	5
Hordaland & Bergen North	Bergen Centrum	6
Hordaland & Bergen North	Hordaland & Bergen East	7
Hordaland & Bergen North	Hordaland & Bergen South	8
Hordaland & Bergen North	Hordaland & Bergen West	9
Hordaland & Bergen North	Askøy	10
Hordaland & Bergen East	Bergen Centrum	11
Hordaland & Bergen East	Hordaland & Bergen North	12
Hordaland & Bergen East	Hordaland & Bergen South	13
Hordaland & Bergen East	Hordaland & Bergen West	14
Hordaland & Bergen East	Askøy	15
Hordaland & Bergen South	Bergen Centrum	16
Hordaland & Bergen South	Hordaland & Bergen North	17
Hordaland & Bergen South	Hordaland & Bergen East	18
Hordaland & Bergen South	Hordaland & Bergen West	19
Hordaland & Bergen South	Askøy	20
Hordaland & Bergen West	Bergen Centrum	21
Hordaland & Bergen West	Hordaland & Bergen North	22
Hordaland & Bergen West	Hordaland & Bergen East	23
Hordaland & Bergen West	Hordaland & Bergen South	24
Hordaland & Bergen West	Askøy	25
Askøy	Bergen Centrum	26
Askøy	Hordaland & Bergen North	27
Askøy	Hordaland & Bergen East	28
Askøy	Hordaland & Bergen South	29
Askøy	Hordaland & Bergen West	30

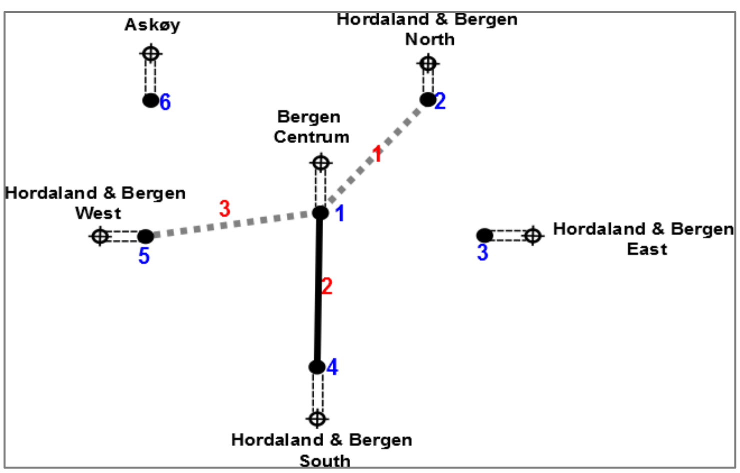
Paths	OD	ID
[1, 2]	[1, 2]	1
[1, 2], [2, 3]	[1, 3]	2
[1, 4]	[1, 4]	3
[1, 5]	[1, 5]	4
[1, 5], [5, 6]	[1, 6]	5
[2, 1]	[2, 1]	6
[2, 3]	[2, 3]	7
[2, 1], [1, 4]	[2, 4]	8
[2, 1], [1, 5]	[2, 5]	9
[2, 1], [1, 5], [5, 6]	[2, 6]	10
[3, 2], [2, 1]	[3, 1]	11
[3, 2]	[3, 2]	12
[3, 4]	[3, 4]	13
[3, 2], [2, 1], [1, 5]	[3, 5]	14
[3, 4], [4, 5]	[3, 5]	15
[3, 2], [2, 1], [1, 5], [5, 6]	[3, 6]	16
[5, 1], [1, 4]	[5, 4]	17
[3, 4], [4, 5], [5, 6]	[3, 6]	18
[4, 1]	[4, 1]	19
[4, 1], [1, 2]	[4, 2]	20
[4, 3]	[4, 3]	21
[4, 5]	[4, 5]	22
[4, 1], [1, 5], [5, 6]	[4, 6]	23
[4, 5], [5, 6]	[4, 6]	24
[5, 1]	[5, 1]	25
[5, 1], [1, 2]	[5, 2]	26
[5, 1], [1, 2], [2, 3]	[5, 3]	27
[5, 4], [4, 3]	[5, 3]	28
[5, 4]	[5, 4]	29
[5, 6]	[5, 6]	30
[6, 5], [5, 1]	[6, 1]	31
[6, 5], [5, 1], [1, 2]	[6, 2]	32
[6, 5], [5, 1], [1, 2], [2, 3]	[6, 3]	33
[4,1],[1,5]	[4, 5]	34
[6, 5], [5, 4], [4, 3]	[6, 3]	35
[6, 5], [5, 1], [1, 4]	[6, 4]	36
[6, 5], [5, 4]	[6, 4]	37
[6, 5]	[6, 5]	38

12.11 Table of Links in the Road Network and Indexed Road Network Graph Bergen



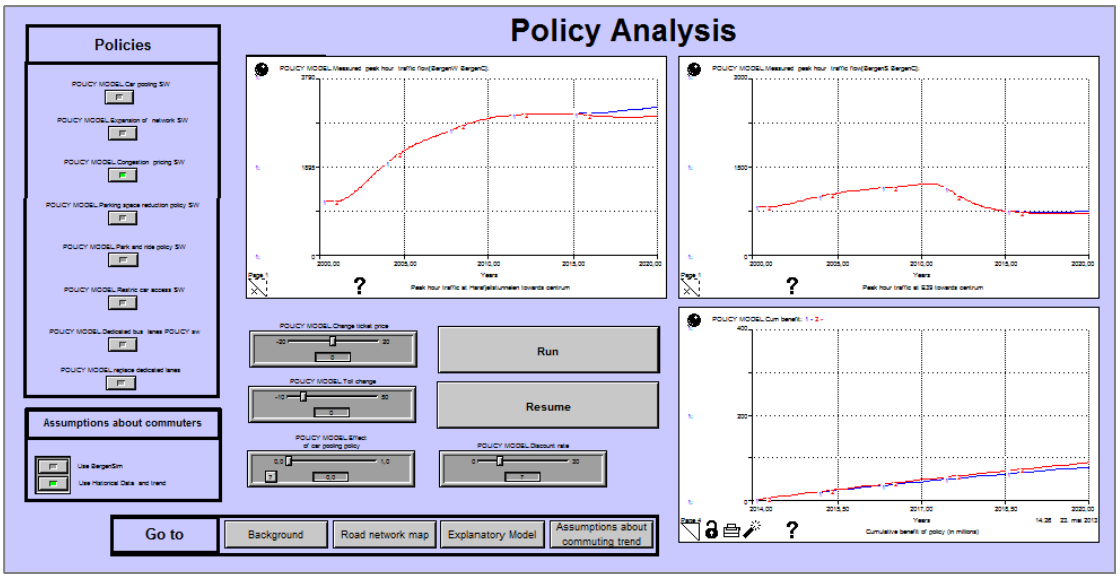
Link	Name of nodes connected	ID
[1, 2]	Bergen Centrum -> Hordaland & Bergen North	1
[2, 1]	Hordaland & Bergen North -> Bergen Centrum	2
[2, 3]	Hordaland & Bergen North -> Hordaland & Bergen East	3
[3, 2]	Hordaland & Bergen East -> Hordaland & Bergen North	4
[3, 4]	Hordaland & Bergen East -> Hordaland & Bergen South	5
[4, 3]	Hordaland & Bergen South -> Hordaland & Bergen East	6
[4, 1]	Hordaland & Bergen South -> Bergen centrum	7
[1, 4]	Bergen centrum -> Hordaland & Bergen South	8
[4, 5]	Hordaland & Bergen South -> Hordaland & Bergen West	9
[5, 4]	Hordaland & Bergen West -> Hordaland & Bergen South	10
[5, 6]	Hordaland & Bergen West -> Askøy	11
[6, 5]	Askøy -> Hordaland & Bergen West	12
[5, 1]	Hordaland & Bergen West -> Bergen centrum	13
[1, 5]	Bergen centrum -> Hordaland & Bergen West	14

12.12 Indexed Tram Network graph Bergen I

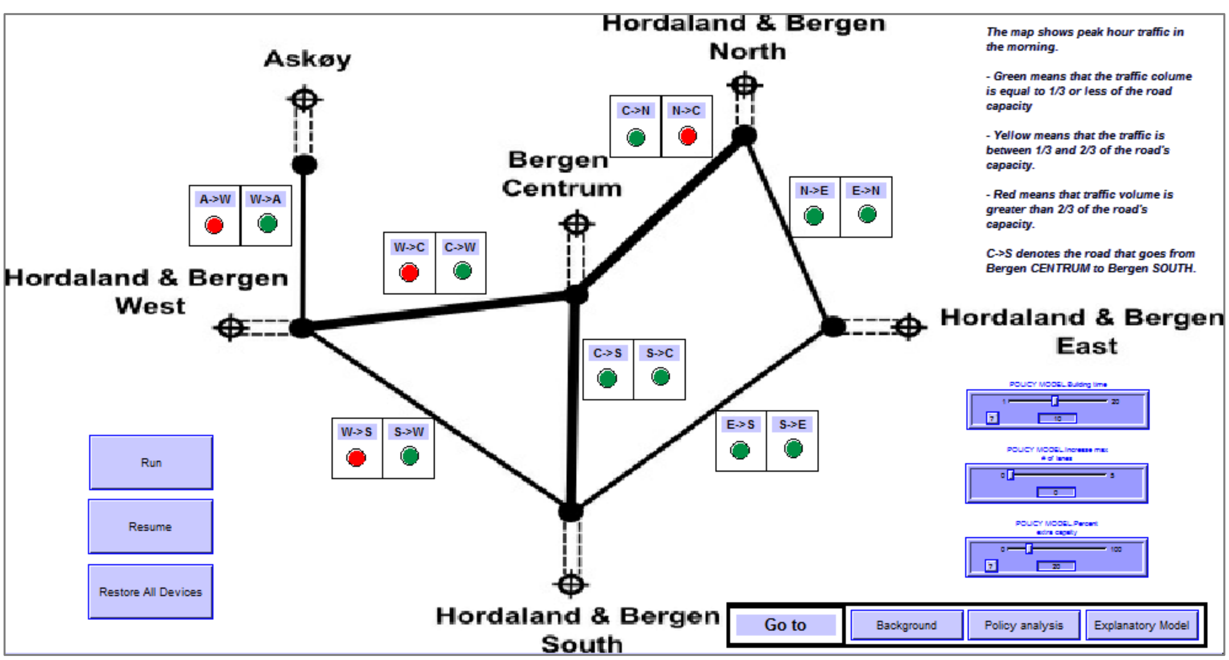


12.13 Interactive Learning Environment

The model includes an interactive learning environment (ILE). The ILE includes description of the system (under “Explanatory Model” in the menu) which allows the user to test the effect of changing model assumptions and test policies (under “Policy Analysis”). A screenshot of the policy analysis part is shown below.



It also contains a network map which makes it possible for the user to explore the spatial dimension of the model and how the traffic flows through the road network. A screenshot of the road network view in the ILE is shown below. The lamp indicates the level of congestion on the different road links.



12.14 Equations explanatory model

Available__space(t) = Available__space(t - dt) + (- parking_spaces_construction) * dt
INIT Available__space = 800000
UNITS: cars
DOCUMENT: {cars}
Unused space (measured in cars) that can be converted to parking spaces. Potential parking spaces.
OUTFLOWS:
parking_spaces_construction = MIN(Parking_spaces_desired_constructred/Parking_space__building_time, Available__space)
UNITS: cars/yr
DOCUMENT: {cars/year}
This is the building rate for parking spaces.
Cars[OD](t) = Cars[OD](t - dt) + (Acquisition[OD] + Cars_imported__or_exported[OD] - Scrapping[OD]) * dt
INIT Cars[OD] =
[673,215,2102,1461,36,4500,168,668,468,12,1055,219,498,103,2,7156,312,277,1561,38,6288,303,52,2078,88,1124,54,9,371,638]
UNITS: cars
DOCUMENT: {cars}
Cars owned by commuters, ordered after work and home zone (i.e. OD).
INFLOWS:
Acquisition[OD] =
MAX(Perceived_scrapping[OD]+Car_acquisition_SW*Desired__car_acquision[OD]/Average_time_spent_to_acquire_a_car, 0)
UNITS: cars/yr
DOCUMENT: {cars/yr}
Yearly cars acquired. Which is the cars scrapped plus cars desired aquired.
Cars_imported__or_exported[OD] = Average_car_ownership*(Commuters[OD]-SMTH1(Commuters[OD], DT))/DT
UNITS: cars/yr
DOCUMENT: {cars/yr}
Cars imported or exported as people move or change work place.
OUTFLOWS:
Scrapping[OD] = DELAY3(Acquisition[OD], Lifetime__of_car)
UNITS: cars/yr
DOCUMENT: {cars/yr}
Yearly number of cars scrapped. Cars rusts and breakdown over time, eventually they are scrapped. It is a higher order delay because cars goes through an aging chain from being a new car, couple of years old, old and acient. The propability that the car is scrapped increases for each state as the car becomes older.
Expected_cost__car[Paths](t) = Expected_cost__car[Paths](t - dt) + (chg_in_cost_of_car[Paths]) * dt
INIT Expected_cost__car[Paths] =
[37.54,47.81,35.83,35.49,38.91,38.74,40.27,44.45,44.12,47.5,48.93,40.33,40.95,54.38,49.17,57.78,46.32,52.6,36.19,43.69,40.95,38.22,45.06,41.64,40.36,47.96,57.83,49.24,38.29,33.42,44.25,51.57,61.45,41.65,52.86,49.93,41.92,33.65]
UNITS: NOK
DOCUMENT: {NOK}
Expected monetary cost of using car.
INFLOWS:
chg_in_cost_of_car[Paths] = (Total_Monetary__cost[Paths]-Expected_cost__car[Paths])/Time_to_perceive_cost_chg
UNITS: nok/yr
DOCUMENT: {NOK/yr}
Adjustment of expected monetary costs of using car.
Expected_travel_time_of_Boat[OD](t) = Expected_travel_time_of_Boat[OD](t - dt) + (chg_perc_travel_time_boat[OD]) * dt
INIT Expected_travel_time_of_Boat[OD] = [00, 0, 0, 0 ,0.5 ,00, 00, 00, 00, 00, 00, 00, 00, 0, 00, 00, 0, 0, 00, 00, 00, 00, 00, 0, 00, 1.3, 00, 0,0000,0000]
UNITS: hours (hr)
DOCUMENT: {hours}
Commuters' expectations about travel time with boat.
INFLOWS:
chg_perc_travel_time_boat[OD] =
(Travel_time_to_boat[OD]*Effect_of_crowding_on_travel_time_to_boat[OD]+Waiting_time_with_boat[OD]+Travel_time__with_boat[OD]-Expected_travel_time_of_Boat[OD])/Time_to_perceive_cost_chg

UNITS: hr/yr
DOCUMENT: {hr/yr}
Commuters' adjustment of expected travel time with car.
Expected_travel_time__with_car[Paths](t) = Expected_travel_time__with_car[Paths](t - dt) + (Chg_in__perceived_cost[Paths]) * dt
INIT Expected_travel_time__with_car[Paths] = [0.3,0.55,0.26,0.25,0.34,0.35,0.37,0.49,0.48,0.56,0.6,0.37,0.39,0.73,0.59,0.81,0.52,0.67,0.27,0.45,0.39,0.32,0.49,0.4,0.38,0.56,0.81,0.59,0.32,0.2,0.47,0.65,0.9,0.4,0.68,0.61,0.41,0.21]
UNITS: hours (hr)
DOCUMENT: {hours}
Commuters' expectations about travel time with car.
INFLOWS:
Chg_in__perceived_cost[Paths] = (Access_regress_time+Search_time_after_parking_space[Paths]+Travel_time_with_car[Paths]-Expected_travel_time__with_car[Paths])/Time_to_perceive_cost_chg
UNITS: hr/yr
DOCUMENT: {Hours}
Adjustment of peoples expected travel time with car.
Expected__cost_of_Bus(t) = Expected__cost_of_Bus(t - dt) + (chg_expected__cost_of_bus) * dt
INIT Expected__cost_of_Bus = 21.9
UNITS: NOK
DOCUMENT: {NOK}
Monetary costs of using bus expected by the commuters.
INFLOWS:
chg_expected__cost_of_bus = (Ticket_price-Expected__cost_of_Bus)/Time_to_perceive_cost_chg
UNITS: nok/yr
DOCUMENT: {NOK/yr}
Change of commuters' expectations about the monetary costs of using bus.
Expected__cost_tram(t) = Expected__cost_tram(t - dt) + (chg_in_expected__cost_of_tram) * dt
INIT Expected__cost_tram = 0
UNITS: NOK
DOCUMENT: {NOK}
Monetary costs of using tram.
INFLOWS:
chg_in_expected__cost_of_tram = (Ticket_price-Expected__cost_tram)/Time_to_perceive_cost_chg
UNITS: nok/yr
DOCUMENT: {NK/yr}
Adjustment of commuters' expected cost of tram.
Expected__travel_time_of_Bus[Paths](t) = Expected__travel_time_of_Bus[Paths](t - dt) + (chg_percv_travel_time__bus[Paths]) * dt
INIT Expected__travel_time_of_Bus[Paths] = [0.67, 0.9, 0.6, 0.6, 0.68, 0.69, 0.68, 0.84, 0.84, 0.92, 0.92, 0.68, 0.77, 1.07, 1.02, 1.15, 1.15, 1.1, 0.6, 0.82, 0.77, 0.75, 0.84, 0.78, 0.85, 1.07, 1.3, 1.02, 1, 0.53, 0.94, 1.15, 1.39, 1.41, 1.1, 1.09, 0.78, 0.53]
UNITS: hours (hr)
DOCUMENT: {hours}
Travel time of using bus expected by the commuters.
INFLOWS:
chg_percv_travel_time__bus[Paths] = (Average_travel__time_with_Bus[Paths]-Expected__travel_time_of_Bus[Paths])/Time_to_perceive_cost_chg
UNITS: hr/yr
DOCUMENT: {time/yr}
Change of commuters' expectations about the travel time of using bus.
Expected_cost_of_Boat(t) = Expected_cost_of_Boat(t - dt) + (chg_expected_cost_of_boat) * dt
INIT Expected_cost_of_Boat = 21.9
UNITS: NOK
DOCUMENT: {NOK}
Monetary cost of using boat expected by commuters.
INFLOWS:
chg_expected_cost_of_boat = (Ticket_price-Expected_cost_of_Boat)/Time_to_perceive_cost_chg
UNITS: nok/yr

DOCUMENT: {NOK/yr}
Adjustment of expectations about monetary cost of boat.
Expected_risk_Boat[OD](t) = Expected_risk_Boat[OD](t - dt) + (chg_in_risk_Boat[OD]) * dt
INIT Expected_risk_Boat[OD] = 15/60
UNITS: hours (hr)
DOCUMENT: {hours}
Risk associated with using boat.
INFLOWS:
chg_in_risk_Boat[OD] = (Normal_standard__deviation_boat-Expected_risk_Boat[OD])/Time_to_perceive_cost_chg
UNITS: hr/yr
DOCUMENT: Adjustment of expected risk.
Expected_risk_bus[Paths](t) = Expected_risk_bus[Paths](t - dt) + (chg_in_risk_bus[Paths]) * dt
INIT Expected_risk_bus[Paths] =
[0.12,0.18,0.16,0.17,0.2,0.42,0.06,0.58,0.59,0.62,0.61,0.19,0.06,0.78,0.19,0.81,0.81,0.22,0.38,0.5,0.05,0.13,0.58,0.16,0.65,0.77,0.82,0.28,0.24,0.03,1,1.12,1.18,0.55,0.64,1.16,0.59,0.35]
UNITS: hours (hr)
DOCUMENT: {hours}
Risk of using bus expected by the commuters.
INFLOWS:
chg_in_risk_bus[Paths] = (Standard_deviation_travel_time_bus[Paths]-Expected_risk_bus[Paths])/Time_to_perceive_cost_chg
UNITS: hr/yr
DOCUMENT: {time/yr}
Change of commuters' expectations about the risk of using bus.
Expected_risk_car[Paths](t) = Expected_risk_car[Paths](t - dt) + (chg_in_risk_car[Paths]) * dt
INIT Expected_risk_car[Paths] = [0.03, 0.02, 0.06, 0.05, 0.03, 0.09, 0.01, 0.08, 0.08, 0.06, 0.07, 0.04, 0.01, 0.06, 0.01, 0.06, 0.03, 0.01, 0.06, 0.04, 0.01, 0.06, 0.05, 0, 0.18, 0.09, 0.06, 0.01, 0.12, 0.01, 0.14, 0.08, 0.06, 0.06, 0.02, 0.11, 0.02, 0.06]
UNITS: hours (hr)
DOCUMENT: {hours}
Expected risk of using car.
INFLOWS:
chg_in_risk_car[Paths] = (Standard_deviation_in_travel_time_car[Paths]-Expected_risk_car[Paths])/Time_to_perceive_cost_chg
UNITS: hr/yr
DOCUMENT: {hr/yr}
Adjustment of expected risk.
Expected_risk_tram(t) = Expected_risk_tram(t - dt) + (chg_in_expected__variance_tram) * dt
INIT Expected_risk_tram = 0
UNITS: hours (hr)
DOCUMENT: {hours}
Risk associated with using tram.
INFLOWS:
chg_in_expected__variance_tram = (Normal_deviation__in_travel_time_with_tram-Expected_risk_tram)/Time_to_perceive_cost_chg
UNITS: hr/yr
DOCUMENT: {hr/yr}
Adjustment of expected risk.
Parking__spaces(t) = Parking__spaces(t - dt) + (parking_spaces_construction) * dt
INIT Parking__spaces = 10000
UNITS: cars
DOCUMENT: {cars}
This is the number of parking paces in Bergen. Includes street parking, p-house, parking at work places and private parking places. Measured in # cars they can hold.
INFLOWS:
parking_spaces_construction = MIN(Parking_spaces_desired_constructred/Parking_space__building_time, Available__space)
UNITS: cars/yr
DOCUMENT: {cars/year}
This is the building rate for parking spaces.
Perceived__travel_time_tram[Paths](t) = Perceived__travel_time_tram[Paths](t - dt) + (chg_in_perv_travel_time_tram[Paths]) * dt
INIT Perceived__travel_time_tram[Paths] = 0

UNITS: hours (hr)
DOCUMENT: {hours}
Expected travel time with tram.
INFLOWS:
chg_in_perv_travel_time_tram[Paths] = (Travel__time_with_tram[Paths]-
Perceived__travel_time_tram[Paths])/Time_to_perceive_cost_chg
UNITS: hr/yr
Perceived_cost__of_paths[Paths](t) = Perceived_cost__of_paths[Paths](t - dt) + (Change_in_perceived_path_costs[Paths]) * dt
INIT Perceived_cost__of_paths[Paths] = Free_flow_path__travel_time[Paths]
UNITS: hours (hr)
DOCUMENT: {hour}
Perceived costs of paths.
INFLOWS:
Change_in_perceived_path_costs[Paths] = (Travel_time_with_car[Paths]-
Perceived_cost__of_paths[Paths])/Time_to_perceive_change_in_path_costs
UNITS: hr/yr
DOCUMENT: {hours/year}
change i perception of costs.
Perceived_scrapping[OD](t) = Perceived_scrapping[OD](t - dt) + (chg_in_perceived_srapping[OD]) * dt
INIT Perceived_scrapping[OD] =
[1.14,0.36,3.71,2.65,0.07,3.02,0.25,1.63,1.15,0.03,2.57,0.39,0,0.04,0,2.52,0.14,0,0.7,0.01,15.91,0.81,0.13,5.44,0.14,3.17,0.16,0.03,1.04,1.4]
UNITS: cars/yr
INFLOWS:
chg_in_perceived_srapping[OD] = (Scrapping[OD]-Perceived_scrapping[OD])/Time_to_pereive_scrapping
UNITS: cars/yr^2
Proportion__using_bicycle[OD](t) = Proportion__using_bicycle[OD](t - dt) + (Change_in_proportion_using_bicycle[OD]) * dt
INIT Proportion__using_bicycle[OD] = Proportion_that_prefer__to_bicycle[OD]
UNITS: Unitless
DOCUMENT: {unitless}
INFLOWS:
Change_in_proportion_using_bicycle[OD] = (Proportion_that_prefer__to_bicycle[OD]-
Proportion__using_bicycle[OD])/Adaptation_time
UNITS: 1/yr
Proportion__using_boat[OD](t) = Proportion__using_boat[OD](t - dt) + (change_in__proportion_using_boat[OD]) * dt
INIT Proportion__using_boat[OD] = Proportion_that_prefer_Boat[OD]
UNITS: Unitless
DOCUMENT: {unitless}
INFLOWS:
change_in__proportion_using_boat[OD] = (Proportion_that_prefer_Boat[OD]-Proportion__using_boat[OD])/Adaptation_time
UNITS: 1/yr
Proportion__using_bus[OD](t) = Proportion__using_bus[OD](t - dt) + (change_in__proportion_using_bus[OD]) * dt
INIT Proportion__using_bus[OD] = Proportion_that_prefer_Bus[OD]
UNITS: Unitless
DOCUMENT: {unitless}
Proportion of people using bus.
INFLOWS:
change_in__proportion_using_bus[OD] = (Proportion_that_prefer_Bus[OD]-Proportion__using_bus[OD])/Adaptation_time
UNITS: 1/yr
DOCUMENT: {unitless/yr}
Change in the proportion using bus.
Proportion__using_car[OD](t) = Proportion__using_car[OD](t - dt) + (Change_in__proportion__using_car[OD]) * dt
INIT Proportion__using_car[OD] =
[0.47,0.47,0.49,0.5,0.48,0.7,0.41,1,0.78,0.79,0.81,0.54,0.43,0.72,0.72,0.65,0.72,0.41,0.7,0.63,0.85,0.89,0.78,0.84,0.43,0.88,0.97,0.93,0.93,0.7]
UNITS: Unitless
DOCUMENT: {unitless}
INFLOWS:

Change_in__proportion__using_car[OD] = (Proportion_that__want_to_use__Car[OD]-Proportion__using_car[OD])/Adaptation_time
UNITS: 1/yr
Proportion__using_tram[OD](t) = Proportion__using_tram[OD](t - dt) + (change_in__proportion_using_tram[OD]) * dt
INIT Proportion__using_tram[OD] = Proportion_prefering_Tram[OD]
UNITS: Unitless
DOCUMENT: {unitless}
INFLOWS:
change_in__proportion_using_tram[OD] = (Proportion_prefering_Tram[OD]-Proportion__using_tram[OD])/Adaptation_time
UNITS: 1/yr
Proportion__walking[OD](t) = Proportion__walking[OD](t - dt) + (Change_in__proportion_walking[OD]) * dt
INIT Proportion__walking[OD] = Proportion_that_prefer_to_walk[OD]
UNITS: Unitless
DOCUMENT: {unitless}
INFLOWS:
Change_in__proportion_walking[OD] = (Proportion_that_prefer_to_walk[OD]-Proportion__walking[OD])/Adaptation_time
UNITS: 1/yr
Road_quality[Links](t) = Road_quality[Links](t - dt) + (Road_construction[Links] - Road__deterioration[Links]) * dt
INIT Road_quality[Links] = [25,25.6,12,12,12.8,12.8,20.4,20.4,9.6,9.6,4,4,12.8,12.8]
UNITS: kilometers (km)
DOCUMENT: {km}
Km of road at a given link. If a road segment of the length 2 km has 4 km of roads then this is equvivalent with saying that the road segment has 2 lanes going towards Bergen. If the same road only has 2.5 km of road, then 50 % of the road segment is a one lane road and the other 50 % is a two lane road (still just considering lanes in one direction).
INFLOWS:
Road_construction[Links] = Desired_total_road_construction[Links]
UNITS: km/yr
DOCUMENT: {km/yr}
Km road constructed and maintained each year.
OUTFLOWS:
Road__deterioration[Links] = Road_quality[Links]/Average_lifetime_of__a_road
UNITS: km/yr
Access_regress_time = 0/60
UNITS: hours (hr)
DOCUMENT: {hr}
Time to enter/exit highway. Also includes "other" costant time factors.
Adaptation_time = 1
UNITS: years (yr)
DOCUMENT: {years}
The time it takes for people to change mode of transportation.
Additional_travel_time_for_bus[Paths] = ARRAYSUM(Average_waiting_time_matrix_bus[*,Paths])/ARRAYSUM(Orgin_path_matrix[*,Paths])+ARRAYSUM(Average_walking_time_Bus_paths[*,Paths])/ARRAYSUM(Orgin_path_matrix[*,Paths])+Average_time_used_at_stops
UNITS: hours (hr)
DOCUMENT: {hours}
Additional_travel_time_for_tram[Paths] = Average_time_used_at_stops+Walking__time_to_tram_station[Paths]+Average__waiting_time_TRAM[Paths]
UNITS: hours (hr)
DOCUMENT: {hours}
Additional__travel_time_factor = 1.5
UNITS: Unitless
DOCUMENT: {unitless}
Additional travel time factor with bus. Increase in travel time for car have an even bigger effect on bus because it must enter and exit traffic at each stop.
Additional_travel__time_bus[OD] = ARRAYSUM(Additional_travel__time_bus_MATRIX[OD,*])
Additional_travel__time_bus_MATRIX[OD,Paths] = Average_waiting_time_matrix_bus[OD,Paths]*Fraction_using__path[Paths]
Aggregated_tram_users = ARRAYSUM(Tram_users[*])
Aggregated__slow_users = ARRAYSUM(Walkers[*]) + ARRAYSUM(bicycle_users[*])
Aggregated_boat__users = ARRAYSUM(Boat_users[*])

Aggregated_bus_users = ARRAYSUM(Bus_users[*])
Aggregated_car_users = ARRAYSUM(Car_Users[*])
Askøy_bridge_SIMULATED = Measured__peak_hour__traffic_flow[Askoy_BergenW]
Attractiveness__of__bicycle[OD] =
EXP((Attractiveness__parameters_Bicycle[TravelTime]*bicycle__time[OD]+Attractiveness__parameters_Bicycle[Convenience])/
Random__residuals)
UNITS: Unitless
DOCUMENT: {unitless}
Attractiveness___parameters_Walking[TravelTime] = -0.28
DOCUMENT: {1/hour}, {1/NOK} and so on.
Attractiveness___parameters_Walking[MonetaryCosts] = 0
Attractiveness___parameters_Walking[Changes] = 0
Attractiveness___parameters_Walking[Convenience] = -1.7
Attractiveness___parameters_Walking[Standarddeviation] = -1
Attractiveness___parameters__PT[TravelTime] = -0.14
Attractiveness___parameters__PT[MonetaryCosts] = -0.008
Attractiveness___parameters__PT[Changes] = -0.01
Attractiveness___parameters__PT[Convenience] = 0.1
DOCUMENT: {1/time, 1/NOK etc.}
Utility parameters that weight risk, monetary cost and so on.
Attractiveness___parameters__PT[Standarddeviation] = -0.69
Attractiveness__of_tram[OD] = EXP(
(Attractiveness___parameters__PT[TravelTime]*Perceived_travel_time__OD_Tram[OD]
+Attractiveness___parameters__PT[MonetaryCosts]*Expected__cost_tram
+Attractiveness___parameters__PT[Standarddeviation]*Expected_risk_tram+Attractiveness___parameters__PT[Convenience]
+Expansion_of__Tram_network[OD])
/Random__residuals)
UNITS: Unitless
Attractiveness__parameters_car[TravelTime] = -0.14
Attractiveness__parameters_car[MonetaryCosts] = -0.005
Attractiveness__parameters_car[Changes] = 0
Attractiveness__parameters_car[Convenience] = -0.03
Attractiveness__parameters_car[Standarddeviation] = -0.42
Attractiveness___of_bus[OD] =
EXP((Attractiveness___parameters__PT[TravelTime]*Travel_time_for_bus_after_orgin[OD]+Attractiveness___parameters__PT[
MonetaryCosts]*Expected__cost_of_Bus+Attractiveness___parameters__PT[Changes]*Average_number__of__bus_changes+A
ttractiveness___parameters__PT[Convenience]+Attractiveness___parameters__PT[Standarddeviation]*(Average_expected_risk
_after_origin_bus[OD]))/Random__residuals)
UNITS: Unitless
DOCUMENT: {unitless}
Attractiveness___of_walking[OD] =
EXP((Attractiveness___parameters_Walking[TravelTime]*Walking___time[OD]+Attractiveness___parameters_Walking[Conveni
ence])/Random__residuals)
UNITS: Unitless
DOCUMENT: {unitless}
Attractiveness___of__boat[BergenC_to_BergenN] =
EXP((Attractiveness___parameters__PT[TravelTime]*Expected_travel_time_of_Boat[BergenC_to_BergenN]+Attractiveness___p
arameters__PT[MonetaryCosts]*Expected_cost_of_Boat+Attractiveness___parameters__PT[Convenience]+Attractiveness___p
arameters__PT[Standarddeviation]*Expected_risk_Boat[BergenC_to_BergenN]
-999999999999)
/Random__residuals)
UNITS: Unitless
Attractiveness___of__boat[BergenC_to_BergenE] =
EXP((Attractiveness___parameters__PT[TravelTime]*Expected_travel_time_of_Boat[BergenC_to_BergenE]+Attractiveness___p
arameters__PT[MonetaryCosts]*Expected_cost_of_Boat+Attractiveness___parameters__PT[Convenience]+Attractiveness___p
arameters__PT[Standarddeviation]*Expected_risk_Boat[BergenC_to_BergenE]
-999999999999
)/Random__residuals)
UNITS: Unitless

Attractiveness___of__boat[BergenC_to_BergenS] =
EXP((Attractiveness___parameters__PT[TravelTime]*Expected_travel_time_of_Boat[BergenC_to_BergenS]+Attractiveness___parameters__PT[MonetaryCosts]*Expected_cost_of_Boat+Attractiveness___parameters__PT[Convenience]+Attractiveness___parameters__PT[Standarddeviation]*Expected_risk_Boat[BergenC_to_BergenS]
-999999999999
)/Random__residuals)
UNITS: Unitless
Attractiveness___of__boat[BergenC_to_BergenW] =
EXP((Attractiveness___parameters__PT[TravelTime]*Expected_travel_time_of_Boat[BergenC_to_BergenW]+Attractiveness___parameters__PT[MonetaryCosts]*Expected_cost_of_Boat+Attractiveness___parameters__PT[Convenience]+Attractiveness___parameters__PT[Standarddeviation]*Expected_risk_Boat[BergenC_to_BergenW]
-999999999999
)/Random__residuals)
UNITS: Unitless
Attractiveness___of__boat[BergenC_to_Askoy] =
EXP((Attractiveness___parameters__PT[TravelTime]*Expected_travel_time_of_Boat[BergenC_to_Askoy]+Attractiveness___parameters__PT[MonetaryCosts]*Expected_cost_of_Boat+Attractiveness___parameters__PT[Convenience]+Attractiveness___parameters__PT[Standarddeviation]*Expected_risk_Boat[BergenC_to_Askoy]+Convenience__of_boat)/Random__residuals)
UNITS: Unitless
Attractiveness___of__boat[BergenN_to_BergenC] =
EXP((Attractiveness___parameters__PT[TravelTime]*Expected_travel_time_of_Boat[BergenN_to_BergenC]+Attractiveness___parameters__PT[MonetaryCosts]*Expected_cost_of_Boat+Attractiveness___parameters__PT[Convenience]+Attractiveness___parameters__PT[Standarddeviation]*Expected_risk_Boat[BergenN_to_BergenC]-999999999999)/Random__residuals)
UNITS: Unitless
Attractiveness___of__boat[BergenN_to_BergenE] =
EXP((Attractiveness___parameters__PT[TravelTime]*Expected_travel_time_of_Boat[BergenN_to_BergenE]+Attractiveness___parameters__PT[MonetaryCosts]*Expected_cost_of_Boat+Attractiveness___parameters__PT[Convenience]+Attractiveness___parameters__PT[Standarddeviation]*Expected_risk_Boat[BergenN_to_BergenE]-999999999999)/Random__residuals)
UNITS: Unitless
Attractiveness___of__boat[BergenN_to_BergenS] =
EXP((Attractiveness___parameters__PT[TravelTime]*Expected_travel_time_of_Boat[BergenN_to_BergenS]+Attractiveness___parameters__PT[MonetaryCosts]*Expected_cost_of_Boat+Attractiveness___parameters__PT[Convenience]+Attractiveness___parameters__PT[Standarddeviation]*Expected_risk_Boat[BergenN_to_BergenS]-999999999999)/Random__residuals)
UNITS: Unitless
Attractiveness___of__boat[BergenN_to_BergenW] =
EXP((Attractiveness___parameters__PT[TravelTime]*Expected_travel_time_of_Boat[BergenN_to_BergenW]+Attractiveness___parameters__PT[MonetaryCosts]*Expected_cost_of_Boat+Attractiveness___parameters__PT[Convenience]+Attractiveness___parameters__PT[Standarddeviation]*Expected_risk_Boat[BergenN_to_BergenW]-999999999999)/Random__residuals)
UNITS: Unitless
Attractiveness___of__boat[BergenN_to_Askoy] =
EXP((Attractiveness___parameters__PT[TravelTime]*Expected_travel_time_of_Boat[BergenN_to_Askoy]+Attractiveness___parameters__PT[MonetaryCosts]*Expected_cost_of_Boat+Attractiveness___parameters__PT[Convenience]+Attractiveness___parameters__PT[Standarddeviation]*Expected_risk_Boat[BergenN_to_Askoy]-999999999999)/Random__residuals)
UNITS: Unitless
Attractiveness___of__boat[BergenE_to_BergenC] =
EXP((Attractiveness___parameters__PT[TravelTime]*Expected_travel_time_of_Boat[BergenE_to_BergenC]+Attractiveness___parameters__PT[MonetaryCosts]*Expected_cost_of_Boat+Attractiveness___parameters__PT[Convenience]+Attractiveness___parameters__PT[Standarddeviation]*Expected_risk_Boat[BergenE_to_BergenC]-999999999999)/Random__residuals)
UNITS: Unitless
Attractiveness___of__boat[BergenE_to_BergenN] =
EXP((Attractiveness___parameters__PT[TravelTime]*Expected_travel_time_of_Boat[BergenE_to_BergenN]+Attractiveness___parameters__PT[MonetaryCosts]*Expected_cost_of_Boat+Attractiveness___parameters__PT[Convenience]+Attractiveness___parameters__PT[Standarddeviation]*Expected_risk_Boat[BergenE_to_BergenN]-999999999999)/Random__residuals)
UNITS: Unitless
Attractiveness___of__boat[BergenE_to_BergenS] =
EXP((Attractiveness___parameters__PT[TravelTime]*Expected_travel_time_of_Boat[BergenE_to_BergenS]+Attractiveness___parameters__PT[MonetaryCosts]*Expected_cost_of_Boat+Attractiveness___parameters__PT[Convenience]+Attractiveness___parameters__PT[Standarddeviation]*Expected_risk_Boat[BergenE_to_BergenS]-999999999999)/Random__residuals)
UNITS: Unitless

Attractiveness___of__boat[BergenE_to_BergenW] =
EXP((Attractiveness___parameters__PT[TravelTime]*Expected_travel_time_of_Boat[BergenE_to_BergenW]+Attractiveness___parameters__PT[MonetaryCosts]*Expected_cost_of_Boat+Attractiveness___parameters__PT[Convenience]+Attractiveness___parameters__PT[Standarddeviation]*Expected_risk_Boat[BergenE_to_BergenW]-999999999999)/Random__residuals)
UNITS: Unitless
Attractiveness___of__boat[BergenE_to_Askoy] =
EXP((Attractiveness___parameters__PT[TravelTime]*Expected_travel_time_of_Boat[BergenE_to_Askoy]+Attractiveness___parameters__PT[MonetaryCosts]*Expected_cost_of_Boat+Attractiveness___parameters__PT[Convenience]+Attractiveness___parameters__PT[Standarddeviation]*Expected_risk_Boat[BergenE_to_Askoy]-999999999999)/Random__residuals)
UNITS: Unitless
Attractiveness___of__boat[BergenS_to_BergenC] =
EXP((Attractiveness___parameters__PT[TravelTime]*Expected_travel_time_of_Boat[BergenS_to_BergenC]+Attractiveness___parameters__PT[MonetaryCosts]*Expected_cost_of_Boat+Attractiveness___parameters__PT[Convenience]+Attractiveness___parameters__PT[Standarddeviation]*Expected_risk_Boat[BergenS_to_BergenC]-999999999999)/Random__residuals)
UNITS: Unitless
Attractiveness___of__boat[BergenS_to_BergenN] =
EXP((Attractiveness___parameters__PT[TravelTime]*Expected_travel_time_of_Boat[BergenS_to_BergenN]+Attractiveness___parameters__PT[MonetaryCosts]*Expected_cost_of_Boat+Attractiveness___parameters__PT[Convenience]+Attractiveness___parameters__PT[Standarddeviation]*Expected_risk_Boat[BergenS_to_BergenN]-999999999999)/Random__residuals)
UNITS: Unitless
Attractiveness___of__boat[BergenS_to_BergenE] =
EXP((Attractiveness___parameters__PT[TravelTime]*Expected_travel_time_of_Boat[BergenS_to_BergenE]+Attractiveness___parameters__PT[MonetaryCosts]*Expected_cost_of_Boat+Attractiveness___parameters__PT[Convenience]+Attractiveness___parameters__PT[Standarddeviation]*Expected_risk_Boat[BergenS_to_BergenE]-999999999999)/Random__residuals)
UNITS: Unitless
Attractiveness___of__boat[BergenS_to_BergenW] =
EXP((Attractiveness___parameters__PT[TravelTime]*Expected_travel_time_of_Boat[BergenS_to_BergenW]+Attractiveness___parameters__PT[MonetaryCosts]*Expected_cost_of_Boat+Attractiveness___parameters__PT[Convenience]+Attractiveness___parameters__PT[Standarddeviation]*Expected_risk_Boat[BergenS_to_BergenW]-999999999999)/Random__residuals)
UNITS: Unitless
Attractiveness___of__boat[BergenS_to_Askoy] =
EXP((Attractiveness___parameters__PT[TravelTime]*Expected_travel_time_of_Boat[BergenS_to_Askoy]+Attractiveness___parameters__PT[MonetaryCosts]*Expected_cost_of_Boat+Attractiveness___parameters__PT[Convenience]+Attractiveness___parameters__PT[Standarddeviation]*Expected_risk_Boat[BergenS_to_Askoy]-999999999999)/Random__residuals)
UNITS: Unitless
Attractiveness___of__boat[BergenW_to_BergenC] =
EXP((Attractiveness___parameters__PT[TravelTime]*Expected_travel_time_of_Boat[BergenW_to_BergenC]+Attractiveness___parameters__PT[MonetaryCosts]*Expected_cost_of_Boat+Attractiveness___parameters__PT[Convenience]+Attractiveness___parameters__PT[Standarddeviation]*Expected_risk_Boat[BergenW_to_BergenC]-999999999999)/Random__residuals)
UNITS: Unitless
Attractiveness___of__boat[BergenW_to_BergenN] =
EXP((Attractiveness___parameters__PT[TravelTime]*Expected_travel_time_of_Boat[BergenW_to_BergenN]+Attractiveness___parameters__PT[MonetaryCosts]*Expected_cost_of_Boat+Attractiveness___parameters__PT[Convenience]+Attractiveness___parameters__PT[Standarddeviation]*Expected_risk_Boat[BergenW_to_BergenN]-999999999999)/Random__residuals)
UNITS: Unitless
Attractiveness___of__boat[BergenW_to_BergenE] =
EXP((Attractiveness___parameters__PT[TravelTime]*Expected_travel_time_of_Boat[BergenW_to_BergenE]+Attractiveness___parameters__PT[MonetaryCosts]*Expected_cost_of_Boat+Attractiveness___parameters__PT[Convenience]+Attractiveness___parameters__PT[Standarddeviation]*Expected_risk_Boat[BergenW_to_BergenE]-999999999999)/Random__residuals)
UNITS: Unitless
Attractiveness___of__boat[BergenW_to_BergenS] =
EXP((Attractiveness___parameters__PT[TravelTime]*Expected_travel_time_of_Boat[BergenW_to_BergenS]+Attractiveness___parameters__PT[MonetaryCosts]*Expected_cost_of_Boat+Attractiveness___parameters__PT[Convenience]+Attractiveness___parameters__PT[Standarddeviation]*Expected_risk_Boat[BergenW_to_BergenS]-999999999999)/Random__residuals)
UNITS: Unitless
Attractiveness___of__boat[BergenW_to_Askoy] =
EXP((Attractiveness___parameters__PT[TravelTime]*Expected_travel_time_of_Boat[BergenW_to_Askoy]+Attractiveness___parameters__PT[MonetaryCosts]*Expected_cost_of_Boat+Attractiveness___parameters__PT[Convenience]+Attractiveness___parameters__PT[Standarddeviation]*Expected_risk_Boat[BergenW_to_Askoy]-999999999999)/Random__residuals)

UNITS: Unitless
Attractiveness___of__boat[Askoy_to_BergenC] =
EXP((Attractiveness___parameters__PT[TravelTime]*Expected_travel_time_of_Boat[Askoy_to_BergenC]+Attractiveness___parameters__PT[MonetaryCosts]*Expected_cost_of_Boat+Attractiveness___parameters__PT[Convenience]+Attractiveness___parameters__PT[Standarddeviation]*Expected_risk_Boat[Askoy_to_BergenC]+Convenience__of_boat)/Random__residuals)
UNITS: Unitless
Attractiveness___of__boat[Askoy_to_BergenN] =
EXP((Attractiveness___parameters__PT[TravelTime]*Expected_travel_time_of_Boat[Askoy_to_BergenN]+Attractiveness___parameters__PT[MonetaryCosts]*Expected_cost_of_Boat+Attractiveness___parameters__PT[Convenience]+Attractiveness___parameters__PT[Standarddeviation]*Expected_risk_Boat[Askoy_to_BergenN]-999999999999)/Random__residuals)
UNITS: Unitless
Attractiveness___of__boat[Askoy_to_BergenE] =
EXP((Attractiveness___parameters__PT[TravelTime]*Expected_travel_time_of_Boat[Askoy_to_BergenE]+Attractiveness___parameters__PT[MonetaryCosts]*Expected_cost_of_Boat+Attractiveness___parameters__PT[Convenience]+Attractiveness___parameters__PT[Standarddeviation]*Expected_risk_Boat[Askoy_to_BergenE]-999999999999)/Random__residuals)
UNITS: Unitless
Attractiveness___of__boat[Askoy_to_BergenS] =
EXP((Attractiveness___parameters__PT[TravelTime]*Expected_travel_time_of_Boat[Askoy_to_BergenS]+Attractiveness___parameters__PT[MonetaryCosts]*Expected_cost_of_Boat+Attractiveness___parameters__PT[Convenience]+Attractiveness___parameters__PT[Standarddeviation]*Expected_risk_Boat[Askoy_to_BergenS]-999999999999)/Random__residuals)
UNITS: Unitless
Attractiveness___of__boat[Askoy_to_BergenW] =
EXP((Attractiveness___parameters__PT[TravelTime]*Expected_travel_time_of_Boat[Askoy_to_BergenW]+Attractiveness___parameters__PT[MonetaryCosts]*Expected_cost_of_Boat+Attractiveness___parameters__PT[Convenience]+Attractiveness___parameters__PT[Standarddeviation]*Expected_risk_Boat[Askoy_to_BergenW]-999999999999)/Random__residuals)
UNITS: Unitless
Attractiveness__of__car[OD] =
EXP((Attractiveness__parameters_car[TravelTime]*Travel_time_car[OD]+Attractiveness__parameters_car[MonetaryCosts]*Monetary_cost__for_car[OD]+Attractiveness__parameters_car[Standarddeviation]*Average_expected_risk_after_origin_car[OD]+Attractiveness__parameters_car[Convenience])/Random__residuals)
UNITS: Unitless
DOCUMENT: [unitless}
Attractiveness__parameters_Bicycle[TravelTime] = -0.25
Attractiveness__parameters_Bicycle[MonetaryCosts] = 0
Attractiveness__parameters_Bicycle[Changes] = 0
Attractiveness__parameters_Bicycle[Convenience] = -1.8
Attractiveness__parameters_Bicycle[Standarddeviation] = 0
average__travel_time[OD,Paths] = Path_travel__time[OD, Paths]*Fraction_using__path[Paths]
UNITS: hours (hr)
DOCUMENT: {hours}
Average__waiting_time_TRAM[Paths] = (0.5/Hourly__Frequency_Tram)
UNITS: hours (hr)
DOCUMENT: {hr}
Average_car_ownership = ARRAYSUM(Average_car_ownership_matrix[*])/Car__sharing
UNITS: cars/person (cars/person)
DOCUMENT: {cars/person}
Average car ownership
Average_car_ownership_matrix[OD] =
(Commuters[OD]/ARRAYSUM(Commuters[*]))*Fraction_people__with_access_to_car[OD]
UNITS: Unitless
DOCUMENT: {unitless}
Average_effect_of_travel_time_on_standard_deviation[Paths] =
ARRAYSUM(Effect_of_travel_time_on_standard_deviation_car[Paths,*])/Distance_km_from_dest_to_origin[Paths]
UNITS: Unitless
DOCUMENT: {unitless}
Average_expected_risk_after_origin_bus[OD] =
ARRAYSUM(Expected_risk_bus_matrix[OD,*])/ARRAYSUM(Orgin_path_matrix[OD,*])
UNITS: hours (hr)
DOCUMENT: {hours}

Average_expected_risk_after_origin_car[OD] = ARRAYSUM(Expected_risk_car_matrix[OD,*])
UNITS: hours (hr)
DOCUMENT: {hours}
Average_gasoline__cost[Paths] = Distance_km_from_dest_to_origin[Paths]*Gas_price*Liters_of_gas_per_kilometer[Paths]
UNITS: NOK
DOCUMENT: {NOK}
Average NOK used for gasoline.
Average_lifetime_of__a_road = 10
UNITS: years (yr)
DOCUMENT: {years}
Average life time of a road.
Average_number__of__bus_changes = 0.25
UNITS: Unitless
DOCUMENT: {unitless}
Average number of bus changes.
Average_speed_on_path[Paths] = Distance_km_from_dest_to_origin[Paths]/Travel_time_with_car[Paths]
UNITS: kilometers per hour (km/hr)
DOCUMENT: {km/hour}
The average speed of car on a path.
Average_time_spent_to_acquire_a_car = 8
UNITS: years (yr)
DOCUMENT: {yr}
Time used to acquire a car.
Average_time_used_at_stops = 2/60
UNITS: hours (hr)
DOCUMENT: {hr}
Average time used at bus stops.
Average_travel__time_with_tram_for_paths[Paths] =
Extra_distance_factor_for_TRAM*Distance_km_from_dest_to_origin[Paths]/Speed_of_tram
UNITS: hours (hr)
DOCUMENT: {hr}
Average travel time with tram spent on trail at each path.
Average_travel__time_with_Bus[1] = Additional_travel_time_for_bus[1]+Time_spent_in__traffic_BUS[1]
UNITS: hours (hr)
Average_travel__time_with_Bus[2] = Additional_travel_time_for_bus[2]+Time_spent_in__traffic_BUS[2]
UNITS: hours (hr)
Average_travel__time_with_Bus[3] = Additional_travel_time_for_bus[3]+Time_spent_in__traffic_BUS[3]
UNITS: hours (hr)
Average_travel__time_with_Bus[4] = Additional_travel_time_for_bus[4]+Time_spent_in__traffic_BUS[4]
UNITS: hours (hr)
Average_travel__time_with_Bus[5] = Additional_travel_time_for_bus[5]+Time_spent_in__traffic_BUS[5]
UNITS: hours (hr)
Average_travel__time_with_Bus[6] = Additional_travel_time_for_bus[6]+Time_spent_in__traffic_BUS[6]
UNITS: hours (hr)
Average_travel__time_with_Bus[7] = Additional_travel_time_for_bus[7]+Time_spent_in__traffic_BUS[7]
UNITS: hours (hr)
Average_travel__time_with_Bus[8] = Additional_travel_time_for_bus[8]+Time_spent_in__traffic_BUS[8]
UNITS: hours (hr)
Average_travel__time_with_Bus[9] = Additional_travel_time_for_bus[9]+Time_spent_in__traffic_BUS[9]
UNITS: hours (hr)
Average_travel__time_with_Bus[10] = Additional_travel_time_for_bus[10]+Time_spent_in__traffic_BUS[10]
UNITS: hours (hr)
Average_travel__time_with_Bus[11] = Additional_travel_time_for_bus[11]+Time_spent_in__traffic_BUS[11]
UNITS: hours (hr)
Average_travel__time_with_Bus[12] = Additional_travel_time_for_bus[12]+Time_spent_in__traffic_BUS[12]
UNITS: hours (hr)
Average_travel__time_with_Bus[13] = Additional_travel_time_for_bus[13]+Time_spent_in__traffic_BUS[13]
UNITS: hours (hr)
Average_travel__time_with_Bus[14] = Additional_travel_time_for_bus[14]+Time_spent_in__traffic_BUS[14]

UNITS: hours (hr)
Average_travel__time_with_Bus[15] = Additional_travel_time_for_bus[15]+Time_spent_in__traffic_BUS[15]
UNITS: hours (hr)
Average_travel__time_with_Bus[16] = Additional_travel_time_for_bus[16]+Time_spent_in__traffic_BUS[16]
UNITS: hours (hr)
Average_travel__time_with_Bus[17] = Additional_travel_time_for_bus[17]+Time_spent_in__traffic_BUS[17]
UNITS: hours (hr)
Average_travel__time_with_Bus[18] = Additional_travel_time_for_bus[18]+Time_spent_in__traffic_BUS[18]
UNITS: hours (hr)
Average_travel__time_with_Bus[19] = Additional_travel_time_for_bus[19]+Time_spent_in__traffic_BUS[19]
UNITS: hours (hr)
Average_travel__time_with_Bus[20] = Additional_travel_time_for_bus[20]+Time_spent_in__traffic_BUS[20]
UNITS: hours (hr)
Average_travel__time_with_Bus[21] = Additional_travel_time_for_bus[21]+Time_spent_in__traffic_BUS[21]
UNITS: hours (hr)
Average_travel__time_with_Bus[22] = Additional_travel_time_for_bus[22]+Time_spent_in__traffic_BUS[22]
UNITS: hours (hr)
Average_travel__time_with_Bus[23] = Additional_travel_time_for_bus[23]+Time_spent_in__traffic_BUS[23]
UNITS: hours (hr)
Average_travel__time_with_Bus[24] = Additional_travel_time_for_bus[24]+Time_spent_in__traffic_BUS[24]
UNITS: hours (hr)
Average_travel__time_with_Bus[25] = Additional_travel_time_for_bus[25]+Time_spent_in__traffic_BUS[25]
UNITS: hours (hr)
Average_travel__time_with_Bus[26] = Additional_travel_time_for_bus[26]+Time_spent_in__traffic_BUS[26]
UNITS: hours (hr)
Average_travel__time_with_Bus[27] = Additional_travel_time_for_bus[27]+Time_spent_in__traffic_BUS[27]
UNITS: hours (hr)
Average_travel__time_with_Bus[28] = Additional_travel_time_for_bus[28]+Time_spent_in__traffic_BUS[28]
UNITS: hours (hr)
Average_travel__time_with_Bus[29] = Additional_travel_time_for_bus[29]+Time_spent_in__traffic_BUS[29]
UNITS: hours (hr)
Average_travel__time_with_Bus[30] = Additional_travel_time_for_bus[30]+Time_spent_in__traffic_BUS[30]
UNITS: hours (hr)
Average_travel__time_with_Bus[31] = Additional_travel_time_for_bus[31]+Time_spent_in__traffic_BUS[31]
UNITS: hours (hr)
Average_travel__time_with_Bus[32] = Additional_travel_time_for_bus[32]+Time_spent_in__traffic_BUS[32]
UNITS: hours (hr)
Average_travel__time_with_Bus[33] = Additional_travel_time_for_bus[33]+Time_spent_in__traffic_BUS[33]
UNITS: hours (hr)
Average_travel__time_with_Bus[34] = Additional_travel_time_for_bus[34]+Time_spent_in__traffic_BUS[34]
UNITS: hours (hr)
Average_travel__time_with_Bus[35] = Additional_travel_time_for_bus[35]+Time_spent_in__traffic_BUS[35]
UNITS: hours (hr)
Average_travel__time_with_Bus[36] = Additional_travel_time_for_bus[36]+Time_spent_in__traffic_BUS[36]
UNITS: hours (hr)
Average_travel__time_with_Bus[37] = Additional_travel_time_for_bus[37]+Time_spent_in__traffic_BUS[37]
UNITS: hours (hr)
Average_travel__time_with_Bus[38] = Additional_travel_time_for_bus[38]+Time_spent_in__traffic_BUS[38]
UNITS: hours (hr)
DOCUMENT: {hour}
Average travel time with bus.
Average_waiting__time[OD] = 0.5/Hourly_frequency_of_bus
UNITS: hours (hr)
DOCUMENT: {Hours}
Time spent waiting for the bus.
Average_waiting_time_matrix_bus[OD,Paths] = Orgin_path_matrix[OD,Paths]*Average_waiting__time[OD]
UNITS: hours (hr)
DOCUMENT: {hours}
Average_walking__time_to_bus_stop[OD] = 10/60

UNITS: hours (hr)
DOCUMENT: {hr}
Time spent walking from home and work to the bus stop.
Average_walking_time_Bus_paths[OD,Paths] = Average_walking__time_to_bus_stop[OD]*Orgin_path_matrix[OD,Paths]
UNITS: hours (hr)
DOCUMENT: {hours}
Bicycle__speed = 12
UNITS: kilometers per hour (km/hr)
DOCUMENT: {km/hr}
bicycle__time[OD] = Slow_distance_factor*Distance_OD__for_slow[OD]/Bicycle__speed
Bicycle_# = ARRAYSUM(bicycle_users[*])
bicycle_users[OD] =
(Commuters_without__car_access[OD]+Commuters__with_access_not_using_car[OD])*Proportion__using_bicycle[OD]
UNITS: people (person)
DOCUMENT: {persons}
This is the number of persons that want to use bicyle or their feets for commuting.
Boat_capacity = 360
UNITS: person/hr (person/hr)
DOCUMENT: {persons/hr}
(Bergen-Nordhordland Rutelag, 2013b)
Boat_commuters_in_peak_hour[OD] = Boat_users[OD]/Length_of_morning_rush
UNITS: person/hr (person/hr)
DOCUMENT: {people/hr}
Boat_users[OD] =
(Commuters_without__car_access[OD]+Commuters__with_access_not_using_car[OD])*Proportion__using_boat[OD]
UNITS: people (person)
DOCUMENT: {people}
This is the number of persons that want to use boat for commuting.
Building_time = 10
UNITS: years (yr)
DOCUMENT: {years}
The time it taes to builf one km of new road.99
Buses__in_car_equivalents_entering_traffic_in_peak_hour[OD] =
Cars_per_bus*(Bus_users[OD]/Capacity_of_a_bus)*Fraction_of_traffic_in_peak_hour
UNITS: cars/hr (cars/hr)
Bus_users[OD] =
Proportion__using_bus[OD]*(Commuters_without__car_access[OD]+Commuters__with_access_not_using_car[OD])
UNITS: people (person)
DOCUMENT: {persons}
This is the number of persons that want to use bus for commuting.
Capacity_of_a_bus = 80
UNITS: person/bus (person/bus)
DOCUMENT: {person/bus}
Capacity_per_lane = 1200
UNITS: cars/hr (cars/hr)
DOCUMENT: {cars/hr}
Maximum flow of cars that can be handled by a road segment per hour. (Statens vegvesen, 1990)
Cars__on_path[Paths] = Fraction_using__path[Paths]*ARRAYSUM(Flow_into_network[*, Paths])
UNITS: cars/hr (cars/hr)
DOCUMENT: {cars/hr}
Cars entering the different paths.
Cars_on__roads[Links] = ARRAYSUM(Traffic_flow_on_links[*, Links])
UNITS: cars/hr (cars/hr)
DOCUMENT: {cars/hr}
Number of cars on a road link.
Cars_per__p_space[OD] = ARRAYSUM(Cars_used__for_commuting[*])/Parking__spaces
UNITS: Unitless
DOCUMENT: {unitless}
Cars per parking space.

Cars_per_bus = 5
UNITS: cars/bus (cars/bus)
DOCUMENT: {cars per bus}
The size of the bus measured in cars.
Cars_per_parking_spaces_at_the_boat_bay[OD] =
Fraction_using_car__to_travel_to_bay*Boat_users[OD]/(Parking_spaces__at_boat_bay*Car__sharing)
UNITS: Unitless
DOCUMENT: {unitless}
Cars_used__for_commuting[OD] = Car_Users[OD]/Car__sharing
UNITS: cars
DOCUMENT: {cars}
Car__sharing = 1.05
UNITS: person/cars (person/cars)
DOCUMENT: {persons/car}
How many people using one and same car.TØI Rapport 1102/2010, page 26.
(Christiansen et al. 2010)
Car_acquisition_SW = 1
UNITS: Unitless
Car_ownership[OD] = Cars[OD]/Commuters[OD]
UNITS: cars/person (cars/person)
DOCUMENT: {cars/person}
Cars per person.
Car_Users[OD] = Proportion__using_car[OD]*Commuters__with_access__to_car[OD]
UNITS: people (person)
DOCUMENT: {persons}
Number of persons that use car for commuting. Includes both car owners (drivers) and passengers. May underestimate since commuters may be overrepresented among car owners. Also it is assumed other places in the model that using car for commuting i a motivation for car aquisition. Future work can improve this.
Commuters[OD] = Commuters_ref_mode[OD]
UNITS: people (person)
DOCUMENT: {persons}
People commuting between zones.
Commuters__with_access_not_using_car[OD] = Commuters__with_access__to_car[OD]*(1-Proportion__using_car[OD])
UNITS: people (person)
DOCUMENT: {persons}
This is the commuters with access to car, but chooses another mode of transportation.
Commuters__with_access__to_car[OD] = Commuters[OD]*Fraction_people__with_access_to_car[OD]
UNITS: people (person)
DOCUMENT: {people}
This is the people that have access to a car.

Inconsistency, car owners should be overrepresented among commuters.
Commuters_from_Fjell_to_Bergen = GRAPH(TIME)
(2000, 1485), (2001, 1633), (2002, 1622), (2003, 1591), (2004, 1831), (2005, 1925), (2006, 2143), (2007, 2364), (2008, 2363), (2009, 2472), (2010, 2601), (2011, 2745)
Commuters_imported_from_t[BergenC_to_BergenN] = GRAPH(TIME)
(2001, 2669), (2002, 2773), (2003, 2866), (2004, 2948), (2005, 3027), (2006, 3123), (2007, 3237), (2008, 3389), (2009, 3526), (2010, 3615), (2011, 3716)
Commuters_imported_from_t[BergenC_to_BergenE] = GRAPH(TIME)
(2001, 667), (2002, 679), (2003, 691), (2004, 708), (2005, 731), (2006, 757), (2007, 790), (2008, 825), (2009, 852), (2010, 886), (2011, 922)
Commuters_imported_from_t[BergenC_to_BergenS] = GRAPH(TIME)
(2001, 667), (2002, 675), (2003, 685), (2004, 687), (2005, 692), (2006, 701), (2007, 712), (2008, 739), (2009, 764), (2010, 762), (2011, 778)
Commuters_imported_from_t[BergenC_to_BergenW] = GRAPH(TIME)
(2001, 133), (2002, 119), (2003, 107), (2004, 97.7), (2005, 89.5), (2006, 82.9), (2007, 77.8), (2008, 73.7), (2009, 69.9), (2010, 64.4), (2011, 60.7)
Commuters_imported_from_t[BergenC_to_Askoy] = GRAPH(TIME)

(2001, 1334), (2002, 1505), (2003, 1652), (2004, 1779), (2005, 1898), (2006, 2013), (2007, 2124), (2008, 2248), (2009, 2354), (2010, 2437), (2011, 2531)
Commuters_imported_from_t[BergenN_to_BergenC] = GRAPH(TIME)
(2001, 334), (2002, 332), (2003, 329), (2004, 330), (2005, 334), (2006, 336), (2007, 337), (2008, 335), (2009, 333), (2010, 335), (2011, 333)
Commuters_imported_from_t[BergenN_to_BergenE] = GRAPH(TIME)
(2001, 2845), (2002, 3340), (2003, 3754), (2004, 4180), (2005, 4616), (2006, 4987), (2007, 5345), (2008, 5593), (2009, 5759), (2010, 6014), (2011, 6211)
Commuters_imported_from_t[BergenN_to_BergenS] = GRAPH(TIME)
(2001, 8519), (2002, 8478), (2003, 8488), (2004, 8498), (2005, 8569), (2006, 8608), (2007, 8582), (2008, 8534), (2009, 8497), (2010, 8406), (2011, 8434)
Commuters_imported_from_t[BergenN_to_BergenW] = GRAPH(TIME)
(2001, 524), (2002, 536), (2003, 547), (2004, 561), (2005, 575), (2006, 584), (2007, 589), (2008, 583), (2009, 573), (2010, 544), (2011, 523)
Commuters_imported_from_t[BergenN_to_Askoy] = GRAPH(TIME)
(2001, 4894), (2002, 4966), (2003, 5026), (2004, 5119), (2005, 5242), (2006, 5341), (2007, 5416), (2008, 5441), (2009, 5456), (2010, 5523), (2011, 5581)
Commuters_imported_from_t[BergenE_to_BergenC] = GRAPH(TIME)
(2001, 91.8), (2002, 113), (2003, 130), (2004, 143), (2005, 157), (2006, 169), (2007, 180), (2008, 193), (2009, 208), (2010, 213), (2011, 217)
Commuters_imported_from_t[BergenE_to_BergenN] = GRAPH(TIME)
(2001, 11404), (2002, 12167), (2003, 12819), (2004, 13236), (2005, 13714), (2006, 14249), (2007, 14828), (2008, 15791), (2009, 16849), (2010, 17097), (2011, 17377)
Commuters_imported_from_t[BergenE_to_BergenS] = GRAPH(TIME)
(2001, 2942), (2002, 2943), (2003, 2945), (2004, 2882), (2005, 2861), (2006, 2865), (2007, 2885), (2008, 3034), (2009, 3213), (2010, 3139), (2011, 3131)
Commuters_imported_from_t[BergenE_to_BergenW] = GRAPH(TIME)
(2001, 813), (2002, 762), (2003, 722), (2004, 683), (2005, 654), (2006, 632), (2007, 615), (2008, 606), (2009, 600), (2010, 559), (2011, 532)
Commuters_imported_from_t[BergenE_to_Askoy] = GRAPH(TIME)
(2001, 2487), (2002, 2710), (2003, 2900), (2004, 3029), (2005, 3177), (2006, 3325), (2007, 3465), (2008, 3684), (2009, 3919), (2010, 3985), (2011, 4068)
Commuters_imported_from_t[BergenS_to_BergenC] = GRAPH(TIME)
(2001, 42.2), (2002, 49.5), (2003, 54.6), (2004, 59.5), (2005, 64.0), (2006, 67.6), (2007, 71.5), (2008, 74.5), (2009, 77.0), (2010, 80.0), (2011, 80.5)
Commuters_imported_from_t[BergenS_to_BergenN] = GRAPH(TIME)
(2001, 9204), (2002, 8666), (2003, 8164), (2004, 7785), (2005, 7476), (2006, 7234), (2007, 7147), (2008, 7105), (2009, 7078), (2010, 7093), (2011, 6990)
Commuters_imported_from_t[BergenS_to_BergenE] = GRAPH(TIME)
(2001, 558), (2002, 655), (2003, 724), (2004, 793), (2005, 860), (2006, 919), (2007, 998), (2008, 1071), (2009, 1124), (2010, 1183), (2011, 1203)
Commuters_imported_from_t[BergenS_to_BergenW] = GRAPH(TIME)
(2001, 285), (2002, 317), (2003, 342), (2004, 365), (2005, 385), (2006, 399), (2007, 416), (2008, 427), (2009, 434), (2010, 426), (2011, 412)
Commuters_imported_from_t[BergenS_to_Askoy] = GRAPH(TIME)
(2001, 2064), (2002, 1949), (2003, 1842), (2004, 1763), (2005, 1700), (2006, 1649), (2007, 1626), (2008, 1609), (2009, 1596), (2010, 1600), (2011, 1583)
Commuters_imported_from_t[BergenW_to_BergenC] = GRAPH(TIME)
(2001, 13.5), (2002, 15.6), (2003, 17.2), (2004, 18.7), (2005, 20.3), (2006, 21.8), (2007, 23.3), (2008, 25.1), (2009, 27.1), (2010, 31.7), (2011, 33.8)
Commuters_imported_from_t[BergenW_to_BergenN] = GRAPH(TIME)
(2001, 2165), (2002, 2212), (2003, 2237), (2004, 2264), (2005, 2314), (2006, 2383), (2007, 2480), (2008, 2643), (2009, 2828), (2010, 3250), (2011, 3457)
Commuters_imported_from_t[BergenW_to_BergenE] = GRAPH(TIME)
(2001, 835), (2002, 813), (2003, 793), (2004, 784), (2005, 789), (2006, 803), (2007, 831), (2008, 873), (2009, 916), (2010, 1051), (2011, 1129)
Commuters_imported_from_t[BergenW_to_BergenS] = GRAPH(TIME)
(2001, 1011), (2002, 1323), (2003, 1562), (2004, 1740), (2005, 1923), (2006, 2099), (2007, 2259), (2008, 2516), (2009, 2789), (2010, 3308), (2011, 3557)

Commuters_imported_from_t[BergenW_to_Askoy] = GRAPH(TIME)
(2001, 377), (2002, 390), (2003, 399), (2004, 407), (2005, 420), (2006, 434), (2007, 452), (2008, 480), (2009, 512), (2010, 592), (2011, 633)
Commuters_imported_from_t[Askoy_to_BergenC] = GRAPH(TIME)
(2001, 138), (2002, 240), (2003, 322), (2004, 392), (2005, 452), (2006, 500), (2007, 538), (2008, 565), (2009, 587), (2010, 611), (2011, 622)
Commuters_imported_from_t[Askoy_to_BergenN] = GRAPH(TIME)
(2001, 18494), (2002, 18256), (2003, 18054), (2004, 17869), (2005, 17693), (2006, 17581), (2007, 17548), (2008, 17540), (2009, 17579), (2010, 17627), (2011, 17592)
Commuters_imported_from_t[Askoy_to_BergenE] = GRAPH(TIME)
(2001, 1379), (2002, 1858), (2003, 2255), (2004, 2614), (2005, 2938), (2006, 3210), (2007, 3466), (2008, 3661), (2009, 3801), (2010, 3980), (2011, 4109)
Commuters_imported_from_t[Askoy_to_BergenS] = GRAPH(TIME)
(2001, 6713), (2002, 6149), (2003, 5696), (2004, 5282), (2005, 4931), (2006, 4642), (2007, 4391), (2008, 4203), (2009, 4066), (2010, 3911), (2011, 3821)
Commuters_imported_from_t[Askoy_to_BergenW] = GRAPH(TIME)
(2001, 274), (2002, 274), (2003, 276), (2004, 276), (2005, 276), (2006, 274), (2007, 272), (2008, 268), (2009, 262), (2010, 248), (2011, 237)
Commuters_ref_mode[BergenC_to_BergenN] = GRAPH(TIME)
(2000, 1390), (2001, 1421), (2002, 1452), (2003, 1484), (2004, 1515), (2005, 1546), (2006, 1578), (2007, 1609), (2008, 1640), (2009, 1672), (2010, 1703), (2011, 1734)
Commuters_ref_mode[BergenC_to_BergenE] = GRAPH(TIME)
(2000, 444), (2001, 431), (2002, 418), (2003, 405), (2004, 392), (2005, 379), (2006, 366), (2007, 353), (2008, 340), (2009, 327), (2010, 314), (2011, 301)
Commuters_ref_mode[BergenC_to_BergenS] = GRAPH(TIME)
(2000, 4341), (2001, 4417), (2002, 4493), (2003, 4569), (2004, 4645), (2005, 4720), (2006, 4796), (2007, 4872), (2008, 4948), (2009, 5024), (2010, 5100), (2011, 5176)
Commuters_ref_mode[BergenC_to_BergenW] = GRAPH(TIME)
(2000, 3017), (2001, 3009), (2002, 3000), (2003, 2991), (2004, 2982), (2005, 2974), (2006, 2965), (2007, 2956), (2008, 2947), (2009, 2939), (2010, 2930), (2011, 2921)
Commuters_ref_mode[BergenC_to_Askoy] = GRAPH(TIME)
(2000, 74.0), (2001, 81.0), (2002, 93.0), (2003, 96.0), (2004, 103), (2005, 115), (2006, 127), (2007, 137), (2008, 162), (2009, 156), (2010, 174), (2011, 184)
Commuters_ref_mode[BergenN_to_BergenC] = GRAPH(TIME)
(2000, 6581), (2001, 6685), (2002, 6789), (2003, 6893), (2004, 6997), (2005, 7101), (2006, 7206), (2007, 7310), (2008, 7414), (2009, 7518), (2010, 7622), (2011, 7726)
Commuters_ref_mode[BergenN_to_BergenE] = GRAPH(TIME)
(2000, 346), (2001, 356), (2002, 365), (2003, 375), (2004, 385), (2005, 394), (2006, 404), (2007, 414), (2008, 424), (2009, 433), (2010, 443), (2011, 453)
Commuters_ref_mode[BergenN_to_BergenS] = GRAPH(TIME)
(2000, 1379), (2001, 1402), (2002, 1424), (2003, 1446), (2004, 1469), (2005, 1491), (2006, 1513), (2007, 1536), (2008, 1558), (2009, 1581), (2010, 1603), (2011, 1625)
Commuters_ref_mode[BergenN_to_BergenW] = GRAPH(TIME)
(2000, 966), (2001, 1005), (2002, 1044), (2003, 1083), (2004, 1122), (2005, 1161), (2006, 1199), (2007, 1238), (2008, 1277), (2009, 1316), (2010, 1355), (2011, 1394)
Commuters_ref_mode[BergenN_to_Askoy] = GRAPH(TIME)
(2000, 24.0), (2001, 27.0), (2002, 32.0), (2003, 35.0), (2004, 39.0), (2005, 45.0), (2006, 51.0), (2007, 57.0), (2008, 70.0), (2009, 70.0), (2010, 80.0), (2011, 88.0)
Commuters_ref_mode[BergenE_to_BergenC] = GRAPH(TIME)
(2000, 2178), (2001, 2121), (2002, 2064), (2003, 2006), (2004, 1949), (2005, 1892), (2006, 1835), (2007, 1778), (2008, 1720), (2009, 1663), (2010, 1606), (2011, 1549)
Commuters_ref_mode[BergenE_to_BergenN] = GRAPH(TIME)
(2000, 452), (2001, 469), (2002, 485), (2003, 502), (2004, 519), (2005, 536), (2006, 552), (2007, 569), (2008, 586), (2009, 602), (2010, 619), (2011, 636)
Commuters_ref_mode[BergenE_to_BergenS] = GRAPH(TIME)
(2000, 669), (2001, 677), (2002, 685), (2003, 693), (2004, 701), (2005, 710), (2006, 718), (2007, 726), (2008, 734), (2009, 742), (2010, 750), (2011, 758)
Commuters_ref_mode[BergenE_to_BergenW] = GRAPH(TIME)

(2000, 138), (2001, 153), (2002, 167), (2003, 181), (2004, 195), (2005, 209), (2006, 223), (2007, 238), (2008, 252), (2009, 266), (2010, 280), (2011, 294)
Commuters_ref_mode[BergenE_to_Askoy] = GRAPH(TIME)
(2000, 3.00), (2001, 4.00), (2002, 5.00), (2003, 6.00), (2004, 7.00), (2005, 8.00), (2006, 10.0), (2007, 11.0), (2008, 14.0), (2009, 14.0), (2010, 17.0), (2011, 18.0)
Commuters_ref_mode[BergenS_to_BergenC] = GRAPH(TIME)
(2000, 9607), (2001, 9736), (2002, 9866), (2003, 9995), (2004, 10124), (2005, 10253), (2006, 10383), (2007, 10512), (2008, 10641), (2009, 10771), (2010, 10900), (2011, 11029)
Commuters_ref_mode[BergenS_to_BergenN] = GRAPH(TIME)
(2000, 419), (2001, 443), (2002, 467), (2003, 491), (2004, 516), (2005, 540), (2006, 564), (2007, 588), (2008, 613), (2009, 637), (2010, 661), (2011, 685)
Commuters_ref_mode[BergenS_to_BergenE] = GRAPH(TIME)
(2000, 372), (2001, 368), (2002, 365), (2003, 361), (2004, 358), (2005, 354), (2006, 351), (2007, 347), (2008, 344), (2009, 340), (2010, 337), (2011, 334)
Commuters_ref_mode[BergenS_to_BergenW] = GRAPH(TIME)
(2000, 2096), (2001, 2131), (2002, 2165), (2003, 2200), (2004, 2235), (2005, 2270), (2006, 2305), (2007, 2340), (2008, 2374), (2009, 2409), (2010, 2444), (2011, 2479)
Commuters_ref_mode[BergenS_to_Askoy] = GRAPH(TIME)
(2000, 51.0), (2001, 57.0), (2002, 67.0), (2003, 71.0), (2004, 77.0), (2005, 88.0), (2006, 99.0), (2007, 108), (2008, 131), (2009, 128), (2010, 145), (2011, 156)
Commuters_ref_mode[BergenW_to_BergenC] = GRAPH(TIME)
(2000, 12987), (2001, 13024), (2002, 13060), (2003, 13097), (2004, 13133), (2005, 13170), (2006, 13207), (2007, 13243), (2008, 13280), (2009, 13316), (2010, 13353), (2011, 13390)
Commuters_ref_mode[BergenW_to_BergenN] = GRAPH(TIME)
(2000, 625), (2001, 662), (2002, 699), (2003, 736), (2004, 773), (2005, 810), (2006, 847), (2007, 885), (2008, 922), (2009, 959), (2010, 996), (2011, 1033)
Commuters_ref_mode[BergenW_to_BergenE] = GRAPH(TIME)
(2000, 108), (2001, 117), (2002, 126), (2003, 135), (2004, 144), (2005, 153), (2006, 162), (2007, 171), (2008, 180), (2009, 189), (2010, 198), (2011, 207)
Commuters_ref_mode[BergenW_to_BergenS] = GRAPH(TIME)
(2000, 4292), (2001, 4347), (2002, 4403), (2003, 4458), (2004, 4514), (2005, 4569), (2006, 4625), (2007, 4680), (2008, 4736), (2009, 4791), (2010, 4847), (2011, 4903)
Commuters_ref_mode[BergenW_to_Askoy] = GRAPH(TIME)
(2000, 181), (2001, 201), (2002, 239), (2003, 252), (2004, 276), (2005, 316), (2006, 355), (2007, 391), (2008, 474), (2009, 465), (2010, 529), (2011, 570)
Commuters_ref_mode[Askoy_to_BergenC] = GRAPH(TIME)
(2000, 2322), (2001, 2326), (2002, 2253), (2003, 2334), (2004, 2363), (2005, 2387), (2006, 2530), (2007, 2704), (2008, 2790), (2009, 2780), (2010, 2771), (2011, 2895)
Commuters_ref_mode[Askoy_to_BergenN] = GRAPH(TIME)
(2000, 112), (2001, 118), (2002, 121), (2003, 131), (2004, 139), (2005, 147), (2006, 162), (2007, 181), (2008, 194), (2009, 200), (2010, 207), (2011, 223)
Commuters_ref_mode[Askoy_to_BergenE] = GRAPH(TIME)
(2000, 19.0), (2001, 21.0), (2002, 22.0), (2003, 24.0), (2004, 26.0), (2005, 28.0), (2006, 31.0), (2007, 35.0), (2008, 38.0), (2009, 39.0), (2010, 41.0), (2011, 45.0)
Commuters_ref_mode[Askoy_to_BergenS] = GRAPH(TIME)
(2000, 767), (2001, 777), (2002, 759), (2003, 794), (2004, 812), (2005, 828), (2006, 886), (2007, 956), (2008, 995), (2009, 1000), (2010, 1006), (2011, 1060)
Commuters_ref_mode[Askoy_to_BergenW] = GRAPH(TIME)
(2000, 1318), (2001, 1345), (2002, 1325), (2003, 1396), (2004, 1437), (2005, 1476), (2006, 1590), (2007, 1726), (2008, 1809), (2009, 1829), (2010, 1851), (2011, 1961)
Commuters_without__car_access[OD] = Commuters[OD]*(1-Fraction_people__with_access_to_car[OD])
UNITS: people (person)
DOCUMENT: {persons}
This is the people that don't have access to a car and therefore must use another mode of transportation.
Comparision_Matrix[Paths,Paths] = [1,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,
0,1,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,
0,0,1,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,
0,0,0,1,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,
0,0,0,0,1,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,

0,0,0,0,0,1,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,
0,0,0,0,0,0,1,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,
0,0,0,0,0,0,0,1,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,
0,0,0,0,0,0,0,0,1,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,
0,0,0,0,0,0,0,0,0,1,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,
0,0,0,0,0,0,0,0,0,0,1,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,
0,0,0,0,0,0,0,0,0,0,0,1,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,
0,0,0,0,0,0,0,0,0,0,0,0,1,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,
0,0,0,0,0,0,0,0,0,0,0,0,0,1,1,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,
0,0,0,0,0,0,0,0,0,0,0,0,0,1,1,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,
0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,1,0,1,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,
0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,1,0,0,0,0,1,0,0,0,0,0,1,0,0,0,0,1,0,0,0,0,0,
0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,1,0,1,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,
0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,1,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,
0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,1,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,
0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,1,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,
0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,1,0,0,0,0,1,0,0,0,0,0,1,0,0,0,0,1,0,0,0,0,0,
0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,1,1,0,0,0,0,0,0,0,0,0,0,0,0,0,0,
0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,1,1,0,0,0,0,0,0,0,0,0,0,0,0,0,0,
0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,1,0,0,0,0,0,0,0,0,0,0,0,0,0,
0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,1,0,0,0,0,0,0,0,0,0,0,0,0,
0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,1,1,0,0,0,0,0,0,0,0,0,0,
0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,1,1,0,0,0,0,0,0,0,0,0,0,
0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,1,0,0,0,0,1,0,0,0,0,0,1,0,0,0,0,1,0,0,0,0,0,
0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,1,0,0,0,0,0,0,0,0,
0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,1,0,0,0,0,0,0,0,
0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,1,0,0,0,0,0,0,
0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,1,0,1,0,0,0,
0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,1,0,0,0,0,1,0,0,0,0,0,1,0,0,0,0,1,0,0,0,0,0,
0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,1,0,1,0,0,0,
0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,1,1,0,
0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,1,1,0,
0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,1]
UNITS: Unitless
DOCUMENT: {unitless}
A matrix, P = {p_ij}, where p_ij = 1 iff path i is to be compared with path j. Otherwise, p_ij = 0. Notice that a path should always be compared to itself, hence p_ii = 1 for all i.
constant__car_ownership = 0.3
UNITS: Unitless
DOCUMENT: {unitless}
The importance of other reasons to acquire car than commuting.
Convenience__of_boat = -1
Converted_imported__commuter_data[BergenC_to_BergenN] = Commuters_imported_from_t[BergenN_to_BergenS]
UNITS: people (person)
Converted_imported__commuter_data[BergenC_to_BergenE] = Commuters_imported_from_t[BergenN_to_BergenW]
UNITS: people (person)
Converted_imported__commuter_data[BergenC_to_BergenS] = Commuters_imported_from_t[BergenN_to_BergenE]
UNITS: people (person)
Converted_imported__commuter_data[BergenC_to_BergenW] = Commuters_imported_from_t[BergenN_to_Askoy]
UNITS: people (person)
Converted_imported__commuter_data[BergenC_to_Askoy] = Commuters_imported_from_t[BergenN_to_BergenC]
UNITS: people (person)
Converted_imported__commuter_data[BergenN_to_BergenC] = Commuters_imported_from_t[BergenS_to_BergenN]
UNITS: people (person)
Converted_imported__commuter_data[BergenN_to_BergenE] = Commuters_imported_from_t[BergenS_to_BergenW]
UNITS: people (person)
Converted_imported__commuter_data[BergenN_to_BergenS] = Commuters_imported_from_t[BergenS_to_BergenE]
UNITS: people (person)
Converted_imported__commuter_data[BergenN_to_BergenW] = Commuters_imported_from_t[BergenS_to_Askoy]

UNITS: people (person)
Converted_imported__commuter_data[BergenN_to_Askoy] = Commuters_imported_from_t[BergenS_to_BergenC]
UNITS: people (person)
Converted_imported__commuter_data[BergenE_to_BergenC] = Commuters_imported_from_t[BergenW_to_BergenN]
UNITS: people (person)
Converted_imported__commuter_data[BergenE_to_BergenN] = Commuters_imported_from_t[BergenW_to_BergenS]
UNITS: people (person)
Converted_imported__commuter_data[BergenE_to_BergenS] = Commuters_imported_from_t[BergenW_to_BergenE]
UNITS: people (person)
Converted_imported__commuter_data[BergenE_to_BergenW] = Commuters_imported_from_t[BergenW_to_Askoy]
UNITS: people (person)
Converted_imported__commuter_data[BergenE_to_Askoy] = Commuters_imported_from_t[BergenW_to_BergenC]
UNITS: people (person)
Converted_imported__commuter_data[BergenS_to_BergenC] = Commuters_imported_from_t[BergenE_to_BergenN]
UNITS: people (person)
Converted_imported__commuter_data[BergenS_to_BergenN] = Commuters_imported_from_t[BergenE_to_BergenS]
UNITS: people (person)
Converted_imported__commuter_data[BergenS_to_BergenE] = Commuters_imported_from_t[BergenE_to_BergenW]
UNITS: people (person)
Converted_imported__commuter_data[BergenS_to_BergenW] = Commuters_imported_from_t[BergenE_to_Askoy]
UNITS: people (person)
Converted_imported__commuter_data[BergenS_to_Askoy] = Commuters_imported_from_t[BergenE_to_BergenC]
UNITS: people (person)
Converted_imported__commuter_data[BergenW_to_BergenC] =
Commuters_imported_from_t[Askoy_to_BergenN]+Commuters_from_Fjell_to_Bergen*2/3
UNITS: people (person)
Converted_imported__commuter_data[BergenW_to_BergenN] = Commuters_imported_from_t[Askoy_to_BergenS]
UNITS: people (person)
Converted_imported__commuter_data[BergenW_to_BergenE] = Commuters_imported_from_t[Askoy_to_BergenW]
UNITS: people (person)
Converted_imported__commuter_data[BergenW_to_BergenS] =
Commuters_imported_from_t[Askoy_to_BergenE]+Commuters_from_Fjell_to_Bergen*1/3
UNITS: people (person)
Converted_imported__commuter_data[BergenW_to_Askoy] = Commuters_imported_from_t[Askoy_to_BergenC]
UNITS: people (person)
Converted_imported__commuter_data[Askoy_to_BergenC] = Commuters_imported_from_t[BergenC_to_BergenN]
UNITS: people (person)
Converted_imported__commuter_data[Askoy_to_BergenN] = Commuters_imported_from_t[BergenC_to_BergenS]
UNITS: people (person)
Converted_imported__commuter_data[Askoy_to_BergenE] = Commuters_imported_from_t[BergenC_to_BergenW]
UNITS: people (person)
Converted_imported__commuter_data[Askoy_to_BergenS] = Commuters_imported_from_t[BergenC_to_BergenE]
UNITS: people (person)
Converted_imported__commuter_data[Askoy_to_BergenW] = Commuters_imported_from_t[BergenC_to_Askoy]*0.63
UNITS: people (person)
Dedicated_bus__lanes = 0
UNITS: Unitless
DOCUMENT: {unitless}
Percent of a lane along the road links dedicated to public transportation. 100 means that one lane is dedicated for public transportation.
Desired__car_acquision[OD] = Commuters[OD]*Fraction_of_commuters_desiring_to_aquire_a_car[OD]/Car__sharing
UNITS: cars
DOCUMENT: {cars}
Cars desired acquired.
Desired___parkings_spaces = ARRAYSUM(Cars_used__for_commuting[*])*(Desired_%__parking_coverage/100)
UNITS: cars
DOCUMENT: {cars}
Desired number of p-spaces
Desired_%__parking_coverage = 110

UNITS: Unitless
DOCUMENT: {cars}
Desired_change_in_road_quality[Links] = MAX(New_lanes_desired_constructed[Links]*Length_of_roads[Links],0)
UNITS: kilometers (km)
DOCUMENT: {km}
Desired km of road constructed on a road segment.
Desired_effective__lanes[Links] =
MIN((ARRAYMAX(Measured_traffic_flow_matrix[*,Links])/Capacity_per_lane)*(1+Percent__extra_capaity/100),
Max__#_lanes[Links])
UNITS: Unitless
DOCUMENT: {unitless}
Desired number of lanes on a road link. Calculated by traffic flow divided by the capacity of an average lane.
Desired_total_road_construction[Links] = Road_maintenance[Links]+Desired_change_in_road_quality[Links]/Building_time
UNITS: km/yr
DOCUMENT: {km/yr}
Desired km of road constructed, including both new roads, road improvements and km road maintained.
Distance_km_from_dest_to_origin[Paths] = ARRAYSUM(Link_path_incidence_length_matrix[*,Paths])
UNITS: kilometers (km)
DOCUMENT: {km}
Length of each path.
Distance_OD__for_slow[OD] = [13,27,9,9,14,13,14,22,22,27,27,14,19,35,40,9,22,19,15,20,9,22,35,15,5,14,27,40,20,5]
UNITS: kilometers (km)
DOCUMENT: {km}
E39_SIMULATED = Measured__peak_hour__traffic_flow[BergenS_BergenC]
Effective_#__of_lanes[Links] = (Road_quality[Links]/Length_of_roads[Links])-Dedicated_bus__lanes
UNITS: Unitless
DOCUMENT: {unitless}
The effective number of lanes going towards Bergen at on road segment/link.
Effect_of_crowding_on_travel_time_to_boat[OD] = Cars_per_parking_spaces_at_the_boat_bay[OD]
UNITS: Unitless
DOCUMENT: {unitless}
Effect_of_search_time_on_walking_and_search_time[OD] = (Cars_per__p_space[OD])
UNITS: Unitless
DOCUMENT: {hours}
The time used by the car users to find a parking space.
Effect_of_travel_time_on_standard_deviation_car[Paths,Links] =
Link_path_incidence_matrix[Links,Paths]*Road_capacity__utilization[Links]*Length_of_roads[Links]
UNITS: Unitless
DOCUMENT: {unitless}
Expansion_of__network_SW = 0
Expansion_of__Tram_network[BergenC_to_BergenN] = -99 + STEP(99, 2015)*Expansion_of__network_SW
Expansion_of__Tram_network[BergenC_to_BergenE] = -99
Expansion_of__Tram_network[BergenC_to_BergenS] = -99+STEP(99,2010)
Expansion_of__Tram_network[BergenC_to_BergenW] = -99 + STEP(99, 2015)*Expansion_of__network_SW
Expansion_of__Tram_network[BergenC_to_Askoy] = -99
Expansion_of__Tram_network[BergenN_to_BergenC] = -99 + STEP(99, 2015)*Expansion_of__network_SW
Expansion_of__Tram_network[BergenN_to_BergenE] = -99
Expansion_of__Tram_network[BergenN_to_BergenS] = -99
Expansion_of__Tram_network[BergenN_to_BergenW] = -99
Expansion_of__Tram_network[BergenN_to_Askoy] = -99
Expansion_of__Tram_network[BergenE_to_BergenC] = -99
Expansion_of__Tram_network[BergenE_to_BergenN] = -99
Expansion_of__Tram_network[BergenE_to_BergenS] = -99
Expansion_of__Tram_network[BergenE_to_BergenW] = -99
Expansion_of__Tram_network[BergenE_to_Askoy] = -99
Expansion_of__Tram_network[BergenS_to_BergenC] = -99+STEP(99,2010)
Expansion_of__Tram_network[BergenS_to_BergenN] = -99
Expansion_of__Tram_network[BergenS_to_BergenE] = -99
Expansion_of__Tram_network[BergenS_to_BergenW] = -99
Expansion_of__Tram_network[BergenS_to_Askoy] = -99
Expansion_of__Tram_network[BergenW_to_BergenC] = -99 + STEP(99, 2015)*Expansion_of__network_SW
Expansion_of__Tram_network[BergenW_to_BergenN] = -99
Expansion_of__Tram_network[BergenW_to_BergenE] = -99
Expansion_of__Tram_network[BergenW_to_BergenS] = -99
Expansion_of__Tram_network[BergenW_to_Askoy] = -99
Expansion_of__Tram_network[Askoy_to_BergenC] = -99

Expansion_of__Tram_network[Askoy_to_BergenN] = -99
Expansion_of__Tram_network[Askoy_to_BergenS] = -99
Expansion_of__Tram_network[Askoy_to_BergenE] = -99
Expansion_of__Tram_network[Askoy_to_BergenW] = -99
Expected_risk_bus_matrix[OD,Paths] = Expected_risk_bus[Paths]*Orgin_path_matrix[OD,Paths]
UNITS: hours (hr)
DOCUMENT: {hours}
Expected_risk_car_matrix[OD,Paths] = Expected_risk_car[Paths]*Orgin_path_matrix[OD,Paths]*Fraction_using__path[Paths]
UNITS: hours (hr)
DOCUMENT: {hours}
Extra_distance_factor_for_TRAM = 1.5
UNITS: Unitless
DOCUMENT: {unitless}
Extra distance when using tram.
Fees_and_tolls[Paths] = Toll_rate[Paths]
UNITS: NOK
DOCUMENT: {NOK}
Average parking house fee, toll and other similar monetary expenditures paid by car users.
(Hansen, 2013)
Flow_into_network[OD,Paths] =
(Cars_used__for_commuting[OD]+Buses__in_car_equivalents_entering_traffic_in_peak_hour[OD])*Fraction_of_traffic_in_peak_hour*Orgin_path_matrix[OD, Paths]
UNITS: cars/hr (cars/hr)
DOCUMENT: {cars/hr}
An intermediate variable necessary for doing the matrix computations.
Fraction_of_commuters_desiring_to_aquire_a_car[OD] = Fraction_of_people__that_want_a_car[OD]-Fraction_people__with_access_to_car[OD]
UNITS: Unitless
DOCUMENT: {unitless}
Fraction of people that want to acquire a car.
Fraction_of_people__that_want_a_car[OD] = (Saturation_level__car_ownership-constant__car_ownership)*Proportion_that__want_to_use__Car[OD]^Want_to_use_car__elasticity_of__car_acquisition+constant__car_ownership
UNITS: Unitless
DOCUMENT: {unitless}
modifed dargay and gately (1998) model of their study " income's effect on car an vehicle ownership, worldwide: 1960-2015".
Fraction_of_traffic_in_peak_hour = 1/Length_of_morning_rush
UNITS: 1/hr (1/hr)
DOCUMENT: {Unitless}
The fraction of traffic occuring in rush hour. Not everyone has the same desired arrival time. TØI Rapport 1102/2010. Assumes that the traffic is uniformly distributed over the rush hours. NOTE:Can be endogenous, see Zhang, Yang, Huang, Zhang (2005).
Fraction_people__with_access_to_car[OD] = Car_ownership[OD]*Car__sharing
UNITS: Unitless
DOCUMENT: {unitless}
Fraction of people that have access to car.
Fraction_using__path[Paths] = IF Total__path__attractiveness[Paths] = 0 THEN 0 ELSE EXP(-20*Perceived_cost__of_paths[Paths])/Total__path__attractiveness[Paths]
UNITS: Unitless
DOCUMENT: {unitless}
The fraction of cars from an origin point that uses a given path to reach a certain destination.
Fraction_using_car__to_travel_to_bay = 0.85
UNITS: Unitless
DOCUMENT: {unitless}
Freeflow_path__incidence_matrix[Links,Paths] = Free_flow_travel_time[Links]*Link_path_incidence_matrix[Links,Paths]
UNITS: hours (hr)
DOCUMENT: {hours}
Intermediate variable needed for matrix operations.
Free_flow_travel_time[Links] = Length_of_roads[Links]/Free_flow__speed
UNITS: hours (hr)
DOCUMENT: {hours}

The time used at average to travel from the beginning of a road segment to its end at low traffic levels, when traffic is unhindred.
Free_flow__speed = 60
UNITS: kilometers per hour (km/hr)
DOCUMENT: {km/hour}
Average speed at low or none traffic.
FREE_FLOW_OD_MATRIX[OD,Paths] =
Fraction_using__path[Paths]*Free_flow_path__travel_time[Paths]*Orgin_path_matrix[OD,Paths]
Free_flow_path__travel_time[Paths] = ARRAYSUM(Freeflow_path__incidence_matrix[*,Paths])
UNITS: hours (hr)
DOCUMENT: {hours}
Time used from origin to destination on each path, given low or none traffic.
FREE_FLOW_TIME_OD_CAR[OD] = ARRAYSUM(FREE_FLOW_OD_MATRIX[OD,*])
Free_flow_travel_time_on_path[Links,Paths] = Free_flow_travel_time[Links]*Link_path_incidence_matrix[Links,Paths]
UNITS: hours (hr)
DOCUMENT: {hours}
Travel time from origin to destination following a given path when there are no traffic.
Gas_price = GRAPH(time)
(1990, 5.22), (1991, 5.98), (1992, 6.29), (1993, 6.63), (1994, 6.68), (1995, 7.10), (1996, 7.22), (1997, 7.80), (1998, 7.80), (1999, 8.37), (2000, 9.56), (2001, 8.65), (2002, 8.26), (2003, 8.49), (2004, 9.03), (2005, 9.89), (2006, 10.7), (2007, 10.9), (2008, 11.6), (2009, 11.1), (2010, 12.0), (2011, 13.2), (2012, 14.0)
UNITS: NOK/l (NOK/l)
DOCUMENT: {nok/l}
Data for gas prices and trends.
(Statistisk sentralbyrå 2013a)
Hourly__frequency_boat = 2
UNITS: Unitless/hr (Unitless/hr)
DOCUMENT: {unitless/hr}
(Bergen-Nordhordland Rutelag, 2013a)
Hourly__Frequency_Tram = 10
UNITS: Unitless
DOCUMENT: {unitless}
(Skyss, 2013c)
Hourly_frequency_of_bus = 6
UNITS: Unitless/hr (Unitless/hr)
DOCUMENT: {unitless/hr}
Number of bus departures per hour.
Length_of_morning_rush = 3
UNITS: hours (hr)
DOCUMENT: {hr}
Length of morning/evening rush.
Length_of_roads[BergenC_BergenN] = 11
UNITS: kilometers (km)
Kilometer lengths of each road/network link.
Length_of_roads[BergenN_BergenC] = 11
Length_of_roads[BergenN_BergenE] = 15
Length_of_roads[BergenE_BergenN] = 15
Length_of_roads[BergenE_BergenS] = 16
Length_of_roads[BergenS_BergenE] = 16
Length_of_roads[BergenS_BergenC] = 8.5
Length_of_roads[BergenC_BergenS] = 8.5
Length_of_roads[BergenS_BergenW] = 12
Length_of_roads[BergenW_BergenS] = 12
Length_of_roads[BergenW_Askoy] = 5
Length_of_roads[Askoy_BergenW] = 5
Length_of_roads[BergenW_BergenC] = 8
Length_of_roads[BergenC_BergenW] = 8
Lifetime__of_car = 7
UNITS: years (yr)
DOCUMENT: {years}
Average lifetime of a car.
LinkDirMatrix[Links,Links] = [1,1,0,0,0,0,0,0,0,0,0,0,0,0,
1,1,0,0,0,0,0,0,0,0,0,0,0,0,
0,0,1,1,0,0,0,0,0,0,0,0,0,0,
0,0,1,1,0,0,0,0,0,0,0,0,0,0,
0,0,0,0,1,1,0,0,0,0,0,0,0,0,
0,0,0,0,1,1,0,0,0,0,0,0,0,0,

0,0,0,0,0,0,1,1,0,0,0,0,0,0,
0,0,0,0,0,0,1,1,0,0,0,0,0,0,
0,0,0,0,0,0,0,0,1,1,0,0,0,0,
0,0,0,0,0,0,0,0,1,1,0,0,0,0,
0,0,0,0,0,0,0,0,0,0,1,1,0,0,
0,0,0,0,0,0,0,0,0,0,1,1,0,0,
0,0,0,0,0,0,0,0,0,0,0,0,1,1,
0,0,0,0,0,0,0,0,0,0,0,0,1,1]
UNITS: Unitless
DOCUMENT: {unitless}
Matrix, L = {l_ij], where l_ij = 1 if link i and j connects the same areas/zonal centroids, otherwise zero. l_ii = 1 for all i.
Link_path_incidence_length_matrix[Links,Paths] = Length_of_roads[Links]*Link_path_incidence_matrix[Links,Paths]
UNITS: kilometers (km)
DOCUMENT: {km}
Link_path_incidence_matrix[Links,Paths] = [1,1,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,1,0,0,0,0,0,1,1,0,0,0,0,1,1,0,0,0,0,0,
0,0,0,0,0,1,0,1,1,1,1,0,0,1,0,1,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,
0,1,0,0,0,0,1,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,1,0,0,0,0,0,1,0,0,0,0,0,
0,0,0,0,0,0,0,0,0,0,1,1,0,1,0,1,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,
0,0,0,0,0,0,0,0,0,0,0,0,1,0,1,0,0,1,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,
0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,1,0,0,0,0,0,0,1,0,0,0,0,0,0,1,0,0,0,
0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,1,1,0,0,1,0,0,0,0,0,0,0,0,0,1,0,0,0,0,
0,0,1,0,0,0,0,1,0,0,0,0,0,0,0,1,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,1,0,0,
0,0,0,0,0,0,0,0,0,0,0,0,0,0,1,0,0,1,0,0,0,1,0,1,0,0,0,0,0,0,0,0,0,0,0,0,
0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,1,1,0,0,0,0,0,1,0,1,0,
0,0,0,0,1,0,0,0,0,1,0,0,0,0,0,1,0,1,0,0,0,0,1,1,0,0,0,0,0,1,0,0,0,0,0,0,0,0,
0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,1,1,1,0,1,1,1,1,
0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,1,0,0,0,0,0,0,0,1,1,1,0,0,0,1,1,1,0,0,1,0,0,
0,0,0,1,1,0,0,0,1,1,0,0,0,1,0,1,0,0,0,0,0,0,1,0,0,0,0,0,0,0,0,0,0,1,0,0,0,0]
UNITS: Unitless
DOCUMENT: {unitless}
Link-path incidence matrix. A matrix, M = {m_ij} , where m_ij = 1 iff link i is in path j, otherwise 0.
Liters_of_gas_per_kilometer[Paths] = 0.295-8.62*(10^-3)*Average_speed_on_path[Paths]+1.19*(10^-4)*(Average_speed_on_path[Paths]^2)-7.13*(10^-7)*(Average_speed_on_path[Paths]^3)+1.76*(10^-9)*(Average_speed_on_path[Paths]^4)
UNITS: l/km (l/km)
DOCUMENT: {l/km}
Gas consumption per kilometers as a function of speed.
(Pfaffenbichler, 2003)
Max__#_lanes[Links] = [3,3,3,3,3,3,3,3,3,3,1,1,3,3]
UNITS: Unitless
DOCUMENT: {unitless}
Measured__peak_hour__traffic_flow[Links] = SMTH3(ARRAYSUM(Traffic_flow_on_links[*,Links]), Measurment__time)
UNITS: cars/hr (cars/hr)
DOCUMENT: {cars/hr}
Perceived number of cars on the road segments.
Measured_traffic_flow_matrix[Links,Links] = Measured__peak_hour__traffic_flow[Links]*LinkDirMatrix[Links,Links]
UNITS: cars/hr (cars/hr)
DOCUMENT: {cars/hr}
This calculation is necessary for taking into account that the traffic "returns", because home- work becomes later work-home traffic going the opposite direction. So a large traffic flow in the morning rush from Askøy to Bergen city center means that the traffic flow in afternoon from Bergen city to askøy should be of equal size. This should be taken into consideration when making decisions.
Measurment__time = 2
UNITS: years (yr)
DOCUMENT: {years}
Time to measure traffic flow. The time to compile sensor data , interpret them and arrive at decision about change of road capacity.
Monetary_cost__for_car[OD] = ARRAYSUM(Origin_path_monetary__cost_matrix[OD,*])
UNITS: NOK

DOCUMENT: {NOK}
New_lanes_desired_constructed[Links] = Road_improvements_SW*(Desired_effective__lanes[Links]-Effective_#__of_lanes[Links])
UNITS: Unitless
DOCUMENT: {unitless}
Desired new lanes.
Normal__standard_deviation_travel_time_bus = 30/60
UNITS: hours (hr)
DOCUMENT: {hours}
Standard deviation when road capacity utilization equals one.
Normal_deviation__in_travel_time_with_tram = 2/60
UNITS: hours (hr)
DOCUMENT: {hours}
Normal_standard__deviation_boat = 0.2
UNITS: hours (hr)
DOCUMENT: {hours}
Normal_standard_deviation_travel_time_car = 5/60
UNITS: hours (hr)
DOCUMENT: {hours}
Normal_walking__time_and_search_time__car = 5/60
UNITS: hours (hr)
DOCUMENT: {hour}
The time it takes to work to and from car.
Orgin_path_matrix[OD,Paths] = [1,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,
0,1,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,
0,0,1,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,
0,0,0,1,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,
0,0,0,0,1,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,
0,0,0,0,0,1,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,
0,0,0,0,0,0,1,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,
0,0,0,0,0,0,0,1,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,
0,0,0,0,0,0,0,0,1,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,
0,0,0,0,0,0,0,0,0,1,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,
0,0,0,0,0,0,0,0,0,0,1,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,
0,0,0,0,0,0,0,0,0,0,0,1,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,
0,0,0,0,0,0,0,0,0,0,0,0,1,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,
0,0,0,0,0,0,0,0,0,0,0,0,0,1,1,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,
0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,1,0,1,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,
0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,1,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,
0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,1,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,
0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,1,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,
0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,1,0,0,0,0,0,0,0,0,0,0,0,1,0,0,0,0,
0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,1,1,0,0,0,0,0,0,0,0,0,0,0,0,0,0,
0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,1,0,0,0,0,0,0,0,0,0,0,0,0,0,
0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,1,0,0,0,0,0,0,0,0,0,0,0,0,
0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,1,1,0,0,0,0,0,0,0,0,0,0,
0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,1,0,0,0,0,0,0,0,0,0,0,0,1,0,0,0,0,0,0,0,0,0,
0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,1,0,0,0,0,0,0,0,0,
0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,1,0,0,0,0,0,0,0,
0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,1,0,0,0,0,0,0,
0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,1,0,1,0,0,0,
0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,1,1,0,
0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,1]
UNITS: Unitless
DOCUMENT: {unitless}
A matrix, O = {o_ij}, showing which path that links which origin-destination pair. i denotes the paths and j denotes the OD pairs. o_ij = 1 iff path i can be used by people travelling between the OD pair j. Otherwise, o_ij = 0.
Origin_path_monetary__cost_matrix[OD,Paths] = Orgin_path_matrix[OD,Paths]*Expected_cost__car[Paths]*Fraction_using__path[Paths]

DOCUMENT: {NOK}
This is an intermediate variable needed for getting the crossproduct.
Parking_space__building_time = 2
UNITS: years (yr)
DOCUMENT: {years}

Parking_spaces__at_boat_bay = 450
UNITS: cars
DOCUMENT: {cars}
(Google, 2013)
Parking_spaces_desired_constructred = SMTH1(Desired___parkings_spaces-Parking__spaces, Time_to_perceive_parking_space_crowding)
UNITS: cars
DOCUMENT: {cars}
Path_cost_matrix[Paths,Paths] = IF Comparision_Matrix[Paths,Paths]=0 THEN 0 ELSE EXP(-(20*Perceived_cost__of_paths[Paths]))
UNITS: hours (hr)
DOCUMENT: {hours}
This is an intermediate variable needed to do some matrix computations.
Path_travel__time[OD,Paths] = Expected_travel_time__with_car[Paths]*Orgin_path_matrix[OD, Paths]
UNITS: hours (hr)
DOCUMENT: {hours}
This is an intermediate variable needed for getting the crossproduct.
Perceived_travel_time__OD_Tram[OD] = ARRAYSUM(Perceived_travel_time_matrix_tram[OD,*])/ARRAYSUM(Orgin_path_matrix[OD,*])
Perceived_travel_time_matrix_tram[OD,Paths] = Perceived__travel_time_tram[Paths]*Orgin_path_matrix[OD,Paths]
Percent_tram_users = 100*Aggregated_tram_users/Total_com
Percent__boat_users = 100*Aggregated_boat__users/Total_com
Percent__bus_users = 100*Aggregated_bus_users/Total_com
Percent__car_users = 100*Aggregated_car_users/Total_com
Percent__extra_capaity = 20
UNITS: Unitless
DOCUMENT: {Unitless}
Percent__slow_users = 100*Aggregated__slow_users/Total_com
Percent_bicycle_users = Walkers_#/Total_com
percent_walkers = Bicycle_#/Total_com
Practical_capacity__factor = 0.8
UNITS: Unitless
DOCUMENT: {unitless}
Coeffisient for practical capacity. (Kutz, 2004)
Proportion_prefering_Tram[OD] = Attractiveness__of_tram[OD]/Sum_of_attractiveness__minus_car[OD]
UNITS: Unitless
DOCUMENT: {unitless}
This is the proportion of people that chooses tram.
Proportion_that_prefer__to_bicycle[OD] = Attractiveness__of__bicycle[OD]/Sum_of_attractiveness__minus_car[OD]
UNITS: Unitless
DOCUMENT: {unitless}
This is the proportion of people that chooses bicycle or feets.
Proportion_that_prefer_Boat[OD] = Attractiveness___of__boat[OD]/Sum_of_attractiveness__minus_car[OD]
UNITS: Unitless
DOCUMENT: {unitless}
This is the proportion of people that chooses boat
. Proportion_that_prefer_Bus[OD] = Attractiveness___of_bus[OD]/Sum_of_attractiveness__minus_car[OD]
UNITS: Unitless
DOCUMENT: {unitless}
This is the proportion of people that want to use bus.
Proportion_that_prefer_to_walk[OD] = Attractiveness___of_walking[OD]/Sum_of_attractiveness__minus_car[OD]
UNITS: Unitless
DOCUMENT: {unitless}

This is the proportion of people that chooses bicycle or feets.
Proportion_that__want_to_use__Car[OD] = Attractiveness__of__car[OD]/Sum_of_attractiveness[OD]
UNITS: Unitless
DOCUMENT: {unitless}
This is the proportion of people with access to car that chooses car.
Random__residuals = 0.22
UNITS: Unitless
DOCUMENT: [unitless]
Scaling parameter used to change the shape (steepness) of function determining the proportion using each transportation mode.
Road_capacity[Links] = Practical_capacity__factor*Effective_#__of_lanes[Links]*Capacity_per_lane
UNITS: cars/hr (cars/hr)
DOCUMENT: {cars/hr}
The practical capacity for a given road segment. (The number of car per hour that can be handled by the road segment, however units used are car for simplicity).
Road_capacity__utilization[Links] = IF Road_capacity[Links] = 0 THEN 3 ELSE Cars_on__roads[Links]/Road_capacity[Links]
UNITS: Unitless
DOCUMENT: {unitless}
Capacity utilization of a road link/segment.
Road_capacity__utilization_paths[Links,Paths] = Link_path_incidence_matrix[Links,Paths]*Road_capacity__utilization[Links]
UNITS: Unitless
DOCUMENT: {unitless}
Utilization of road links in paths matrix.
Road_improvements_SW = 1
UNITS: Unitless
Road_maintenance[Links] = SMTH1(Road__deterioration[Links], Time_to_perceive_road_detoriation)
UNITS: km/yr
DOCUMENT: {km}
Km of road needed maintance.
Saturation_level__car_ownership = 1
UNITS: Unitless
DOCUMENT: {unitless}
Maximum car ownership. Level where car onwership saturates.
Search_time_after_parking_space[Paths] =
Normal_walking__time_and_search_time__car*ARRAYSUM(Weighted_effect_of_search__time_matrix[Paths,*])
UNITS: hours (hr)
DOCUMENT: {Hours}
Search_time_in__RUSH_HOUR[OD] =
Effect_of_search_time_on_walking_and_search_time[OD]*Normal_walking__time_and_search_time__car
Slow_distance_factor = 1
UNITS: Unitless
DOCUMENT: {unitless}
Speed_of_tram = 50
UNITS: kilometers per hour (km/hr)
DOCUMENT: {km/hr}
Speed of the tram.
Standard_deviation_in_travel_time_car[Paths] =
Normal_standard_deviation_travel_time_car*Average_effect_of_travel_time_on_standard_deviation[Paths]
UNITS: hours (hr)
DOCUMENT: {hours}
Standard_deviation_travel_time_bus[Paths] = Normal__standard_deviation_travel_time_bus
((ARRAYSUM(Road_capacity__utilization_paths[,Paths])
-ARRAYSUM(Road_capacity__utilization_paths[*,Paths])
*(Dedicated_bus__lanes/100)
+(Dedicated_bus__lanes/100)))
UNITS: hours (hr)
DOCUMENT: {hours}
Standard deviation experienced when using bus.

Sum_of_attractiveness__minus_car[OD] =
Attractiveness__of__bicycle[OD]+Attractiveness___of_bus[OD]+Attractiveness___of__boat[OD]+Attractiveness__of_tram[OD]+
Attractiveness___of_walking[OD]
UNITS: Unitless
DOCUMENT: {unitless}
Total utility for all transport modes when car is excluded from the choice set.
Sum_of_attractiveness[OD] = Attractiveness__of__car[OD]+Sum_of_attractiveness__minus_car[OD]
UNITS: Unitless
DOCUMENT: {unitless}
This is the total utility of all transport modes from a given origin.
Ticket_price = GRAPH(TIME)
(2000, 23.0), (2010, 27.5)
UNITS: NOK
DOCUMENT: {NOK}
Price of using public transportation.
Time_to_perceive_change_in_path_costs = 5
UNITS: years (yr)
DOCUMENT: {year}
Average time to perceive and act on changes in path costs.
Time_spent_in__traffic_BUS[Paths] =
(Dedicated_bus__lanes/100)*ARRAYSUM(Free_flow_travel_time_on_path[*,Paths])+Travel_time_with_bus[Paths]*(1-
Dedicated_bus__lanes/100)*Additional__travel_time_factor
UNITS: hours (hr)
DOCUMENT: {hours}
Time spent in traffic with bus ordered after paths.
Time_to_perceive_cost_chg = 0.25
UNITS: years (yr)
DOCUMENT: {hours}
The time it takes for the users to perceive the monetary costs.Could also be interpreted as "responsiveness" to changes.
Time_to_perceive_road_detoriation = 1
UNITS: years (yr)
DOCUMENT: {years}
Time to perceive road detoration and initate plans for improvement.
Time_to_perceive_parking_space_crowding = 0.5
UNITS: years (yr)
DOCUMENT: {years}
Time_to_pereive_scrapping = 1
UNITS: years (yr)
DOCUMENT: {years}
Time to perceive/adapt expectations about scrapping rate.
Toll_rate[1] = 30
UNITS: NOK
Toll_rate[6] = 30
Toll_rate[7] = 30
Toll_rate[8] = 30
Toll_rate[9] = 30
Toll_rate[10] = 30-STEP(30, 2006)
Toll_rate[11] = 30
Toll_rate[12] = 30
Toll_rate[13] = 30
Toll_rate[14] = 30
Toll_rate[15] = 30
Toll_rate[35] = 30-STEP(30,2006)
Toll_rate[36] = 30-STEP(30,2006)
Toll_rate[2] = 30
Toll_rate[3] = 30
Toll_rate[16] = 30-STEP(30,2006)
Toll_rate[17] = 30
Toll_rate[18] = 30-STEP(30,2006)
Toll_rate[19] = 30
Toll_rate[20] = 30
Toll_rate[21] = 30
Toll_rate[22] = 30
Toll_rate[23] = 30-STEP(30,2006)
Toll_rate[24] = 30-STEP(30,2006)
Toll_rate[25] = 30
Toll_rate[37] = 30-STEP(30,2006)
Toll_rate[38] = 30-STEP(30,2006)
Toll_rate[4] = 30
Toll_rate[5] = 30-STEP(30, 2006)
Toll_rate[26] = 30
Toll_rate[27] = 30
Toll_rate[28] = 30
Toll_rate[29] = 30
Toll_rate[30] = 30-STEP(30,2006)
Toll_rate[31] = 30-STEP(30,2006)*0
Toll_rate[32] = 30-STEP(30,2006)
Toll_rate[33] = 30-STEP(30,2006)
Toll_rate[34] = 30
DOCUMENT: KVU 22
Total__path__attractiveness[Paths] = ARRAYSUM(Path_cost_matrix[*,Paths])
UNITS: Unitless
DOCUMENT: {unitless}
Sum of the paths utility.

Total_com = Aggregated_boat__users + Aggregated_bus_users + Aggregated_car_users + Aggregated_tram_users + Aggregated__slow_users
Total_measured_traffic_flow = SMTH3(ARRAYSUM(Cars_on__roads[*]),2)
Total_Monetary__cost[Paths] = Average_gasoline__cost[Paths]+Fees_and_tolls[Paths]
UNITS: NOK
DOCUMENT: {NOK}
Traffic_flow_on_links[Paths,Links] = Link_path_incidence_matrix[Links,Paths]*Cars__on_path[Paths]
UNITS: cars/hr (cars/hr)
DOCUMENT: {cars/hr}
Number of cars on each link, sorted by the different paths through the network.
Tram_users[OD] =
Proportion__using_tram[OD]*(Commuters_without__car_access[OD]+Commuters__with_access_not_using_car[OD])
UNITS: people (person)
DOCUMENT: {people}
This is the number of persons that want to use tram for commuting.
Travel__time_with_tram[Paths] = Additional_travel_time_for_tram[Paths]+Average_travel__time_with_tram_for_paths[Paths]
UNITS: hours (hr)
DOCUMENT: {hours}
Travel_time_for_bus_after_orgin[OD] = ARRAYSUM(Travel_time_paths_for_bus_weighted[OD,*])
UNITS: hours (hr)
DOCUMENT: {hours}
Travel_time_on_road[Links] = Free_flow_travel_time[Links]*(1+0.15*(Road_capacity__utilization[Links]^4))
UNITS: hours (hr)
DOCUMENT: {hour}
The average time used to travel from the beginning of a road segment to its end given rush hour traffic.
Travel_time_on_roads_matrix[Paths,Links] = Travel_time_on_road[Links]*Link_path_incidence_matrix[Links,Paths]
UNITS: hours (hr)
DOCUMENT: {hours}
Intermediate variable needed to do matrix computations.
Travel_time_on_roads_matrix_bus[Paths,Links] = Travel_time_on_road_bus[Links]*Link_path_incidence_matrix[Links,Paths]
UNITS: hours (hr)
DOCUMENT: {hours}
Intermediate variable needed to do matrix computations.
Travel_time_on_road_bus[Links] = Free_flow_travel_time[Links]*(1+0.15*(Road_capacity__utilization[Links]^4))
UNITS: hours (hr)
DOCUMENT: {hour}
The average time used to travel from the beginning of a road segment to its end given rush hour traffic.
Travel_time_to_boat[OD] = [0, 0, 0, 0,0.35 ,0, 0, 0, 0, 0,00,0,0,0,0,0,0,0,0,0,00,0,0,00,00,0.35,0,0,00,0]
UNITS: hours (hr)
DOCUMENT: {hour}
Travel_time_with_bus[Paths] = ARRAYSUM(Travel_time_on_roads_matrix_bus[Paths,*])
UNITS: hours (hr)
DOCUMENT: {hours}
Travel time from a given origin to a destination when choosing path i.
Travel_time_with_car[Paths] = ARRAYSUM(Travel_time_on_roads_matrix[Paths,*])
UNITS: hours (hr)
DOCUMENT: {hours}
Travel time from a given origin to a destination when choosing path i.
TRAVEL_TIME__ON_HIGHWAY_CAR[OD] = SMTH1(ARRAYSUM(Travel_time_on__highway_matrix[*,OD]), Time_to_perceive_cost_chg)
Travel_time__with_boat[OD] = [0,00,0,0,0.2,0,0,0, 0, 0, 0, 0, 0, 0, 0, 0, 00, 00, 0, 0, 0, 0, 000, 0, 0, 0.2, 0,0, 0, 0]
UNITS: hours (hr)
DOCUMENT: {hour}
Travel_time_car[OD] = ARRAYSUM(average__travel_time[OD,*])
UNITS: hours (hr)
DOCUMENT: {hours}
This is the time used at average when travelling from origin i to city center.
Travel_time_on__highway_matrix[Paths,OD] =
Fraction_using__path[Paths]*Orgin_path_matrix[OD,Paths]*Travel_time_with_car[Paths]

Travel_time_paths_for_bus_weighted[OD,Paths] = Travel__time__with__bus[Paths,OD]*Fraction_using__path[Paths]
UNITS: hours (hr)
DOCUMENT: {hours}
TRAVEL_TIME_WITH_CAR_WITHOUT_TIME_ON_HIGHWAY[OD] = Travel_time_car[OD]-
TRAVEL_TIME__ON_HIGHWAY_CAR[OD]
Travel__time__with__bus[Paths,OD] = Expected__travel_time_of_Bus[Paths]*Orgin_path_matrix[OD, Paths]
UNITS: hours (hr)
DOCUMENT: {hours}
Waiting_time_with_boat[OD] = IF Boat_commuters_in_peak_hour[OD]>Boat_capacity
THEN (0.5/Hourly__frequency_boat)*(Boat_commuters_in_peak_hour[OD]/Boat_capacity)
ELSE (0.5/Hourly__frequency_boat)
UNITS: hours (hr)
DOCUMENT: {unitless}
If the number of passengers is greater than the capacity then some must either wait for the boat or arrange another form of transportation. Either way, this means that the average travel time increases for boat passengers.
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Walkers[OD] =
(Commuters_without__car_access[OD]+Commuters__with_access_not_using_car[OD])*Proportion__walking[OD]
UNITS: people (person)
DOCUMENT: {persons}
This is the number of persons that want to use bicyle or their feets for commuting.
Walkers_# = ARRAYSUM(Walkers[*])
Walking__time_to_tram_station[Paths] = 20/60
UNITS: hours (hr)
Walking___time[OD] = Slow_distance_factor*Distance_OD__for_slow[OD]/Walking_speed
UNITS: hours (hr)
DOCUMENT: {hours}
Walking_speed = 5
UNITS: kilometers per hour (km/hr)
DOCUMENT: {km/r}
Want_to_use_car__elasticity_of__car_acquisition = 0.5
UNITS: Unitless
DOCUMENT: {unitless}
Decides the effect of proportion that want to use car on the fraction that wan to use car.
Weighted_effect_of_search__time_matrix[Paths,OD] =
Effect_of_search_time_on_walking_and_search_time[OD]*Orgin_path_matrix[OD,Paths]
UNITS: Unitless
DOCUMENT: {Hours}
Weighted_travel_time_PT[OD] =
(Expected_travel_time_of_Boat[OD]*Proportion_that_prefer_Boat[OD]+Perceived_travel_time__OD_Tram[OD]*Proportion_prefering_Tram[OD]+bicycle__time[OD]*Proportion_that_prefer__to_bicycle[OD]+Walking___time[OD]*Proportion_that_prefer_to_walk[OD]+Travel_time_for_bus_after_orgin[OD]*Proportion_that_prefer_Bus[OD])*0
+
(Expected_travel_time_of_Boat[OD]+bicycle__time[OD]+Perceived_travel_time__OD_Tram[OD]+Travel_time_for_bus_after_orgin[OD]+Walking___time[OD])/5

12.15 Equations policy model

Congestion_charge[Links](t) = Congestion_charge[Links](t - dt) + (adjustment_of__congestion_charge[Links]) * dt
INIT Congestion_charge[Links] = 0
UNITS: NOK
DOCUMENT: {NOK}
INFLOWS:
adjustment_of__congestion_charge[Links] = IF
Desired_increase_in_congestion_charge[Links]/Time_to_adjust__congestion_charge < 0 THEN
MAX(Desired_increase_in_congestion_charge[Links]/Time_to_adjust__congestion_charge, -Congestion_charge[Links]) ELSE
Desired_increase_in_congestion_charge[Links]/Time_to_adjust__congestion_charge
UNITS: nok/yr

Cum_benefit(t) = Cum_benefit(t - dt) + (Change_in_benefit) * dt
INIT Cum_benefit = 0
INFLOWS:
Change_in_benefit = STEP(1, START_TIME__FOR_POLICIES)*(Business_as_usual_yearly_peak_hour_costs-yearly_peak_hour_cost)/((1+Discount_rate/100)^(TIME-2014))
Cum__peak_hour_congestion_costs(t) = Cum__peak_hour_congestion_costs(t - dt) + (Social_economical_expenses) * dt
INIT Cum__peak_hour_congestion_costs = 0
INFLOWS:
Social_economical_expenses = STEP(1, START_TIME__FOR_POLICIES)*yearly_peak_hour_cost
UNATTACHED:
chg_expected__cost_of_bus = (Ticket_price+Change_ticket_price*STEP(1,2014)-Expected__cost_of_Bus)/Time_to_perceive_cost_chg
UNATTACHED:
chg_expected_cost_of_boat = (Ticket_price+Change_ticket_price*STEP(1,2014)-Expected_cost_of_Boat)/Time_to_perceive_cost_chg
UNITS: nok/yr
UNATTACHED:
chg_in_expected__cost_of_tram = (Ticket_price+Change_ticket_price*STEP(1,2014)-Expected__cost_tram)/Time_to_perceive_cost_chg
UNITS: nok/yr
Additional_travel_time_for_bus[Paths] = ARRAYSUM(Average_waiting_time_matrix_bus[*,Paths])/ARRAYSUM(Orgin_path_matrix[*,Paths])+ARRAYSUM(Average_walking_time_Bus_paths[*,Paths])/ARRAYSUM(Orgin_path_matrix[*,Paths])+Average_time_used_at_stops
UNITS: hours (hr)
DOCUMENT: {hours}
Additional_travel_time_for_tram[Paths] = Average_time_used_at_stops+Walking__time_to_tram_station[Paths]*(1-Park_and_rides_%_reduction_in_walking_time_to_bus_stop*Park_and_ride_policy_SW*STEP(1,START_TIME__FOR_POLICIES))+Average__waiting_time_TRAM[Paths]
UNITS: hours (hr)
DOCUMENT: {hours}
Attractiveness__of_tram[OD] = EXP(
(Attractiveness___parameters__PT[TravelTime]*Perceived_travel_time__OD_Tram[OD]
+Attractiveness___parameters__PT[MonetaryCosts]*Expected__cost_tram
+Attractiveness___parameters__PT[Standarddeviation]*Expected_risk_tram+Attractiveness___parameters__PT[Convenience]
+Expansion_of__Tram_network[OD])
/Random__residuals)
UNITS: Unitless
Average_travel__time_with_Bus[1] = Additional_travel_time_for_bus[1]+Time_spent_in__traffic_BUS[1]
UNITS: hours (hr)
Average_travel__time_with_Bus[2] = Additional_travel_time_for_bus[2]+Time_spent_in__traffic_BUS[2]
Average_travel__time_with_Bus[3] = Additional_travel_time_for_bus[3]+Time_spent_in__traffic_BUS[3]+Change_in_travel_time_after_opening_of_the_tram*STEP(1, 2010)
Average_travel__time_with_Bus[4] = Additional_travel_time_for_bus[4]+Time_spent_in__traffic_BUS[4]
Average_travel__time_with_Bus[5] = Additional_travel_time_for_bus[5]+Time_spent_in__traffic_BUS[5]
Average_travel__time_with_Bus[6] = Additional_travel_time_for_bus[6]+Time_spent_in__traffic_BUS[6]
Average_travel__time_with_Bus[7] = Additional_travel_time_for_bus[7]+Time_spent_in__traffic_BUS[7]
Average_travel__time_with_Bus[8] = Additional_travel_time_for_bus[8]+Time_spent_in__traffic_BUS[8]
Average_travel__time_with_Bus[9] = Additional_travel_time_for_bus[9]+Time_spent_in__traffic_BUS[9]
Average_travel__time_with_Bus[10] = Additional_travel_time_for_bus[10]+Time_spent_in__traffic_BUS[10]
Average_travel__time_with_Bus[11] = Additional_travel_time_for_bus[11]+Time_spent_in__traffic_BUS[11]
Average_travel__time_with_Bus[12] = Additional_travel_time_for_bus[12]+Time_spent_in__traffic_BUS[12]
Average_travel__time_with_Bus[13] = Additional_travel_time_for_bus[13]+Time_spent_in__traffic_BUS[13]
Average_travel__time_with_Bus[14] = Additional_travel_time_for_bus[14]+Time_spent_in__traffic_BUS[14]
Average_travel__time_with_Bus[15] = Additional_travel_time_for_bus[15]+Time_spent_in__traffic_BUS[15]
Average_travel__time_with_Bus[16] = Additional_travel_time_for_bus[16]+Time_spent_in__traffic_BUS[16]
Average_travel__time_with_Bus[17] = Additional_travel_time_for_bus[17]+Time_spent_in__traffic_BUS[17]
Average_travel__time_with_Bus[18] = Additional_travel_time_for_bus[18]+Time_spent_in__traffic_BUS[18]

Average_travel__time_with_Bus[19] =
Additional_travel_time_for_bus[19]+Time_spent_in__traffic_BUS[19]+Change_in_travel_time_after_opening_of_the_tram*STEP(1, 2010)
Average_travel__time_with_Bus[20] = Additional_travel_time_for_bus[20]+Time_spent_in__traffic_BUS[20]
Average_travel__time_with_Bus[21] = Additional_travel_time_for_bus[21]+Time_spent_in__traffic_BUS[21]
Average_travel__time_with_Bus[22] = Additional_travel_time_for_bus[22]+Time_spent_in__traffic_BUS[22]
Average_travel__time_with_Bus[23] = Additional_travel_time_for_bus[23]+Time_spent_in__traffic_BUS[23]
Average_travel__time_with_Bus[24] = Additional_travel_time_for_bus[24]+Time_spent_in__traffic_BUS[24]
Average_travel__time_with_Bus[25] = Additional_travel_time_for_bus[25]+Time_spent_in__traffic_BUS[25]
Average_travel__time_with_Bus[26] = Additional_travel_time_for_bus[26]+Time_spent_in__traffic_BUS[26]
Average_travel__time_with_Bus[27] = Additional_travel_time_for_bus[27]+Time_spent_in__traffic_BUS[27]
Average_travel__time_with_Bus[28] = Additional_travel_time_for_bus[28]+Time_spent_in__traffic_BUS[28]
Average_travel__time_with_Bus[29] = Additional_travel_time_for_bus[29]+Time_spent_in__traffic_BUS[29]
Average_travel__time_with_Bus[30] = Additional_travel_time_for_bus[30]+Time_spent_in__traffic_BUS[30]
Average_travel__time_with_Bus[31] = Additional_travel_time_for_bus[31]+Time_spent_in__traffic_BUS[31]
Average_travel__time_with_Bus[32] = Additional_travel_time_for_bus[32]+Time_spent_in__traffic_BUS[32]
Average_travel__time_with_Bus[33] = Additional_travel_time_for_bus[33]+Time_spent_in__traffic_BUS[33]
Average_travel__time_with_Bus[34] = Additional_travel_time_for_bus[34]+Time_spent_in__traffic_BUS[34]
Average_travel__time_with_Bus[35] = Additional_travel_time_for_bus[35]+Time_spent_in__traffic_BUS[35]
Average_travel__time_with_Bus[36] = Additional_travel_time_for_bus[36]+Time_spent_in__traffic_BUS[36]
Average_travel__time_with_Bus[37] = Additional_travel_time_for_bus[37]+Time_spent_in__traffic_BUS[37]
Average_travel__time_with_Bus[38] = Additional_travel_time_for_bus[38]+Time_spent_in__traffic_BUS[38]
Average_wage__in_Bergen = 248
Average_waiting_time_matrix_bus[OD,Paths] = Orgin_path_matrix[OD,Paths]*Average_waiting__time[OD]
UNITS: hours (hr)
DOCUMENT: {hours}
Average_walking_time_Bus_paths[OD,Paths] = (1-STEP(1,START_TIME__FOR_POLICIES)*Park_and_rides_%_reduction_in_walking_time_to_bus_stop*Park_and_ride_policy_SW/100)*Average_walking__time_to_bus_stop[OD]*Orgin_path_matrix[OD,Paths]
UNITS: hours (hr)
DOCUMENT: {hours}
Average_work_days = 230
Business_as_usual_yearly_peak_hour_costs = GRAPH(TIME)
(2000, 16.9), (2000, 16.6), (2000, 16.4), (2000, 16.3), (2000, 16.1), (2000, 16.0), (2000, 15.9), (2000, 15.8), (2000, 15.7), (2000, 15.6), (2000, 15.5), (2000, 15.4), (2000, 15.4), (2000, 15.3), (2000, 15.3), (2000, 15.2), (2000, 15.2), (2000, 15.1), (2000, 15.1), (2000, 15.1), (2001, 15.1), (2001, 15.1), (2001, 15.1), (2001, 15.1), (2001, 15.1), (2001, 15.1), (2001, 15.1), (2001, 15.1), (2001, 15.1), (2001, 15.2), (2001, 15.2), (2001, 15.2), (2001, 15.3), (2001, 15.3), (2001, 15.3), (2001, 15.4), (2001, 15.4), (2001, 15.4), (2001, 15.5), (2001, 15.6), (2001, 15.6), (2001, 15.7), (2001, 15.7), (2001, 15.8), (2001, 15.8), (2001, 15.9), (2001, 16.0), (2001, 16.0), (2001, 16.1), (2001, 16.2), (2001, 16.3), (2001, 16.3), (2001, 16.4), (2001, 16.5), (2001, 16.6), (2001, 16.7), (2001, 16.8), (2001, 16.8), (2001, 16.9), (2001, 17.0), (2002, 17.1), (2002, 17.2), (2002, 17.3), (2002, 17.4), (2002, 17.5), (2002, 17.6), (2002, 17.7), (2002, 17.9), (2002, 18.0), (2002, 18.1), (2002, 18.2), (2002, 18.3), (2002, 18.4), (2002, 18.6), (2002, 18.7), (2002, 18.8), (2002, 18.9), (2002, 19.1), (2002, 19.2), (2002, 19.3), (2002, 19.4), (2002, 19.6), (2002, 19.8), (2002, 19.9), (2002, 20.1), (2002, 20.3), (2002, 20.5), (2002, 20.6), (2002, 20.8), (2002, 21.0), (2002, 21.2), (2002, 21.4), (2002, 21.6), (2002, 21.8), (2002, 21.9), (2002, 22.1), (2002, 22.4), (2002, 22.6), (2002, 22.8), (2002, 22.9), (2003, 23.2), (2003, 23.4), (2003, 23.6), (2003, 23.8), (2003, 24.0), (2003, 24.2), (2003, 24.4), (2003, 24.7), (2003, 24.9), (2003, 25.1), (2003, 25.4), (2003, 25.6), (2003, 25.8), (2003, 26.1), (2003, 26.3), (2003, 26.5), (2003, 26.8), (2003, 27.0), (2003, 27.3), (2003, 27.5), (2003, 27.8), (2003, 28.0), (2003, 28.3), (2003, 28.6), (2003, 28.9), (2003, 29.3), (2003, 29.6), (2003, 29.9), (2003, 30.2), (2003, 30.5), (2003, 30.8), (2003, 31.2), (2003, 31.5), (2003, 31.8), (2003, 32.1), (2003, 32.5), (2003, 32.8), (2003, 33.2), (2003, 33.5), (2003, 33.9), (2004, 34.2), (2004, 34.6), (2004, 34.9), (2004, 35.3), (2004, 35.6), (2004, 36.0), (2004, 36.4), (2004, 36.7), (2004, 37.1), (2004, 37.5), (2004, 37.8), (2004, 38.2), (2004, 38.6), (2004, 39.0), (2004, 39.4), (2004, 39.8), (2004, 40.1), (2004, 40.5), (2004, 40.9), (2004, 41.3), (2004, 41.7), (2004, 42.1), (2004, 42.5), (2004, 43.0), (2004, 43.4), (2004, 43.9), (2004, 44.3), (2004, 44.8), (2004, 45.2), (2004, 45.6), (2004, 46.1), (2004, 46.5), (2004, 47.0), (2004, 47.5), (2004, 47.9), (2004, 48.4), (2004, 48.8), (2004, 49.3), (2004, 49.8), (2004, 50.2), (2005, 50.7), (2005, 51.2), (2005, 51.7), (2005, 52.1), (2005, 52.6), (2005, 53.1), (2005, 53.6), (2005, 54.1), (2005, 54.6), (2005, 55.1), (2005, 55.6), (2005, 56.0), (2005, 56.5), (2005, 57.0), (2005, 57.6), (2005, 58.1), (2005, 58.6), (2005, 59.1), (2005, 59.6), (2005, 60.1), (2005, 60.6), (2005, 61.1), (2005, 61.7), (2005, 62.2), (2005, 62.7), (2005, 63.3), (2005, 63.8), (2005, 64.3), (2005, 64.9), (2005, 65.4), (2005, 66.0), (2005, 66.5), (2005, 67.0), (2005, 67.6), (2005, 68.1), (2005, 68.7), (2005, 69.2), (2005, 69.8), (2005, 70.3), (2005, 70.9), (2006, 71.5), (2006, 72.0), (2006, 72.6), (2006, 73.1), (2006, 73.7), (2006, 74.3), (2006, 74.8), (2006, 75.4), (2006, 76.0), (2006, 76.5), (2006, 77.1), (2006, 77.7), (2006, 78.2), (2006, 78.8), (2006, 79.4), (2006, 79.9), (2006, 80.5), (2006, 81.1), (2006, 81.7), (2006, 82.2), (2006, 82.8), (2006, 83.4), (2006, 83.9), (2006, 84.5), (2006, 85.1), (2006, 85.6), (2006, 86.2),

(2006, 86.8), (2006, 87.4), (2006, 88.0), (2006, 88.5), (2006, 89.2), (2006, 89.8), (2006, 90.3), (2006, 91.0), (2006, 91.6), (2006, 92.2), (2006, 92.8), (2006, 93.4), (2006, 94.0), (2007, 94.6), (2007, 95.3), (2007, 95.9), (2007, 96.5), (2007, 97.1), (2007, 97.8), (2007, 98.4), (2007, 99.0), (2007, 99.7), (2007, 100), (2007, 101), (2007, 102), (2007, 102), (2007, 103), (2007, 104), (2007, 104), (2007, 105), (2007, 105), (2007, 106), (2007, 107), (2007, 107), (2007, 108), (2007, 109), (2007, 109), (2007, 110), (2007, 110), (2007, 111), (2007, 111), (2007, 112), (2007, 112), (2007, 113), (2007, 113), (2007, 114), (2007, 114), (2007, 115), (2007, 115), (2007, 116), (2007, 117), (2007, 117), (2007, 118), (2008, 118), (2008, 119), (2008, 119), (2008, 120), (2008, 120), (2008, 121), (2008, 121), (2008, 122), (2008, 122), (2008, 123), (2008, 123), (2008, 124), (2008, 124), (2008, 125), (2008, 125), (2008, 126), (2008, 126), (2008, 127), (2008, 127), (2008, 128), (2008, 129), (2008, 129), 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Cars_used__for_commuting[OD] = (1-Car_pooling_SW*Effect_of_car_pooling_policy*STEP(1,START_TIME__FOR_POLICIES))*(Car_users[OD]/Car__sharing)

UNITS: cars

Car__sharing = 1.05
UNITS: person/cars (person/cars)
DOCUMENT: {persons/car}
How many people using one and same car.TØI Rapport 1102/2010, page 26.
(Christiansen et al. 2010)
Car_pooling_SW = 0
Change_in_travel_time_after_opening_of_the_tram = 10/60
Change_ticket_price = 0
Commuters[OD] = .Use_Historical_Data__and_trend*(.Trend_commuters[OD]*STEP(1,2011)+.Commuters_ref_mode[OD]*(1-STEP(1,2011)))+.Use_BergenSim*Simulated_commuters_from_BergenSim[OD]
UNITS: people (person)
Commuters_ref_mode[BergenC_to_BergenN] = GRAPH(TIME)
(2000, 1390), (2001, 1421), (2002, 1452), (2003, 1484), (2004, 1515), (2005, 1546), (2006, 1578), (2007, 1609), (2008, 1640), (2009, 1672), (2010, 1703), (2011, 1734)
UNITS: people (person)
Commuters_ref_mode[BergenC_to_BergenE] = GRAPH(TIME)
(2000, 444), (2001, 431), (2002, 418), (2003, 405), (2004, 392), (2005, 379), (2006, 366), (2007, 353), (2008, 340), (2009, 327), (2010, 314), (2011, 301)
UNITS: people (person)
Commuters_ref_mode[BergenC_to_BergenS] = GRAPH(TIME)
(2000, 4341), (2001, 4417), (2002, 4493), (2003, 4569), (2004, 4645), (2005, 4720), (2006, 4796), (2007, 4872), (2008, 4948), (2009, 5024), (2010, 5100), (2011, 5176)
UNITS: people (person)
Commuters_ref_mode[BergenC_to_BergenW] = GRAPH(TIME)
(2000, 3017), (2001, 3009), (2002, 3000), (2003, 2991), (2004, 2982), (2005, 2974), (2006, 2965), (2007, 2956), (2008, 2947), (2009, 2939), (2010, 2930), (2011, 2921)
UNITS: people (person)
Commuters_ref_mode[BergenC_to_Askoy] = GRAPH(TIME)
(2000, 74.0), (2001, 81.0), (2002, 93.0), (2003, 96.0), (2004, 103), (2005, 115), (2006, 127), (2007, 137), (2008, 162), (2009, 156), (2010, 174), (2011, 184)
UNITS: people (person)
Commuters_ref_mode[BergenN_to_BergenC] = GRAPH(TIME)
(2000, 6581), (2001, 6685), (2002, 6789), (2003, 6893), (2004, 6997), (2005, 7101), (2006, 7206), (2007, 7310), (2008, 7414), (2009, 7518), (2010, 7622), (2011, 7726)
UNITS: people (person)
Commuters_ref_mode[BergenN_to_BergenE] = GRAPH(TIME)
(2000, 346), (2001, 356), (2002, 365), (2003, 375), (2004, 385), (2005, 394), (2006, 404), (2007, 414), (2008, 424), (2009, 433), (2010, 443), (2011, 453)
UNITS: people (person)
Commuters_ref_mode[BergenN_to_BergenS] = GRAPH(TIME)
(2000, 1379), (2001, 1402), (2002, 1424), (2003, 1446), (2004, 1469), (2005, 1491), (2006, 1513), (2007, 1536), (2008, 1558), (2009, 1581), (2010, 1603), (2011, 1625)
UNITS: people (person)
Commuters_ref_mode[BergenN_to_BergenW] = GRAPH(TIME)
(2000, 966), (2001, 1005), (2002, 1044), (2003, 1083), (2004, 1122), (2005, 1161), (2006, 1199), (2007, 1238), (2008, 1277), (2009, 1316), (2010, 1355), (2011, 1394)
UNITS: people (person)
Commuters_ref_mode[BergenN_to_Askoy] = GRAPH(TIME)
(2000, 24.0), (2001, 27.0), (2002, 32.0), (2003, 35.0), (2004, 39.0), (2005, 45.0), (2006, 51.0), (2007, 57.0), (2008, 70.0), (2009, 70.0), (2010, 80.0), (2011, 88.0)
UNITS: people (person)
Commuters_ref_mode[BergenE_to_BergenC] = GRAPH(TIME)
(2000, 2178), (2001, 2121), (2002, 2064), (2003, 2006), (2004, 1949), (2005, 1892), (2006, 1835), (2007, 1778), (2008, 1720), (2009, 1663), (2010, 1606), (2011, 1549)
UNITS: people (person)
Commuters_ref_mode[BergenE_to_BergenN] = GRAPH(TIME)
(2000, 452), (2001, 469), (2002, 485), (2003, 502), (2004, 519), (2005, 536), (2006, 552), (2007, 569), (2008, 586), (2009, 602), (2010, 619), (2011, 636)
UNITS: people (person)

Commuters_ref_mode[BergenE_to_BergenS] = GRAPH(TIME)
(2000, 669), (2001, 677), (2002, 685), (2003, 693), (2004, 701), (2005, 710), (2006, 718), (2007, 726), (2008, 734), (2009, 742), (2010, 750), (2011, 758)
UNITS: people (person)
Commuters_ref_mode[BergenE_to_BergenW] = GRAPH(TIME)
(2000, 138), (2001, 153), (2002, 167), (2003, 181), (2004, 195), (2005, 209), (2006, 223), (2007, 238), (2008, 252), (2009, 266), (2010, 280), (2011, 294)
UNITS: people (person)
Commuters_ref_mode[BergenE_to_Askoy] = GRAPH(TIME)
(2000, 3.00), (2001, 4.00), (2002, 5.00), (2003, 6.00), (2004, 7.00), (2005, 8.00), (2006, 10.0), (2007, 11.0), (2008, 14.0), (2009, 14.0), (2010, 17.0), (2011, 18.0)
UNITS: people (person)
Commuters_ref_mode[BergenS_to_BergenC] = GRAPH(TIME)
(2000, 9607), (2001, 9736), (2002, 9866), (2003, 9995), (2004, 10124), (2005, 10253), (2006, 10383), (2007, 10512), (2008, 10641), (2009, 10771), (2010, 10900), (2011, 11029)
UNITS: people (person)
Commuters_ref_mode[BergenS_to_BergenN] = GRAPH(TIME)
(2000, 419), (2001, 443), (2002, 467), (2003, 491), (2004, 516), (2005, 540), (2006, 564), (2007, 588), (2008, 613), (2009, 637), (2010, 661), (2011, 685)
UNITS: people (person)
Commuters_ref_mode[BergenS_to_BergenE] = GRAPH(TIME)
(2000, 372), (2001, 368), (2002, 365), (2003, 361), (2004, 358), (2005, 354), (2006, 351), (2007, 347), (2008, 344), (2009, 340), (2010, 337), (2011, 334)
UNITS: people (person)
Commuters_ref_mode[BergenS_to_BergenW] = GRAPH(TIME)
(2000, 2096), (2001, 2131), (2002, 2165), (2003, 2200), (2004, 2235), (2005, 2270), (2006, 2305), (2007, 2340), (2008, 2374), (2009, 2409), (2010, 2444), (2011, 2479)
UNITS: people (person)
Commuters_ref_mode[BergenS_to_Askoy] = GRAPH(TIME)
(2000, 51.0), (2001, 57.0), (2002, 67.0), (2003, 71.0), (2004, 77.0), (2005, 88.0), (2006, 99.0), (2007, 108), (2008, 131), (2009, 128), (2010, 145), (2011, 156)
UNITS: people (person)
Commuters_ref_mode[BergenW_to_BergenC] = GRAPH(TIME)
(2000, 12987), (2001, 13024), (2002, 13060), (2003, 13097), (2004, 13133), (2005, 13170), (2006, 13207), (2007, 13243), (2008, 13280), (2009, 13316), (2010, 13353), (2011, 13390)
UNITS: people (person)
Commuters_ref_mode[BergenW_to_BergenN] = GRAPH(TIME)
(2000, 625), (2001, 662), (2002, 699), (2003, 736), (2004, 773), (2005, 810), (2006, 847), (2007, 885), (2008, 922), (2009, 959), (2010, 996), (2011, 1033)
UNITS: people (person)
Commuters_ref_mode[BergenW_to_BergenE] = GRAPH(TIME)
(2000, 108), (2001, 117), (2002, 126), (2003, 135), (2004, 144), (2005, 153), (2006, 162), (2007, 171), (2008, 180), (2009, 189), (2010, 198), (2011, 207)
UNITS: people (person)
Commuters_ref_mode[BergenW_to_BergenS] = GRAPH(TIME)
(2000, 4292), (2001, 4347), (2002, 4403), (2003, 4458), (2004, 4514), (2005, 4569), (2006, 4625), (2007, 4680), (2008, 4736), (2009, 4791), (2010, 4847), (2011, 4903)
UNITS: people (person)
Commuters_ref_mode[BergenW_to_Askoy] = GRAPH(TIME)
(2000, 181), (2001, 201), (2002, 239), (2003, 252), (2004, 276), (2005, 316), (2006, 355), (2007, 391), (2008, 474), (2009, 465), (2010, 529), (2011, 570)
UNITS: people (person)
Commuters_ref_mode[Askoy_to_BergenC] = GRAPH(TIME)
(2000, 2322), (2001, 2326), (2002, 2253), (2003, 2334), (2004, 2363), (2005, 2387), (2006, 2530), (2007, 2704), (2008, 2790), (2009, 2780), (2010, 2771), (2011, 2895)
UNITS: people (person)
Commuters_ref_mode[Askoy_to_BergenN] = GRAPH(TIME)
(2000, 112), (2001, 118), (2002, 121), (2003, 131), (2004, 139), (2005, 147), (2006, 162), (2007, 181), (2008, 194), (2009, 200), (2010, 207), (2011, 223)

UNITS: people (person)
Commuters_ref_mode[Askoy_to_BergenE] = GRAPH(TIME)
(2000, 19.0), (2001, 21.0), (2002, 22.0), (2003, 24.0), (2004, 26.0), (2005, 28.0), (2006, 31.0), (2007, 35.0), (2008, 38.0), (2009, 39.0), (2010, 41.0), (2011, 45.0)
UNITS: people (person)
Commuters_ref_mode[Askoy_to_BergenS] = GRAPH(TIME)
(2000, 767), (2001, 777), (2002, 759), (2003, 794), (2004, 812), (2005, 828), (2006, 886), (2007, 956), (2008, 995), (2009, 1000), (2010, 1006), (2011, 1060)
UNITS: people (person)
Commuters_ref_mode[Askoy_to_BergenW] = GRAPH(TIME)
(2000, 1318), (2001, 1345), (2002, 1325), (2003, 1396), (2004, 1437), (2005, 1476), (2006, 1590), (2007, 1726), (2008, 1809), (2009, 1829), (2010, 1851), (2011, 1961)
UNITS: people (person)
Congestion__charge_matrix[Links,Paths] = Congestion_charge[Links]*Link_path__incidence_matrix[Links,Paths]
UNITS: NOK
DOCUMENT: {NOK}
Congestion__pricing_SW = 0
DOCUMENT: {unitless}
Congestion_charge__paths[Paths] =
ARRAYSUM(Congestion__charge_matrix[*,Paths])*POLICY_MODEL.Congestion__pricing_SW*STEP(1, POLICY_MODEL.START_TIME__FOR_POLICIES)
UNITS: NOK
DOCUMENT: {NOK}
Dedicated_bus__lanes = SMTH1(Dedicated_lanes_%*Dedicated_bus__lanes_POLICY_sw*STEP(1, START_TIME__FOR_POLICIES), Time_to_dedicate_lanes)
UNITS: lane
DOCUMENT: {lanes}
Lanes along the road links dedicated to public transportation. (Statens vegvesen, 2011a)
Dedicated_bus__lanes_POLICY_sw = 0
UNITS: lane
Dedicated_lanes_% = 70
UNITS: Unitless
Desired___parkings_spaces = (1+Parking_space_reduction_policy_SW*STEP(1, START_TIME__FOR_POLICIES)*(Desired_%_change_in_parking_coverage/100))
ARRAYSUM(Cars_used__for_commuting[*])(Desired_%__parking_coverage/100)
UNITS: cars
DOCUMENT: {cars}
Desired number of p-spaces
Desired_%__parking_coverage = 110
UNITS: Unitless
DOCUMENT: {cars}
Desired_%_change_in_parking_coverage = -50
Desired_increase_in_congestion_charge[Links] =
Gap_between_desired_and_actual_speed_in_%[Links]*POLICY_MODEL.Max_yearly_increase_in__congestion_charge
UNITS: NOK
DOCUMENT: {NOK}
Desired_speed = 50
UNITS: kilometers per hour (km/hr)
DOCUMENT: {km/h}
Discount_rate = 7
Effective_#__of_lanes[Links] = MAX((Road_quality[Links]/Length_of_roads[Links])-Dedicated_bus__lanes*(1-replace_dedicated_lanes)/100, 0)
UNITS: lane
DOCUMENT: {lane}
The effective number of lanes going towards Bergen at on road segment/link.
Effect_of_car_pooling_policy = 0
UNITS: Unitless
DOCUMENT: {unitless}
Expansion_of__network_SW = 0

Expansion_of__Tram_network[BergenC_to_BergenN] = -99+STEP(99,2014)*Expansion_of__network_SW
Expansion_of__Tram_network[BergenC_to_BergenE] = -99+STEP(99,2014)*Expansion_of__network_SW
Expansion_of__Tram_network[BergenC_to_BergenS] = -99+STEP(99,2010)
Expansion_of__Tram_network[BergenC_to_BergenW] = -99+STEP(99,2014)*Expansion_of__network_SW
Expansion_of__Tram_network[BergenC_to_Askoy] = -99
Expansion_of__Tram_network[BergenN_to_BergenC] = -99+STEP(99,2014)*Expansion_of__network_SW
Expansion_of__Tram_network[BergenN_to_BergenE] = -99+STEP(99,2014)*Expansion_of__network_SW
Expansion_of__Tram_network[BergenN_to_BergenS] = -99+STEP(99,2014)*Expansion_of__network_SW
Expansion_of__Tram_network[BergenN_to_BergenW] = -99+STEP(99,2014)*Expansion_of__network_SW
Expansion_of__Tram_network[BergenN_to_Askoy] = -99
Expansion_of__Tram_network[BergenE_to_BergenC] = -99+STEP(99,2014)*Expansion_of__network_SW
Expansion_of__Tram_network[BergenE_to_BergenN] = -99+STEP(99,2014)*Expansion_of__network_SW
Expansion_of__Tram_network[BergenE_to_BergenS] = -99+STEP(99,2014)*Expansion_of__network_SW
Expansion_of__Tram_network[BergenE_to_BergenW] = -99+STEP(99,2014)*Expansion_of__network_SW
Expansion_of__Tram_network[BergenE_to_Askoy] = -99
Expansion_of__Tram_network[BergenS_to_BergenC] = -99+STEP(99,2010)
Expansion_of__Tram_network[BergenS_to_BergenN] = -99+STEP(99,2014)*Expansion_of__network_SW
Expansion_of__Tram_network[BergenS_to_BergenE] = -99+STEP(99,2014)*Expansion_of__network_SW
Expansion_of__Tram_network[BergenS_to_BergenW] = -99+STEP(99,2014)*Expansion_of__network_SW
Expansion_of__Tram_network[BergenS_to_Askoy] = -99
Expansion_of__Tram_network[BergenW_to_BergenC] = -99+STEP(99,2014)*Expansion_of__network_SW
Expansion_of__Tram_network[BergenW_to_BergenN] = -99+STEP(99,2014)*Expansion_of__network_SW
Expansion_of__Tram_network[BergenW_to_BergenE] = -99+STEP(99,2014)*Expansion_of__network_SW
Expansion_of__Tram_network[BergenW_to_BergenS] = -99+STEP(99,2014)*Expansion_of__network_SW
Expansion_of__Tram_network[BergenW_to_Askoy] = -99
Expansion_of__Tram_network[Askoy_to_BergenC] = -99
Expansion_of__Tram_network[Askoy_to_BergenN] = -99
Expansion_of__Tram_network[Askoy_to_BergenE] = -99
Expansion_of__Tram_network[Askoy_to_BergenS] = -99
Expansion_of__Tram_network[Askoy_to_BergenW] = -99
Fees_and_tolls[Paths] = Toll_rate[Paths]+Congestion_pricing__Policy.Congestion_charge__paths[Paths]+Toll_change
UNITS: NOK
DOCUMENT: {NOK}
Average parking house fee, toll and other similar monetary expenditures paid by car users.
(Hansen, 2013)
Fraction_people__with_access_to_car[OD] = Car_ownership[OD]*Car__sharing*(1-
Restrict_car_access*Restric_car_access_SW*STEP(1,START_TIME__FOR_POLICIES))
UNITS: Unitless
DOCUMENT: {unitless}
(P. Pfaffenbichler 2003)
Fraction_using__path[Paths] = IF Total__path__attractiveness[Paths] = 0 THEN 0 ELSE EXP(-
20*Perceived_cost__of_paths[Paths]-
0.12*Congestion_pricing__Policy.Congestion_charge__paths[Paths])/Total__path__attractiveness[Paths]
UNITS: Unitless
DOCUMENT: {unitless}
The fraction of cars from an origin point that uses a given path.
Gap_between_desired_and_actual_speed_in_%[Links] = (POLICY_MODEL.Desired_speed-
Perceived_average_speed__on_road_link[Links])/POLICY_MODEL.Desired_speed
UNITS: Unitless
DOCUMENT: {unitless}
Max_yearly_increase_in__congestion_charge = 5
UNITS: NOK
DOCUMENT: {NOK}
Noname_2[Links] = { Place right hand side of equation here... }
Parking_space_reduction_policy_SW = 0
Park_and_rides_%_reduction_in_walking_time_to_bus_stop = 50
Park_and_ride_policy_SW = 0

Path_cost_matrix[Paths,Paths] = IF Comparision_Matrix[Paths,Paths]=0 THEN 0 ELSE EXP(-(20*Perceived_cost__of_paths[Paths]+0.12*Congestion_pricing__Policy.Congestion_charge__paths[Paths])*Comparision_Matrix[Paths,Paths])
UNITS: hours (hr)
DOCUMENT: {hours}
This is an intermediate variable needed to do some matrix computations.
Peak_hour_cost = ARRAYSUM(Peak_hour_cost_paths[*])
Peak_hour_cost_paths[Paths] = (Travel_time_with_car[Paths]-Free_flow_path__travel_time[Paths])*Cars__on_path[Paths]*Average_wage__in_Bergen
Perceived_average_speed__on_road_link[Links] = SMTH1(Length_of_roads[Links]/Noname_2[Links],Time_to_measure__speed)
UNITS: kilometers per hour (km/hr)
DOCUMENT: {km/h}
replace_dedicated_lanes = 0
UNITS: Unitless
DOCUMENT: {unitless}
Restrict_car_access = 0.5
UNITS: Unitless
DOCUMENT: {unitless}
Restric_car_access_SW = 0
Simulated_commuters_from_BergenSim[BergenC_to_BergenN] = GRAPH(TIME)
(2000, 1390), (2001, 1430), (2002, 1563), (2003, 1672), (2004, 1744), (2005, 1805), (2006, 1857), (2007, 1907), (2008, 1957), (2009, 2005), (2010, 2051), (2011, 2099), (2012, 2147), (2013, 2193), (2014, 2234), (2015, 2272), (2016, 2306), (2017, 2337), (2018, 2367), (2019, 2396), (2020, 2426)
Simulated_commuters_from_BergenSim[BergenC_to_BergenE] = GRAPH(TIME)
(2000, 444), (2001, 426), (2002, 433), (2003, 443), (2004, 450), (2005, 458), (2006, 466), (2007, 476), (2008, 488), (2009, 502), (2010, 516), (2011, 533), (2012, 550), (2013, 563), (2014, 575), (2015, 586), (2016, 595), (2017, 602), (2018, 609), (2019, 615), (2020, 621)
Simulated_commuters_from_BergenSim[BergenC_to_BergenS] = GRAPH(TIME)
(2000, 4341), (2001, 4252), (2002, 4161), (2003, 4050), (2004, 3899), (2005, 3758), (2006, 3637), (2007, 3539), (2008, 3470), (2009, 3414), (2010, 3358), (2011, 3167), (2012, 3021), (2013, 2913), (2014, 2833), (2015, 2777), (2016, 2740), (2017, 2722), (2018, 2725), (2019, 2751), (2020, 2797)
Simulated_commuters_from_BergenSim[BergenC_to_BergenW] = GRAPH(TIME)
(2000, 3017), (2001, 2831), (2002, 2768), (2003, 2748), (2004, 2743), (2005, 2755), (2006, 2766), (2007, 2779), (2008, 2795), (2009, 2804), (2010, 2803), (2011, 2804), (2012, 2815), (2013, 2831), (2014, 2852), (2015, 2876), (2016, 2903), (2017, 2932), (2018, 2965), (2019, 3000), (2020, 3039)
Simulated_commuters_from_BergenSim[BergenC_to_Askoy] = GRAPH(TIME)
(2000, 73.9), (2001, 201), (2002, 333), (2003, 430), (2004, 502), (2005, 557), (2006, 599), (2007, 629), (2008, 650), (2009, 666), (2010, 677), (2011, 688), (2012, 700), (2013, 711), (2014, 722), (2015, 734), (2016, 746), (2017, 759), (2018, 772), (2019, 785), (2020, 798)
Simulated_commuters_from_BergenSim[BergenN_to_BergenC] = GRAPH(TIME)
(2000, 8390), (2001, 8698), (2002, 9031), (2003, 9361), (2004, 9634), (2005, 9708), (2006, 9778), (2007, 9886), (2008, 10028), (2009, 10175), (2010, 10340), (2011, 10540), (2012, 10782), (2013, 11034), (2014, 11283), (2015, 11527), (2016, 11764), (2017, 11990), (2018, 12205), (2019, 12403), (2020, 12586)
Simulated_commuters_from_BergenSim[BergenN_to_BergenE] = GRAPH(TIME)
(2000, 441), (2001, 470), (2002, 525), (2003, 570), (2004, 607), (2005, 635), (2006, 658), (2007, 678), (2008, 700), (2009, 721), (2010, 741), (2011, 760), (2012, 780), (2013, 795), (2014, 810), (2015, 826), (2016, 842), (2017, 857), (2018, 874), (2019, 892), (2020, 912)
Simulated_commuters_from_BergenSim[BergenN_to_BergenS] = GRAPH(TIME)
(2000, 1758), (2001, 1801), (2002, 1857), (2003, 1897), (2004, 1904), (2005, 1886), (2006, 1868), (2007, 1855), (2008, 1852), (2009, 1850), (2010, 1845), (2011, 1847), (2012, 1862), (2013, 1884), (2014, 1911), (2015, 1941), (2016, 1972), (2017, 2004), (2018, 2037), (2019, 2072), (2020, 2108)
Simulated_commuters_from_BergenSim[BergenN_to_BergenW] = GRAPH(TIME)
(2000, 1232), (2001, 1194), (2002, 1228), (2003, 1277), (2004, 1328), (2005, 1369), (2006, 1403), (2007, 1434), (2008, 1462), (2009, 1483), (2010, 1497), (2011, 1502), (2012, 1512), (2013, 1525), (2014, 1541), (2015, 1559), (2016, 1577), (2017, 1596), (2018, 1615), (2019, 1634), (2020, 1651)
Simulated_commuters_from_BergenSim[BergenN_to_Askoy] = GRAPH(TIME)
(2000, 30.2), (2001, 58.5), (2002, 104), (2003, 144), (2004, 181), (2005, 213), (2006, 240), (2007, 262), (2008, 278), (2009, 292), (2010, 302), (2011, 309), (2012, 315), (2013, 321), (2014, 327), (2015, 333), (2016, 340), (2017, 346), (2018, 352), (2019, 358), (2020, 363)

Simulated_commuters_from_BergenSim[BergenE_to_BergenC] = GRAPH(TIME)
(2000, 2178), (2001, 2412), (2002, 2556), (2003, 2543), (2004, 2531), (2005, 2521), (2006, 2515), (2007, 2519), (2008, 2527), (2009, 2536), (2010, 2551), (2011, 2576), (2012, 2613), (2013, 2654), (2014, 2694), (2015, 2732), (2016, 2769), (2017, 2804), (2018, 2835), (2019, 2861), (2020, 2882)
Simulated_commuters_from_BergenSim[BergenE_to_BergenN] = GRAPH(TIME)
(2000, 452), (2001, 513), (2002, 587), (2003, 617), (2004, 634), (2005, 648), (2006, 658), (2007, 666), (2008, 674), (2009, 681), (2010, 688), (2011, 692), (2012, 697), (2013, 703), (2014, 709), (2015, 715), (2016, 723), (2017, 731), (2018, 740), (2019, 750), (2020, 760)
Simulated_commuters_from_BergenSim[BergenE_to_BergenS] = GRAPH(TIME)
(2000, 669), (2001, 807), (2002, 959), (2003, 1042), (2004, 1109), (2005, 1169), (2006, 1221), (2007, 1266), (2008, 1308), (2009, 1343), (2010, 1368), (2011, 1394), (2012, 1424), (2013, 1457), (2014, 1492), (2015, 1529), (2016, 1570), (2017, 1614), (2018, 1662), (2019, 1716), (2020, 1773)
Simulated_commuters_from_BergenSim[BergenE_to_BergenW] = GRAPH(TIME)
(2000, 138), (2001, 164), (2002, 203), (2003, 228), (2004, 250), (2005, 269), (2006, 286), (2007, 300), (2008, 313), (2009, 322), (2010, 328), (2011, 331), (2012, 335), (2013, 339), (2014, 342), (2015, 346), (2016, 350), (2017, 353), (2018, 356), (2019, 358), (2020, 359)
Simulated_commuters_from_BergenSim[BergenE_to_Askoy] = GRAPH(TIME)
(2000, 3.39), (2001, 8.57), (2002, 19.5), (2003, 28.8), (2004, 36.9), (2005, 43.9), (2006, 49.9), (2007, 54.9), (2008, 58.7), (2009, 61.7), (2010, 64.0), (2011, 65.6), (2012, 66.7), (2013, 67.9), (2014, 69.0), (2015, 70.1), (2016, 71.2), (2017, 72.1), (2018, 72.9), (2019, 73.6), (2020, 74.1)
Simulated_commuters_from_BergenSim[BergenS_to_BergenC] = GRAPH(TIME)
(2000, 9607), (2001, 9825), (2002, 9763), (2003, 9612), (2004, 9462), (2005, 9311), (2006, 9167), (2007, 9038), (2008, 8932), (2009, 8882), (2010, 8918), (2011, 8609), (2012, 8384), (2013, 8222), (2014, 8114), (2015, 8049), (2016, 8021), (2017, 8031), (2018, 8076), (2019, 8153), (2020, 8260)
Simulated_commuters_from_BergenSim[BergenS_to_BergenN] = GRAPH(TIME)
(2000, 419), (2001, 495), (2002, 598), (2003, 669), (2004, 717), (2005, 757), (2006, 788), (2007, 815), (2008, 840), (2009, 864), (2010, 888), (2011, 918), (2012, 946), (2013, 971), (2014, 993), (2015, 1013), (2016, 1030), (2017, 1044), (2018, 1057), (2019, 1068), (2020, 1078)
Simulated_commuters_from_BergenSim[BergenS_to_BergenE] = GRAPH(TIME)
(2000, 372), (2001, 380), (2002, 411), (2003, 434), (2004, 453), (2005, 469), (2006, 484), (2007, 499), (2008, 517), (2009, 536), (2010, 557), (2011, 583), (2012, 605), (2013, 621), (2014, 635), (2015, 646), (2016, 655), (2017, 661), (2018, 667), (2019, 671), (2020, 675)
Simulated_commuters_from_BergenSim[BergenS_to_BergenW] = GRAPH(TIME)
(2000, 2096), (2001, 1914), (2002, 1785), (2003, 1683), (2004, 1600), (2005, 1537), (2006, 1482), (2007, 1438), (2008, 1403), (2009, 1373), (2010, 1348), (2011, 1334), (2012, 1326), (2013, 1323), (2014, 1324), (2015, 1327), (2016, 1333), (2017, 1341), (2018, 1349), (2019, 1358), (2020, 1367)
Simulated_commuters_from_BergenSim[BergenS_to_Askoy] = GRAPH(TIME)
(2000, 51.3), (2001, 80.5), (2002, 123), (2003, 157), (2004, 187), (2005, 213), (2006, 235), (2007, 254), (2008, 269), (2009, 281), (2010, 291), (2011, 302), (2012, 311), (2013, 319), (2014, 325), (2015, 332), (2016, 338), (2017, 343), (2018, 349), (2019, 353), (2020, 358)
Simulated_commuters_from_BergenSim[BergenW_to_BergenC] = GRAPH(TIME)
(2000, 12987), (2001, 12481), (2002, 11964), (2003, 11777), (2004, 11905), (2005, 12239), (2006, 12673), (2007, 13079), (2008, 13330), (2009, 13490), (2010, 13655), (2011, 13913), (2012, 14090), (2013, 14227), (2014, 14367), (2015, 14527), (2016, 14700), (2017, 14872), (2018, 15022), (2019, 15141), (2020, 15225)
Simulated_commuters_from_BergenSim[BergenW_to_BergenN] = GRAPH(TIME)
(2000, 625), (2001, 665), (2002, 760), (2003, 848), (2004, 931), (2005, 1019), (2006, 1105), (2007, 1186), (2008, 1252), (2009, 1305), (2010, 1351), (2011, 1390), (2012, 1419), (2013, 1443), (2014, 1464), (2015, 1484), (2016, 1503), (2017, 1519), (2018, 1532), (2019, 1541), (2020, 1547)
Simulated_commuters_from_BergenSim[BergenW_to_BergenE] = GRAPH(TIME)
(2000, 108), (2001, 121), (2002, 149), (2003, 175), (2004, 200), (2005, 225), (2006, 250), (2007, 273), (2008, 294), (2009, 312), (2010, 329), (2011, 343), (2012, 355), (2013, 364), (2014, 372), (2015, 379), (2016, 385), (2017, 389), (2018, 393), (2019, 396), (2020, 398)
Simulated_commuters_from_BergenSim[BergenW_to_BergenS] = GRAPH(TIME)
(2000, 4292), (2001, 3914), (2002, 3556), (2003, 3296), (2004, 3089), (2005, 2942), (2006, 2840), (2007, 2766), (2008, 2702), (2009, 2639), (2010, 2579), (2011, 2543), (2012, 2513), (2013, 2492), (2014, 2483), (2015, 2483), (2016, 2492), (2017, 2506), (2018, 2520), (2019, 2538), (2020, 2554)
Simulated_commuters_from_BergenSim[BergenW_to_Askoy] = GRAPH(TIME)

(2000, 181), (2001, 331), (2002, 540), (2003, 692), (2004, 812), (2005, 909), (2006, 991), (2007, 1061), (2008, 1125), (2009, 1187), (2010, 1244), (2011, 1293), (2012, 1338), (2013, 1379), (2014, 1417), (2015, 1453), (2016, 1487), (2017, 1520), (2018, 1553), (2019, 1585), (2020, 1618)
Simulated_commuters_from_BergenSim[Askoy_to_BergenC] = GRAPH(TIME)
(2000, 2322), (2001, 2536), (2002, 2670), (2003, 2788), (2004, 2919), (2005, 3050), (2006, 3167), (2007, 3254), (2008, 3290), (2009, 3292), (2010, 3288), (2011, 3298), (2012, 3291), (2013, 3279), (2014, 3272), (2015, 3273), (2016, 3281), (2017, 3292), (2018, 3302), (2019, 3308), (2020, 3309)
Simulated_commuters_from_BergenSim[Askoy_to_BergenN] = GRAPH(TIME)
(2000, 112), (2001, 145), (2002, 199), (2003, 248), (2004, 293), (2005, 337), (2006, 377), (2007, 412), (2008, 437), (2009, 454), (2010, 464), (2011, 471), (2012, 473), (2013, 473), (2014, 473), (2015, 473), (2016, 472), (2017, 471), (2018, 468), (2019, 463), (2020, 457)
Simulated_commuters_from_BergenSim[Askoy_to_BergenE] = GRAPH(TIME)
(2000, 19.3), (2001, 26.5), (2002, 40.0), (2003, 52.5), (2004, 64.6), (2005, 76.3), (2006, 87.2), (2007, 97.0), (2008, 105), (2009, 111), (2010, 115), (2011, 119), (2012, 121), (2013, 122), (2014, 123), (2015, 123), (2016, 123), (2017, 123), (2018, 122), (2019, 121), (2020, 120)
Simulated_commuters_from_BergenSim[Askoy_to_BergenS] = GRAPH(TIME)
(2000, 767), (2001, 922), (2002, 1116), (2003, 1268), (2004, 1378), (2005, 1465), (2006, 1532), (2007, 1584), (2008, 1625), (2009, 1656), (2010, 1681), (2011, 1709), (2012, 1730), (2013, 1747), (2014, 1761), (2015, 1773), (2016, 1783), (2017, 1791), (2018, 1796), (2019, 1802), (2020, 1806)
Simulated_commuters_from_BergenSim[Askoy_to_BergenW] = GRAPH(TIME)
(2000, 1318), (2001, 1389), (2002, 1535), (2003, 1652), (2004, 1752), (2005, 1841), (2006, 1907), (2007, 1960), (2008, 2000), (2009, 2028), (2010, 2047), (2011, 2056), (2012, 2058), (2013, 2058), (2014, 2057), (2015, 2056), (2016, 2054), (2017, 2052), (2018, 2049), (2019, 2044), (2020, 2038)
Standard_deviation_travel_time_bus[Paths] = Normal__standard_deviation_travel_time_bus
((ARRAYSUM(Road_capacity__utilization_paths[,Paths])
-ARRAYSUM(Road_capacity__utilization_paths[*,Paths])
*(Dedicated_bus__lanes/100)
+(Dedicated_bus__lanes/100)))
UNITS: hours (hr)
DOCUMENT: {hours}
START_TIME__FOR_POLICIES = 2014
Ticket_price = GRAPH(TIME)
(2000, 23.0), (2010, 27.5)
UNITS: NOK
DOCUMENT: {NOK}
Time_spent_in__traffic_BUS[Paths] =
(Dedicated_bus__lanes/100)*ARRAYSUM(Free_flow_travel_time_on_path[*,Paths])+Travel_time_with_bus[Paths]*(1-Dedicated_bus__lanes/100)*Additional__travel_time_factor
UNITS: hours (hr)
DOCUMENT: {hours}
Time_to_adjust__congestion_charge = 2
UNITS: years (yr)
Time_to_dedicate_lanes = 1
Time_to_measure__speed = 0.25
Toll_change = 0
Total__path__attractiveness[Paths] = ARRAYSUM(Path_cost_matrix[*,Paths])
UNITS: Unitless
DOCUMENT: {unitless}
Sum of the paths utility.
Trend_commuters[BergenC_to_BergenN] = GRAPH(Time)
(2011, 1734), (2012, 1766), (2013, 1797), (2014, 1828), (2015, 1860), (2016, 1891), (2017, 1922), (2018, 1954), (2019, 1985), (2020, 2016)
Trend_commuters[BergenC_to_BergenE] = GRAPH(Time)
(2011, 301), (2012, 288), (2013, 275), (2014, 262), (2015, 249), (2016, 236), (2017, 223), (2018, 210), (2019, 197), (2020, 184)
Trend_commuters[BergenC_to_BergenS] = GRAPH(Time)
(2011, 5176), (2012, 5252), (2013, 5328), (2014, 5403), (2015, 5479), (2016, 5555), (2017, 5631), (2018, 5707), (2019, 5783), (2020, 5859)
Trend_commuters[BergenC_to_BergenW] = GRAPH(Time)

(2011, 2921), (2012, 2913), (2013, 2904), (2014, 2895), (2015, 2886), (2016, 2878), (2017, 2869), (2018, 2860), (2019, 2851), (2020, 2843)
Trend_commuters[BergenC_to_Askoy] = GRAPH(Time)
(2011, 184), (2012, 194), (2013, 204), (2014, 214), (2015, 225), (2016, 235), (2017, 245), (2018, 255), (2019, 265), (2020, 275)
Trend_commuters[BergenN_to_BergenC] = GRAPH(Time)
(2011, 7726), (2012, 7830), (2013, 7934), (2014, 8039), (2015, 8143), (2016, 8247), (2017, 8351), (2018, 8455), (2019, 8559), (2020, 8663)
Trend_commuters[BergenN_to_BergenE] = GRAPH(Time)
(2011, 453), (2012, 462), (2013, 472), (2014, 482), (2015, 492), (2016, 501), (2017, 511), (2018, 521), (2019, 530), (2020, 540)
Trend_commuters[BergenN_to_BergenS] = GRAPH(Time)
(2011, 1625), (2012, 1648), (2013, 1670), (2014, 1693), (2015, 1715), (2016, 1737), (2017, 1760), (2018, 1782), (2019, 1804), (2020, 1827)
Trend_commuters[BergenN_to_BergenW] = GRAPH(Time)
(2011, 1394), (2012, 1433), (2013, 1472), (2014, 1510), (2015, 1549), (2016, 1588), (2017, 1627), (2018, 1666), (2019, 1705), (2020, 1744)
Trend_commuters[BergenN_to_Askoy] = GRAPH(Time)
(2011, 85.7), (2012, 91.3), (2013, 97.0), (2014, 103), (2015, 108), (2016, 114), (2017, 120), (2018, 125), (2019, 131), (2020, 137)
Trend_commuters[BergenE_to_BergenC] = GRAPH(Time)
(2011, 1549), (2012, 1492), (2013, 1434), (2014, 1377), (2015, 1320), (2016, 1263), (2017, 1205), (2018, 1148), (2019, 1091), (2020, 1034)
Trend_commuters[BergenE_to_BergenN] = GRAPH(Time)
(2011, 636), (2012, 652), (2013, 669), (2014, 686), (2015, 703), (2016, 719), (2017, 736), (2018, 753), (2019, 769), (2020, 786)
Trend_commuters[BergenE_to_BergenS] = GRAPH(Time)
(2011, 758), (2012, 766), (2013, 774), (2014, 783), (2015, 791), (2016, 799), (2017, 807), (2018, 815), (2019, 823), (2020, 831)
Trend_commuters[BergenE_to_BergenW] = GRAPH(Time)
(2011, 294), (2012, 308), (2013, 323), (2014, 337), (2015, 351), (2016, 365), (2017, 379), (2018, 393), (2019, 408), (2020, 422)
Trend_commuters[BergenE_to_Askoy] = GRAPH(Time)
(2011, 18.4), (2012, 19.7), (2013, 21.1), (2014, 22.5), (2015, 23.8), (2016, 25.2), (2017, 26.5), (2018, 27.9), (2019, 29.3), (2020, 30.6)
Trend_commuters[BergenS_to_BergenC] = GRAPH(Time)
(2011, 11029), (2012, 11159), (2013, 11288), (2014, 11417), (2015, 11547), (2016, 11676), (2017, 11805), (2018, 11934), (2019, 12064), (2020, 12193)
Trend_commuters[BergenS_to_BergenN] = GRAPH(Time)
(2011, 685), (2012, 709), (2013, 734), (2014, 758), (2015, 782), (2016, 806), (2017, 831), (2018, 855), (2019, 879), (2020, 903)
Trend_commuters[BergenS_to_BergenE] = GRAPH(Time)
(2011, 334), (2012, 330), (2013, 327), (2014, 323), (2015, 320), (2016, 316), (2017, 313), (2018, 309), (2019, 306), (2020, 302)
Trend_commuters[BergenS_to_BergenW] = GRAPH(Time)
(2011, 2479), (2012, 2514), (2013, 2548), (2014, 2583), (2015, 2618), (2016, 2653), (2017, 2688), (2018, 2722), (2019, 2757), (2020, 2792)
Trend_commuters[BergenS_to_Askoy] = GRAPH(Time)
(2011, 154), (2012, 164), (2013, 173), (2014, 183), (2015, 192), (2016, 202), (2017, 211), (2018, 221), (2019, 230), (2020, 240)
Trend_commuters[BergenW_to_BergenC] = GRAPH(Time)
(2011, 13390), (2012, 13426), (2013, 13463), (2014, 13499), (2015, 13536), (2016, 13572), (2017, 13609), (2018, 13646), (2019, 13682), (2020, 13719)
Trend_commuters[BergenW_to_BergenN] = GRAPH(Time)
(2011, 1033), (2012, 1070), (2013, 1107), (2014, 1145), (2015, 1182), (2016, 1219), (2017, 1256), (2018, 1293), (2019, 1330), (2020, 1367)
Trend_commuters[BergenW_to_BergenE] = GRAPH(Time)
(2011, 207), (2012, 216), (2013, 225), (2014, 234), (2015, 243), (2016, 252), (2017, 261), (2018, 270), (2019, 279), (2020, 288)
Trend_commuters[BergenW_to_BergenS] = GRAPH(Time)
(2011, 4903), (2012, 4958), (2013, 5014), (2014, 5069), (2015, 5125), (2016, 5180), (2017, 5236), (2018, 5291), (2019, 5347), (2020, 5402)
Trend_commuters[BergenW_to_Askoy] = GRAPH(Time)
(2011, 564), (2012, 599), (2013, 634), (2014, 669), (2015, 704), (2016, 739), (2017, 775), (2018, 810), (2019, 845), (2020, 880)
Trend_commuters[Askoy_to_BergenC] = GRAPH(Time)
(2011, 2831), (2012, 2891), (2013, 2950), (2014, 3010), (2015, 3070), (2016, 3130), (2017, 3190), (2018, 3249), (2019, 3309), (2020, 3369)
Trend_commuters[Askoy_to_BergenN] = GRAPH(Time)
(2011, 217), (2012, 228), (2013, 238), (2014, 249), (2015, 259), (2016, 269), (2017, 280), (2018, 290), (2019, 301), (2020, 311)

Trend_commuters[Askoy_to_BergenE] = GRAPH(Time)
(2011, 43.3), (2012, 45.7), (2013, 48.0), (2014, 50.3), (2015, 52.7), (2016, 55.0), (2017, 57.4), (2018, 59.7), (2019, 62.0), (2020, 64.4)
Trend_commuters[Askoy_to_BergenS] = GRAPH(Time)
(2011, 1035), (2012, 1064), (2013, 1093), (2014, 1122), (2015, 1151), (2016, 1180), (2017, 1209), (2018, 1238), (2019, 1267), (2020, 1296)
Trend_commuters[Askoy_to_BergenW] = GRAPH(Time)
(2011, 1913), (2012, 1976), (2013, 2038), (2014, 2101), (2015, 2163), (2016, 2226), (2017, 2288), (2018, 2350), (2019, 2413), (2020, 2475)
Use_BergenSim = 0
Use_Historical_Data__and_trend = 1
yearly_peak_hour_cost = Average_work_days*Peak_hour_cost/1E+6

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