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Utveckling av en prognosmodell för kollektivtrafik i mindre städer

Marie Hedström

Johanna Johansson

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Department of Science and Technology
Linköping University
SE-601 74 Norrköping, Sweden

Institutionen för teknik och naturvetenskap
Linköpings universitet
601 74 Norrköping

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Marie Hedström
Johanna Johansson

Handledare Johan Olstam
Examinator Anders Peterson

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LINKÖPING UNIVERSITY
DEPARTMENT OF SCIENCE AND TECHNOLOGY

Development of a forecast model for public transport trips in smaller cities

Master Thesis carried out at Division of Communication, Transport and Infrastructure

Marie Hedström
Johanna Johansson

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Institute of Technology, Department of Science and Technology
SE-581 83 Linköping, Sweden

Abstract

It has become more important for operators to be able to predict the future number of public transport passengers when consider to place a tender for operating public transport in a city or region, this is due to the new types of operator contracts was introduced quite recently. There are models in use today that can predict this, but they are often time consuming and complex and therefore it can be expensive to perform a forecast. Aside from this, most models in use for Sweden today are adapted for larger cities. Thus, the aim of this thesis is to propose a model that requires minimal input data with a short set up and execution time that can be used to predict a forecast for the public transport system in smaller cities without notably affecting the quality of the result.

The developed model is based on a forecast model called LuTrans, which in turn is based on a common method, the four step model. The aim of the model lies within public transportation but it also consider other modes. The input data used by the model mainly consists of socio-economic data, the travel time and distance between all the zones in the network. The model also considers the cost for traveling by car or public transport.

The developed model was applied to the Swedish city, Örebro, where a forecast was conducted for a future scenario. It is easily to apply the model to different cities to estimate a forecast for the public transport system. The developed model for the base scenario predicts trips for individual bus lines with an accuracy of 85 % for the city of Örebro. The developed model gave the result that the trips made by public transport in the future scenario of Örebro 2025 will increase annually by 0.94 %.

The conclusion is that it is possible to develop a simple model that can be easily applied for a desired city. Although the developed model produced a plausible result for Örebro, further work such as implementation on other cities are required in order to fully evaluate the developed model.

Sammanfattning

Nyligen introducerades nya typer av avtalskontrakt vilket gör att det blivit viktigare för operatörer att kunna förutse det framtida resandet när operatörer överväger att lägga ett anbud för driva kollektivtrafiken i en stad eller region. De modeller som finns tillgängliga idag kan användas för att erhålla en prognos om det framtida resandet, dock är modellerna ofta tidskrävande eller komplicerade att använda vilket kan resultera i att det är dyrt att genomföra en körning. Utöver detta så är de flesta modellerna avsedda för större svenska städer. Därför är syftet med detta examensarbete att föreslå en modell som kräver minimalt med indata, har en kort uppsättnings- samt körtid som kan användas för att prediktera det framtida resandet i mindre städer utan att kvalitén på resultaten påverkas märkbart.

Den utvecklade modellen är baserad på en trafikprognosmodell, LuTrans, som i sin tur grundar sig på en vanligt förkommande metod, fyrstegsmodellen. Huvudsakligen är modellen avsedd för kollektivtrafik men den tar även hänsyn till andra färdsätt. De indata som modellen använder består till största delen av socioekonomisk data samt restiden och avståndet mellan alla zoner i ett nätverk. Modellen tar även hänsyn till vad det kostar att färdas med bil respektive kollektivtrafik.

Den utvecklade modellen applicerades på Örebro där en prognos erhölls för ett framtida scenario, 2025. Sammanfattningsvis är den utvecklade modellen enkel att applicera på olika städer för att uppskatta en kollektivtrafikprognos. För basscenariot som utfördes för Örebro kan den utvecklade modellen uppskatta resandet på individuella busslinjer med en noggrannhet på 85 %. Modellen ger resultet att resandet i Örebro årligen ökar med 0,94 % fram till 2025.

Slutsatsen är att det är fullt möjligt att utveckla och förenkla en modell som enkelt kan appliceras för en vald stad. Trots att den utvecklade modellen producerar ett trovärdigt resultat för Örebro så är ett framtida arbete att implementera modellen på andra svenska städer för att fullständigt kunna utvärdera modellens prestanda.

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Marie Hedström and Johanna Johansson
Stockholm, June 2015

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1

Introduction

Nowadays, it is common that the public transport system in Swedish regions and cities are managed and operated by different organizations and operators. According to Transportstyrelsen (2015) a new law was launched in 2012 which gave the operators an opportunity to freely establish commercial public transport on roads, rails and water. This was done to minimize the costs for operating public transport by making it competitive. Also, according to Ling (2014) a new goal was proposed with the purpose to double the public transportation until 2020 compared to 2006. A result is that the counties put a larger responsibility on the operators to increase the number of passengers and it has become more common to use incentive tender. This is because the operators now get paid for each boarding passenger instead of a kilometer-based payment. Hence, it is important among the operators to predict the number of passengers to be able to determine the operators' income for a future tender.

The forecasts made in Sweden for private and public transportation are mainly performed using a model framework called Sampers which is maintained by Trafikverket (2015). Sampers is a complex system which holds a great amount of parameters and sub models which can make it difficult and time consuming to use. Also, Sampers may not be suitable for cities with an area and population smaller than Stockholm, Göteborg and Malmö. This means that a forecast for the public transport trips in smaller cities than the ones mentioned, can be difficult to perform. The operators may have to take a risk when choosing to make an offer for a small city. Hence, it is of interest to find a model for predicting the passenger rate for the coming years that is easy to adapt for different cities. The model will then give a reference to the operator if it is worth to make an offer for operating the public transport system.

1.1 Background

Operators can choose if they want to make an offer to operate the public transport in a municipality or county by placing a tender. When an operator is offered the opportunity to place a tender, according to Arriva (2015) there are three different contracts available that decides how the traffic will be operated. Only one type of operator contract existed before 2012 which was called “the gross contract”. The gross contract is based on a kilometer based production. After 2012 two other contract types are available which are called incentive and concession contracts. The incentive contract is built on a 100 percentage rate of verified paid passenger, production and bonus. The concession contract means that the operator can keep the ticket revenue and decide the price level, which is common for operation of train traffic. When an operator places an offer they have to take into consideration that apart from offering a price they must also include a quality documentation where the operator describes how the traffic will be operated. For instance, it should describe how the operator will pursue to improve the flow, the passenger safety and the reliability. The quality documentation is graded and evaluated by the county. The grades are transformed into a monetary cost which is added to the total cost offered by the operator. Therefore, the total cost can be much higher than intended. It is usually the operator with the lowest total price that wins the tender and a contract usually ranges 8-12 years.

To predict how the traffic will change in the cities for the coming years, different models can be used for forecasts. When performing forecasts it is important to have a thorough theory of which factors that affect the travel demand. It is also important to have access to data regarding the traffic and society. A great deal of socio-economic data for Sweden can be found in databases at Statistics Sweden, SCB, and at municipalities. Travel surveys are quite common for regions and they can also be used as a foundation for the socio-economic data or as calibration data.

A common model for predicting changes in traffic is the four step model. The four steps consist of trip generation, trip distribution, mode choice and route choice. Sampers processes the first three steps and uses a software, Emme, to perform the final step where the route choices are distributed over the network and Sampers requires data in form of matrices. Since Sampers is complex and the execution time is quite long, WSP (2013) mentions that another simpler program called LuTrans have been developed in order to reduce the execution time. LuTrans is applicable on smaller cities but it also contains numerous input data, although less than Sampers.

1.2 Purpose

Since it has been more common for operators to receive their income depending on the number of passengers instead of the kilometer based payment, it is important for the operators to predict the future trips made by public transport. Therefore, the aim of this thesis is to develop a simple model with short set up and execution time that can be used for predicting public transport forecasts in smaller cities. The simplicity of the model lies in the ability to handle minimum input without notably affecting the quality of the result. This is, if the users do not have access to a great amount of data, the model will still produce a usable result. The model would be able to answer the question if it is interesting to make an offer to operate the public transport in that city. Part of the aim is to test and evaluate the model by applying it to a smaller city which was chosen to be Örebro. The questions that will be investigated are:

How can an existing public transport demand model be simplified in order to be applicable to smaller cities?

- What kind of input is necessary to develop a model?
- How should the value of the parameters be selected?

1.3 Methodology

Different methods have been investigated for developing a model. A frame for reference in form of a existing demand model, LuTrans, was available and therefore the structure of LuTrans was selected to work as a base to maintain a high quality results. Subsequently, a thorough review of the LuTrans code was required in order to simplify it. Thereafter, the final step in the four step model, route choice, was chosen to be included since the route choice was considered to have an impact for the public transport mode. The population data is collected from SCB (2011) and provides detailed data that covers the entire country of Sweden which is beneficial since it is easy to apply to different cities.

The latest release of Emme which is developed by INRO (2015) allows the user to easily import and adapt a road network from OpenStreetMap (2015) into the software. Örebro was chosen as a case study since it is considered to be a small city and they recently made changes in their public transportation network which makes it an interesting city to analyze. Also, a travel survey conducted for the year 2011 by Markör (2011) was available to use as calibration data. Emme possess the possibility to run Python scripts which could hold the first three steps, meaning no additional software would be required.

After multiple attempts to get the Python scripts to work, this method was discarded and the developed model was implemented using MATLAB instead. Excel, a software, was used to manage the matrices and to store the results. During the implementation of the model, the population data were extracted from SCB (2011) and by using the output from a traffic and transit assignment in Emme. Also, a study about passengers' arrival rate to a bus stop was performed to obtain a suitable parameter value to use for the transit assignment in Emme. The developed model is then calibrated with passenger data from 2010, obtained from Region Örebro County, and with the travel survey. Since operators are interested to investigate the outcome for the public transport for the coming ten years, a future scenario for Örebro 2025 was implemented, with the current transit network which differs from the network used in 2010. A sensitivity analysis was performed where the impact of the parameters were analyzed. Finally, the model was analyzed and suggestions for measures and alternatives are given together with conclusions.

1.4 Delimitations

The delimitations presented here lies as a foundation for this thesis, additional delimitations are presented as they appear in the thesis.

The thesis focuses on the first three steps of the four step model, which are trip generation, trip distribution and mode choice. The fourth and final step, route assignment will be conducted using the pre-defined traffic and transit assignment models in Emme. In this thesis, the definition of smaller cities is a city with a population of 70 000 – 170 000 inhabitants.

The road and bus network was delimited to only include the areas of Örebro covered by the city bus routes, likewise the start and end points for a trip, the zones, which are retrieved from the population data and therefore covers the same area. In order to simplify the model, congestion is not considered since it is not particularly common in smaller cities. Also, since peak hour does not differ distinctively from other working hours in smaller cities due to less congestion compared to larger cities, the scenarios cover the entire day and not just the peak hour.

1.5 Outline

The following three chapters' presents a literature survey where Chapter 2 describe the four step model in detail among with the methods used in the different steps. Chapter 3 presents the procedure involving a transit assignment in terms of setting, methods and parameters. Chapter 4 presents two demand models, Sampers and LuTrans, for predicting trips. Chapter 5 presents the modeling and implementation of the network by using Emme and MATLAB. The calibration, the future scenario, and a sensitivity analysis are presented in Chapter 6 followed by the analysis which is presented in Chapter 7. Finally, Chapter 8 presents the conclusion and further work.

2

The four step model

In this chapter the foundation of the four step model is presented along with different methods for modeling the steps. The text in this chapter is based on the fundamental theory of the four step model as presented in Ortúzar & Willumsen (2011), Immers & Stada (1998), Hydén (ed.) (2008) and WSP (2007). An overview of the steps is presented below.

Initialization: Before implementing the model, the time period for a region must be defined where the four step model will be applied. The region is then divided into a zonal system and a road network is added.

1. **Trip generation:** Determines the total number of trips generated and attracted in each zone for various trip purposes, i.e. *how often do people travel?*
2. **Trip distribution:** Determines the proportion of the total number of trips conducted between every two pair of zones. The result is often presented as an Origin-Destination matrix, OD-matrix, i.e. *where do people want to travel?*
3. **Mode choice:** Determines the relative distribution of trips between the zones by alternative transportation modes, i.e. *which travel mode do people choose?*
4. **Route choice:** Determines how the estimated trips are assigned by their mode between different roads in the network i.e. *the chosen travel route*

The steps in the model are normally performed in the described order but they could also be conducted simultaneously and one or more steps could be combined. Figure 1 shows an illustration of how the steps in the four step model are performed.

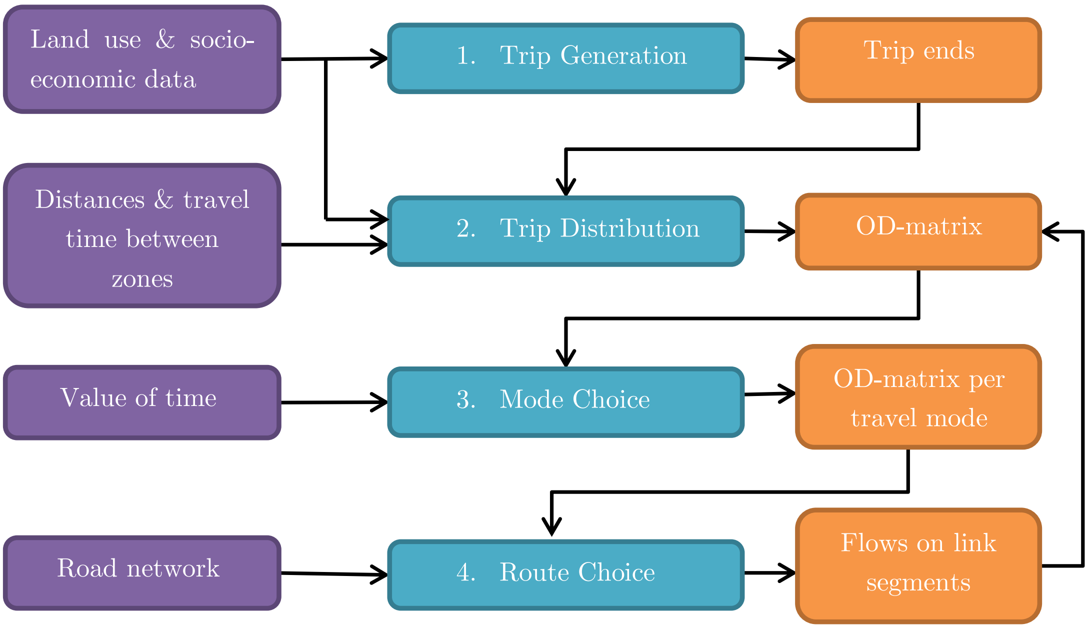

Figure 1: An overview of the processes in the four step model where purple = input data, blue = model steps and orange = output.

Input data such as land use and socio-economic data is needed for the trip generation step. For instance socio-economic data can be the population or employment. The result from the trip generation step is the total number produced or attracted trips from every zone. The output from the trip generation step is then used together with distance matrices etc. for the trip distribution step. The outcome from the trip distribution step is a matrix that illustrates how many trips that are made between every pair of zones in the network. The matrix is called an OD-matrix which is used as an input in the mode choice step together with input data about how passengers rate their time. The output from the mode choice step is several OD-matrices, one for every mode choice, e.g. one OD-matrix for bus trips and one for car trips. The OD-matrices for every mode works as input data for the route assignment step. The final output will result in flows on road segments in the network. The first three steps in the four step model can be calculated by using a logit model. A logit model describes the probability that a traveler will choose a certain travel mode depending on which mode that has the largest utility for each traveler. The utility for a travel mode depends on a number of probabilities such as travel time, travel cost, waiting time etc. The logit model is built on the reasoning that every traveler wants to maximize their utility and therefore only chooses the travel mode they find gives the best utility.

When all steps have been completed, the calibration of the model for the base scenario is performed and thereafter alternative scenarios can be applied.

2.1 Trip generation

The objective of the trip generation step is to predict the total number of trips that begins or ends in each zone for various trip purposes. The trips beginning in a zone are called produced trips and the trips ending in a zone are called attracted trips. The produced and attracted trips are independent of the destination and origin. As recently mentioned, typical input data is socio-economic data such as population, employment and land use. The trips can be categorized into different groups which can be identified by a purpose, such as work trips, school trips, shopping trips etc. They could also be categorized into the time of day the trip is carried out or by the type of person, since travel behavior depends on socio-economic attributes such as income level, car ownership, family size or accessibility to urban areas. To be able to predict the number of trips, it is important to investigate factors that affect trip generation.

2.1.1 Growth factor methods

There are several approaches to model trip generation. The simplest one, is the growth factor method presented in Equation (1), which estimate the future trips.

$$y_i = \tau \cdot x_i \tag{1}$$

Where y_i and x_i are future and current trips respectively in zone i and τ is the growth factor. The growth factor is often formulated as a function of variables such as size of population, income and car ownership.

2.1.2 Regression analysis

One additional approach, described by Blom et al. (2005) to estimate trip generation is by using a regression analysis. The future trips, y_i, can be estimated as seen in Equation (2).

$$y_i = \alpha + \beta x_i + \varepsilon_i \tag{2}$$

A regression analysis is a statistical process for estimating the relationship between one dependent variable, y and a series of other changing independent variables x_i, which makes y a function of x. α is a constant coefficient, β is a regression coefficient and ε_i denote the random sized errors between x and y. The α and β coefficients can be estimated by collecting socio-economic data for a period of years.

2.2 Trip distribution

The aim of the trip distribution step is to connect the produced and attracted trips to receive a relationship between the start and end points retrieved from the trip generation step. Traveler's behavior and decisions to travel mainly depends on improvements in the transportation system and also, by construction of new areas and facilities as e.g. shopping centers and offices. The trip distribution connects the origins from one zone with a destination in another zone i.e. it calculates the proportion of the trips in the zones that will be traveling between each pair of zones. The output is often presented as an OD-matrix which reflects the future trips where each row and column represents a zone, i.e. each value, T_{ij} in the matrices represents the amount of trips from zone i to zone j which is shown in Table 1.

Table 1: The structure for the Origin Destination-matrix.

		Destination				
		1	2	3	. . . j	$\sum_j T_{ij}$
Origin	1	T_{11}	T_{12}	T_{13}	T_{1j}	O_1
	2	T_{21}	T_{22}	T_{23}	T_{2j}	O_2
	3	T_{31}	T_{32}	T_{33}	T_{3j}	O_3
	. . . i	T_{i1}	T_{i2}	T_{i3}	T_{ij}	$\ldots O_i$
	$\sum_i T_{ij}$	D_1	D_2	D_3	$\ldots D_j$	$\sum_i \sum_j T_{ij} = T$

The sum of the trips in a row is the total number of trips attracted from that zone, origin, i.e. the number of trips calculated from trip generation for that zone and the sum of the trips in a column is the number of trips produced, destination, at that zone. If the available input data includes estimates of both the origins and destinations, the model must satisfy both conditions and the model is then said to be doubly constrained, which can be described mathematically using the following constraints in Equation (3) and (4).

$$\sum_j T_{ij} = O_i \tag{3}$$

$$\sum_i T_{ij} = D_j \tag{4}$$

Where O_i is the total number of trips starting in zone i and D_j is the total number of trips ending in zone j. In the case where only one, either the origin or the destination data is available, only one of the constraints in Equation (3) and (4) have to be satisfied and the model is then said to have one constraint. Typically when predicting future trips, a base year OD-matrix is used as a benchmark which is adjusted depending on estimated trip changes. The base year matrix could be estimated either from the trip generation step or by collecting data from travel surveys, although these OD-matrices may give an incorrect result since the surveys are only conducted on a selection of people. The base year OD-matrix together with new information regarding the marginal totals calculated from the trip generation step will generate a new OD-matrix for the future trips.

2.2.1 Growth factor methods

The growth factor method can also be applied in the trip distribution step which adjusts a base year OD-matrix, with a general growth factor τ or a zone specific τ_i, without changing the behavioral interpretation. The future trips y_{ij} is estimated by multiplying every cell x_{ij} in the matrix with a growth factor as shown in Equation (5).

$$y_{ij} = \tau \cdot x_{ij} \tag{5}$$

If only the produced or the attracted trips are available from the trip generation step, it is possible to use the growth factor method described by Wilson (2000) which is called the Fratar method. It can be single constraint or be double constrained and determines growth factors (the target value divided by the sum of the row or column) so they satisfy the produced or attracted trip constraints, and multiply the growth factors with its corresponding cell in the base year matrix. This means that the total amount of trips in a zone or to a zone are matching the total target amount of trips in a zone or to a zone. When the method uses double constrains as described by Veenstra et al. (2010) i.e. if the both target values should be fulfilled, produced and attracted, it is called the Furness method. This can be applied where an iteration process are performed in three steps.

1. Determine growth factors that satisfies the produced trip constraints i.e. one factor per row in the OD-matrix. By multiplying each row factor with its corresponding row in the base year matrix, the produced trips will satisfy the produced trip constraints i.e. the sum for each row.
2. Keep the updated cells from step 1 and determine new growth factors that satisfy the attracted trip constraints. By multiplying the new growth factor with its corresponding column in the base year matrix, the attracted trips will satisfy the attracted trip constraints i.e. the sum for each column.

3. Construct or revise the OD-matrix according to the output of step 2 and repeat step 1 and step 2 until the row and column totals are both close enough to the forecast data.

2.2.2 Synthetic methods

The growth factor methods do not take any behavioral interpretation of the trip passengers into consideration, such as cost or distance. Therefore, it might be of interest to investigate other methods that takes cost into consideration. These methods are called synthetic methods since they estimate the trips for each cell without directly using the observed trip pattern. This cost could either be in terms of distance, a time or a monetary cost or a combination of all of them. This cost is known as the generalized cost of travel and it combines all the main attributes related to the disutility of the journey weighted by coefficients which attempt to represent their relative importance as perceived by the traveler. Time is converted to a monetary cost using value of time which estimates the passengers' ratio for time over cost. The value of time is a subjective value which makes it difficult to measure since the value of time depends on a person's income and the purpose for making the trip. The generalized cost for public transport passengers can for example be calculated using Equation (6).

$$c_{ij} = \beta \cdot traveltime_{ij} + \theta \cdot walkingtime_{ij} + \rho \cdot changes_{ij} + \gamma \cdot cost_{ij} \tag{6}$$

Where $traveltime_{ij}$ represents in-vehicle travel time between i and j, $walkingtime_{ij}$ is the total walking time to and from stops or from parking areas between i and j, $changes_{ij}$ is a binary variable with the value of 1 if the traveler has to change modes between i and j and $cost_{ij}$ represents the monetary charge for the trip between i and j. β, θ, ρ and γ are weights attached to each element of cost.

Another synthetic approach is the gravity model which is based on the theory of Newton's gravitation law and the simplest gravity model for calculating the trips between origin i and destination j is shown in Equation (7).

$$T_{ij} \propto \frac{P_i P_j}{d_{ij}^2} \tag{7}$$

Where P_i and P_j are the populations of the zones of origin and destination, d_{ij} is the distance between zone i and zone j and $\propto$ is a proportionality factor. This approach is quite simple and further developments of the model have been conducted, where for example P_i and P_j has been replaced by O_i and D_j and by a calibration parameter n as the power of the generalized cost. The problem can be seen as a trade of between cost minimization and maximal dispersion.

2.3 Mode choice

The next step is to determine the travel mode. There are a number of factors that influences the process of choosing the travel mode. According to Ortúzar & Willumsen (2011), these factors are divided into three groups depending on the characteristics that influence the factors. The factors in the first group affect the features of the trip maker such as if the traveler has a driver's license and access to a car. The second group consists of factors that influence the mode choice and the characteristics of the journey such as the purpose of the trip, the time of the day and if the trip is made alone or with others. The third group consists of the characteristics that strongly influence the transport usage. The group consists of quantitative factors and qualitative factors. The quantitative factors contains the travel time components such as walking, waiting and in-vehicle time. The qualitative factors consist of the safety for the chosen mode and how convenient the chosen mode is. A proper mode choice model should include the most important factors from each group and it should be based on tours made from home and back to home. Trips are made on a tour basis, meaning that if a traveler choses a mode, he or she will most likely stick with this mode for the other legs of the trip. Another feature that affects the model is if the model should be based on zonal information or based on household and individual data. For instance, not all people have a car which limits the choices further and give the required minimum segmentation. Also since the roads can suffer from congestion which also affects public transport, more than one alternative route should be available for the traveler.

2.3.1 The logit model

The logit model is built on the theory that if a traveler is forced to choose between different discrete choices for a travel mode e.g. bus, bike or walking, the traveler will then categorize the modes depending on their utility. For instance, the bus may be the alternative with the shortest travel time but the bus will not arrive for another hour. The traveler then decides between taking the bike or walking. If the traveler prefers to arrive to their destination relatively soon the traveler will most likely take the bike since this is the mode with the greatest utility. This procedure is called a discrete choice model and can be used to determine which travel mode that is most likely to be used.

The utility, U_a, of a travel mode can be calculated using Equation (8).

$$U_a = V_a + \varepsilon_a \tag{8}$$

Where the observable utility of travel mode a is a stochastic variable that consist of V_a, which is a non-stochastic element and an error term ε_a which is a stochastic element. The observed characteristic of the travel mode is represented by the element V_a while the error term has a expected mean value equal to zero. This gives that the utility is noted as the observed value V_a.

When building a model specification the utilities for each mode can consist of more variables such as travel time, gender, in-vehicle time, transit fare, car ownership, and the travel cost etc. The utilities also consist of parameters that are to be estimated. The utility with respect to travel time and travel cost can be expressed as Equation (9).

$$V_a = \alpha_a + \beta t_a + \gamma c_a \tag{9}$$

Where α, β and γ are the parameters to be estimated and t_a and c_a are the travel time and travel cost for travel mode a.

This gives that the probability that a traveler chooses travel mode a among K other modes is represented by a logit model which is showed in Equation (10).

$$p(a) = \frac{e^{\mu V_a}}{\sum\limits_{k=1}^{K} e^{\mu V_k}} \tag{10}$$

The full name for Equation (10) is the multinomial logit model if the traveler can select from more than two travel modes, but from now on this model will be referred to as the logit model. It is also called a binary logit model if there are only two different travel modes choices. When inserting the values for V_a and μ (where μ is a Gumbel distribution variance parameter) the logit model will estimate the probability for choosing travel mode a. To determine the utilities for V_k it must first be classified as a generic or alternative-specific variable. V_k is classified as a generic variable when all functions for the different alternatives have the same coefficient, i.e. when the the variables are unequal to zero. V_k is classified as an alternative-specific variable when the variable is used in the utility function of one alternative. The variable can for instance be the travel cost, which may differ for two alternatives but the variable has the same coefficients in the utility functions where they are used.

2.3.2 Nestled logit models

The logit model has some limitations which sometimes imply that it produces erroneous results when the error terms are non-identical and when the error terms are not statistically independent. Immers & Stada (1998) mentions what will happen when the error terms are not statistically independent. This is when a traveler can choose from a number of different travel modes with equal utilities. For instance, a city that only used to have two modes to choose from, car and red bus receives a third option when a new bus alternative, the blue bus, is introduced to the city. Before the blue buses were introduced, the two options had equal utilities and therefore the logit model would give the result that 50 % of the travelers chooses car and 50 % of the travelers chooses the bus. When the bus alternative is introduced and the utilities' remain equal the logit model would give the result that each mode has a probability of 33.33 % to be chosen, see Figure 2, although that is not the actual case.

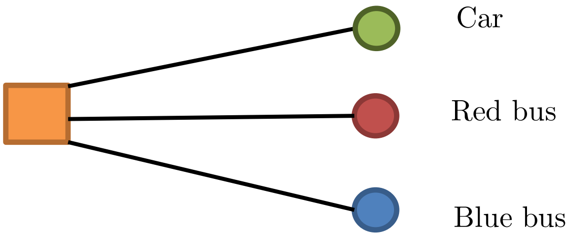

Figure 2: The logit model when the new bus alternative of a blue bus is introduced, giving the modes equal probabilities for being chosen.

The people who chose to travel by car will most likely not change their mode choice. It is the amount of travelers that uses the red bus that will change and therefore the red and blue bus option must be integrated into a mutual mode called public transport. This is required to overcome the limitations of the logit model and it is called a hierarchical or a nested logit model which is showed in Figure 3.

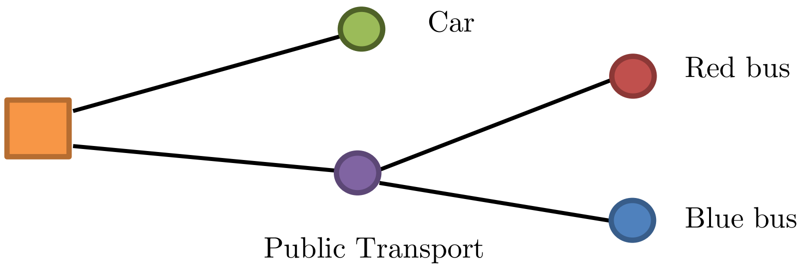

FIGURE 3: The logit model when the red and blue buses are integrated into a mode called public transport.

This model builds on the fact that one choice happens after another choice when the process of choosing a travel mode is divided over a number of levels. For instance, a traveler can decide if he or she wants to travel by car or the public transport alternatives such as the red or blue buses. The traveler first chooses that he or she want to travel by public transport and then chooses what kind of public transport mode to travel with. The utilities of the bus mode and the public transportation mode are then combined into a log sum, M_{PT}, which Koppelman & Bhat (2006) expressed as Equation (11).

$$M_{PT} = \frac{1}{\mu_{PT}} ln(e^{\mu_{PT} V_{Bred}} + e^{\mu_{PT} V_{Bblue}}) \tag{11}$$

Where V_{Bred} is the utility for the red bus alternative and V_{Bblue} is the utility for the blue bus alternative. For instance, the probability that the traveler chooses the car mode can be calculated by using Equation (12).

$$p(car) = \frac{e^{V_C}}{e^{V_C} + e^{M_{PT}}} \tag{12}$$

2.4 Route choice

The final step is the route choice which determines how all the travelers will be distributed between different links in the network. The main reasons for the spreading of routes depend on the driver's perspective. Does the driver want to minimize the time, the cost or does the driver possess an incorrect observation about the links and travel costs? The generalized cost is used to evaluate the route choice. There are different types of reasons that affect which route that will be selected such as the driver's perception of what is the most favorable route and how familiar the driver is with other existing route options. The route choice is conducted by using a traffic or transit assignment. Congestion also plays a part in which route that is being chosen. How the traffic flow will distribute on the routes when congestion occurs can be determined by using the principle called user equilibrium. When user equilibrium is obtained, no travelers want to change their route since the costs are the same for all used routes. This step differs from the first three steps since the first three are usually conducted simultaneously. The route assignment is typically conducted in separate standardized software such as Emme, Contram, Aimsun or Visum which have a built in process for calculating the user equilibrium.

3

Public transit assignment

This section describes a literature review of the public transit assignment and the related parameters together with presentations on how the parameters are used in other developed models. Emme, Equilibre Multimodal, Multimodal Equilibrium, is a macroscopic traffic assignment model. According to the latest Software manual from INRO (2014) Emme can perform different types of transit assignments i.e. user equilibrium (also known as the standard transit assignment), stochastic, congested or capacitated transit assignment.

3.1 Standard and stochastic transit assignment in Emme

A standard transit assignment according to the Software manual from INRO (1999) and Spiess and Florian (1988) is based on optimal strategies, where it is assumed that the traveler wants to optimize the total expected travel time for a trip by minimizing the waiting, in-vehicle and walking time for any transit trip from an origin to a destination. In order to get to the desired destination, a traveler may choose from a set of paths and let the first arriving vehicle decide which path will take the traveler to their destination. A statistical distribution of waiting times for the arrival of the first bus of a given transit line at a given stop is used to compute the waiting time. The other parts of the trip such as the time spent in the bus are computed as a cost. The strategy is a frequency based and not a timetable based transit assignment which can be expressed as follows: the traveler waits at a head node where a set of attractive lines is chosen and the traveler boards the first vehicle of these lines that arrive. If the path requires changes, the traveler alights at a predetermined node and this process will be repeated until the traveler has reached the destination.

A stochastic transit assignment, as described in the latest Software manual from INRO (2014), computes the average of several strategies, where the segment travel times, the perceived headways, and the perception factors are perturbed using one, from a choice of three distribution functions. Here it is assumed that the traveler does not have exact knowledge about the bus frequencies and the travel times, this error is quantified by the probability distribution used.

3.2 Assignment parameters

A transit assignment requires that values are selected for the parameters involved, for instance, the boarding time can be set to three minutes. The time spent waiting at a bus stop or station is usually considered by many passengers as time consuming and is not appreciated. Therefore, waiting time and perception factors have a major impact when choosing public transportation as a travel mode. Different transit assignment parameters are discussed below and the information can be found in the manuals from INRO released 1999 and 2014.

In-vehicle time

- The *perception factor* is assumed to be 1 minute and is the factor used to compare the time and cost associated with waiting time, boarding time, and cost.

Waiting time

- The *headway fraction* is a parameter for capturing the passengers arrival distribution and its effect on waiting times at transit stops. The factor ranges uniformly between 0 and 1. A value of 0.5 means that passengers wait in average half of the interval. If it is a lower value it corresponds to the case that passenger arrive closer to the departure time.
- A *spread factor* adjusts the waiting time in order to give the passengers fewer or more alternatives at a bus stop. A higher value decides the willingness to consider several attractive lines at a given bus stop and a lower value corresponds to that the traveler chooses a strategy closer to a single path.
- A *perception factor* is used to quantify the perception of waiting time with respect to the in-vehicle time. For example, a perception factor of 2.5 for the waiting time at the station means that passengers perceive 1 minute spent on waiting is equivalent to 2.5 minutes of traveling in a vehicle.

Boarding time

- *Boarding time* is the time it takes for all passengers to board the public transport vehicle. The boarding time penalty can either be applied as the same value for the whole network, or as a node or line specific value, or as a combination of both.
- A *perception factor* is used to quantify the perception of boarding time with respect to the in-vehicle time.

Boarding cost

- The *penalty* can represent the fare converted to minutes.
- A *perception factor* is used to quantify the perception of boarding cost with respect to the in-vehicle time.

Auxiliary transit time

- A *perception factor* is used to quantify the perception of walking time with respect to the in-vehicle time.

The recommended way for finding suitable parameters is to collect data that is specific for the area or city that is being modeled. If this is not possible because it is too expensive or difficult to find a suitable place to collect data, three other approaches are presented. Parveen et al. (2007) describes that one approach for finding suitable parameter values is to use the predefined values that Emme is using as default parameters, although the values can be inadequate and do not necessarily represent the optimal set of values for the given city. Another approach is to use same parameter values, the weights for various time components, from the mode choice in the demand model. A problem with this approach is that such parameter values reflect the behavior of all urban passengers, whereas the parameters included in the transit assignment model need to reflect the behavior of people that travel by public transport. A third approach is to estimate the parameter values by trial and error. However, this approach is tedious and inconvenient and does not necessarily ensure finding the optimal set of parameter values. Parveen et al. (2007) propose a genetic algorithm, based on a calibration model, for finding suitable parameter values for the assignment values. The optimal parameters using the genetic algorithm for the Toronto Transit Commission system can be seen in Table 2. For the full algorithm see Parveen et al. (2007).

Table 2: Best estimates of the assignment parameters for the Toronto Transit Commission system with a genetic algorithm based calibration model. (Parveen et al., 2007)

Headway fraction	0.49
Waiting time perception	1.667
Boarding time	2.6
Boarding time perception	2.07
Auxiliary perception	1

The values in Table 2 can be compared to the values used as standard values by Sampers for Sweden which is presented in Table 3.

Table 3: The standard assignment parameters used by Sampers for Sweden.

Headway fraction	0.5
Waiting time perception	1.5
Boarding time	5
Boarding time perception	1
Auxiliary perception	2

A study performed by Zhang et al. (2014) for bus lines with timetable-dependent and timetable-independent passengers in Shanghai shows that the passengers traveling by a bus with a timetable, plan their trips to minimize the waiting time at the bus stop. The timetable-independent passengers showed up at the bus stop based on previous experiences. Zhang et al. (2014) mention a common model proposed by Osuna & Newell (1972) which describes the waiting time and the arrival patterns of the passengers. By assuming a uniform passenger arrival, the average passenger waiting time can be expressed as a function of the average headway and the headway variance. Passengers appear to schedule their arrivals at the bus stops to minimize their waiting times as the headway increase. The study showed that commuters recognized the timetable better than non-commuters and therefore arrived according to the schedule. This makes the commuters more reliant on the timetable which makes them more sensitive to changes than non-commuters. The study observed two bus lines with a timetable during the morning peak period and the off-peak period. The headways and average headway fraction for the two bus lines can be seen in Table 4.

Table 4: Headway, in minutes and average headway fraction for line 1 and 2 in Jiangqiao, Shanghai. (Zhang et al., 2014)

	Headway			**Headway fraction**			
				High frequency		**Low frequency**	
	Min	Max	Mean	Commuter	Non-commuter	Commuter	Non-commuter
Line 1	12	20	15.8	0.36	0.42	0.43	0.42
Line 2	15	25	18.6	0.36	0.39	0.42	0.41

Fung (2005) applied a frequency-based model to the subway network in Hong Kong for the morning peak hour. Fung (2005) uses an approach assuming that the ranges of the weightings for the waiting time and walking time component are within the interval of 0 - 3. The in-vehicle component is always set equal to 1. Fung (2005) also sets a condition that the walking time is always larger or equal to the waiting time and that the waiting time is always larger or equal to the in-vehicle time. The motivation for this is to make sure that the passengers stay at their current platform in order to avoid illogical behavior such as switching platforms without gaining any time.

Rydergren (2013) evaluates the output from four different headway-based public transport model variants to find the most suitable parameter values. Rydergren (2013) finds that it is more important to select the best type of model variant than finding the optimal parameter values for the generalized cost functions.

According to Parveen et al. (2007) the values of the assignment parameters vary depending on the transit network, since every city or area has its own characteristics. Every model requires that the best suitable values that reflect the passengers' behavior in the current network should be found. Therefore, the model needs to be calibrated for each city by finding the optimal parameters so that the parameters minimize the total difference between the model output and observed passenger counts.

3.3 Pedestrian free-flow speeds

When performing a transit assignment, a pedestrian speed is required and therefore, it is of interest to analyze what is a proper speed value for pedestrians in a model. An article by Laxman et al. (2010) analyzes data for pedestrians flow characteristics in mixed traffic conditions and presents a table containing studies of pedestrian speed under free-flow conditions in different countries. The table presented in the article shows among others a study performed by Oeding in 1963 which showed that in Germany, a mixed pedestrian traffic has a free-flow speed of 5.39 km/h. It also contains a study by Fruin in 1971 which showed that the speed for commuters in the United States is 4.88 km/h.

Weidmann (1992) published a paper where the desired free-flow pedestrian speed is 4.83 km/h but differs depending on the place, time of day and the purpose. When taking those factors into consideration, the free-flow speed for commuters is 5.36 km/h. The paper also mentions that when a pedestrian have to cross the street, the pedestrian use a lower speed of 4.60 km/h. Weidmann (1992) also states that different speeds are used depending on the gender. In general, males use a speed of 5.08 km/h and females use a speed of 4.57 km/h. Vägverket (2002) published an article containing information how the roads should be shaped in order to plan their usage for cyclists and pedestrians and the free flow speed is noted to be 5.04 km/h.

3.4 Field study of headway fraction

A field study was performed in order to observe how the distribution of passengers appears at a bus stop with a bus headway of twenty minutes. The field study was performed Tuesday May 5^{th} 2015, on two independent bus stops in Råcksta which is on the outside of Stockholm between 9:00 and 12:00 AM. The passengers' behavior is assumed to be equal to the behavior of passengers in a small city. The observations can be seen in Figure 4.

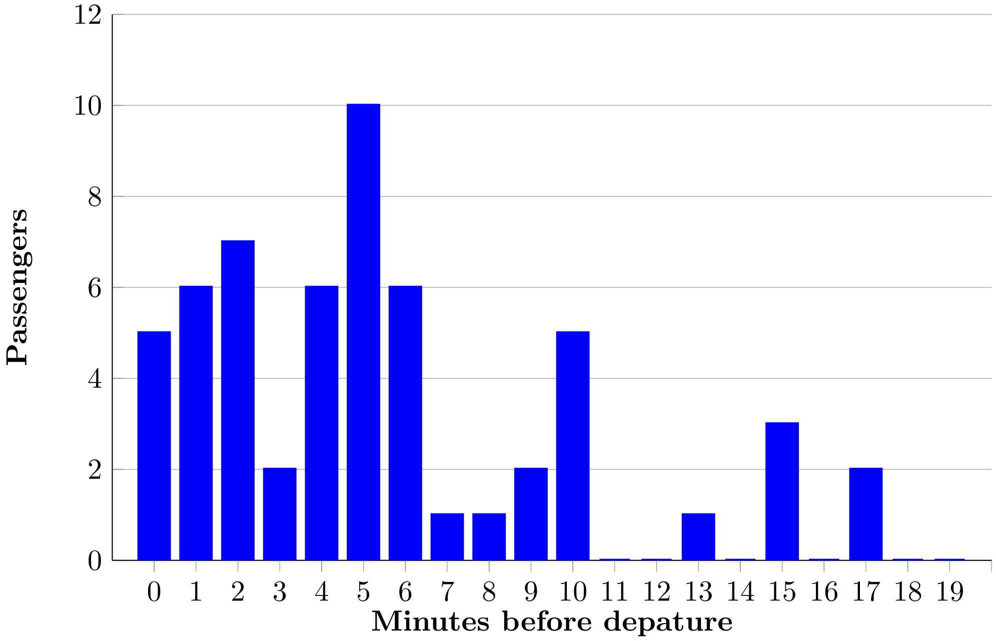

Figure 4: The number of minutes before departure the 58 measured passengers arrive at the bus stop between 9:00 - 12:00 AM.

For the 58 registered passengers, the average headway fraction is 0.278. This value is lower than the values used for both Sampers and Toronto, this is probably since Toronto is a larger city than Stockholm and may have more frequent bus line departures. Also, Sampers assume that the travelers do not know the timetable and shows up randomly. The value correspond better to the study performed by Zhang et al. (2014) since they have a more frequent headway. Although, since the headway mean is slightly lower than in the field study it is reasonable that they have a higher headway fraction.

4

Existing demand models

This chapter presents a literture survey of two forecast models in use today. The models described further in this chapter are Sampers and LuTrans. The text in this chapter is based on the following papers: Algers & Beser (2000), Algers et al. (2009) and WSP (2013).

4.1 Sampers

Sampers is the Swedish national forecasting model for passenger transport and is based on overall assumptions regarding economic development and changes in population and occupation. The aim of the model is to predict impacts on passenger travel in short and long term for various measures in the transport system. These effects could for instance be changes in travel costs, travel demand or travel times divided between socio-economic groups, errands, mode choice and geographical areas.

The first version of Sampers was launched in 1999 with the goal to create an integrated and policy-sensitive model for short trips (less than 100 kilometers), long trips (more than 100 kilometers) and international trips, for both private and business errands. Sweden is divided into five regions and the sub models are run separately, and according to Sehlin (2012) the regions contain around 9 200 zones that consist of start and end points for the trips. The regional models in Sampers includes six different types of trip purposes, work based trips, business trips, school-based trips, social trips, recreation trips and other trips. For each purpose, the frequency, destination, travel mode, and route choice are modeled.

There is one common sub model for all regions to estimate travel times and travel costs for each purpose. Regional differences are captured with different socio-economic variables and with regional constants. The socio-economic variables are specified for each zone and include among others, car ownership, driving license, gender, income etc. Sampers uses population data provided by SCB (2011) that contains information for every municipality in Sweden.

Sampers have the structure of a nested multinomial logit model to estimate the travel mode used for each traveler, see Section 2.3.2 for a more detailed description of the nested logit model. The travel mode choices used in Sampers are driving, being a car passenger, being a train commuter, being a bus commuter, walking or riding a bike.

When Sampers has generated the travel time matrices for each mode choice, it uses Emme to perform a traffic and transit assignment. For car trips, the traffic is assigned using the network equilibrium principle. For public transport, the traffic is assigned according to the principle that the passengers choose the route that will minimize their expected travel time given that they know the frequency. Since the choice of destination and travel mode depends on car travel times which in turn is dependent of the congestion in the road network, several iterations are made between the logit based traffic demand model and the traffic assignment model. One drawback with Sampers is that it can be very time consuming to run the models depending on the size of the network.

4.2 LuTrans

LuTrans stands for Land use Transport Model and is based on models similar to Sampers but with the aim to minimize calculation times and simplify the data collection. According to Almström (2015) the set up time for a city in LuTrans are often 100 hours or more. One simplification is that LuTrans only handles two purposes, working trips and other trips. LuTrans is similar to Sampers in terms of structure of the model, i.e. both models are based on logit models. The structure of LuTrans can be seen in Figure 5.

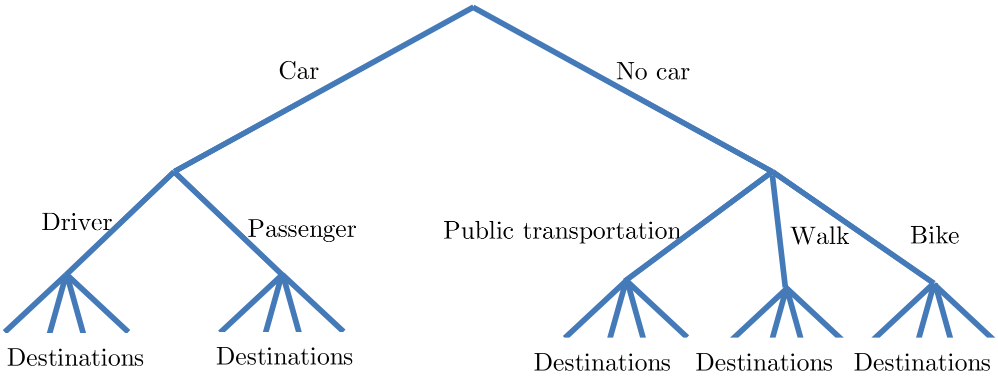

FIGURE 5: The nested logit model structure of LuTrans for both trip purposes.

In the top of Figure 5, the trip generation step is performed. Thereafter, the logit model determines the choice of using the car or not, followed by the real mode choice (for car choice it is car driver or car passenger and for no car it is walk, bike or public transportation). The reason for dividing the mode choice in two nests is due to correlation between car driver and car passenger and a correlation between public transport, walk and bike. Finally, the destination is chosen.

4.2.1 Car ownership model and driver's license model

LuTrans uses a separate car ownership model with the purpose of estimating the amount of households having access to a car in each zone. LuTrans also have a separate driver's license model with the purpose to describe the shares of driver's licenses in each zone and the average number of cars a traveler have access to in each zone.

The car ownership model is divided into two sub models where the first one answers the question if there is access to a car or not, which makes it a binary model. The car model uses variables that are related to the area and to the individuals, also the utility function is specified for the alternative of having access to a car. The variables have been estimated and consist among others of gender, income, age, if you live in a house or not and the density of the population. One major factor for having access to a car, is if you live in a house with free parking spaces. The density of people in an area describes the possibilities that a household have a car. For instance when living in an area with a high density such as Stockholm, it is less likely that the people in the city have a car. The second sub model in the car model uses the same input data and estimates the probability for how many cars there are in a household.

The driver's license model estimates the total numbers of driver's license in a zone. The sub models estimate the probability of having a driver's license granted there is access to a car in the household. For the driver's license model, the economy is the factor that affects the models the most.

4.2.2 The demand model

The results from the car ownership and driver's license models are used as input parameters in the demand model. The first, second, and third steps in the four step model are integrated in LuTrans. A short overview of the step integration is presented below.

1. Calculate the generalized cost for:

   - **Trip distribution:** Defines the generalized costs for each travel mode between every two pair of zones. The generalized cost is then transformed into a log sum.
   - **Mode choice:** Decides the generalized cost in every originating zone for each travel mode. The generalized cost is then transformed into a log sum.
   - **Trip generation:** Decides the generalized cost for making a trip from each zone.

2. Calculate the **choice probabilities** for:

   - Trip distribution, from origin to destination with travel mode
   - Mode choice, from origin with the chosen travel mode
   - Trip generation, from origin

3. Calculate the **total number of trips** from origin to destination with each travel mode

4. **Route assignment:** Calls Emme and performs a traffic and transit assignment.

In LuTrans, the first three steps are conducted in reversed order compared to the four step model described in Chapter 2. Also, the trip distribution is performed before mode choice. However, this does not affect the final OD-matrices for each travel mode.

A utility function in trip distribution contains parameters and variables associated with the different travel modes. The utility function for car covers in addition to travel time, distance and cost, the output data from the car ownership model and the driver's license model. The utility function for public transportation includes variables such as travel time in the vehicle, waiting time and walking time to the stop or station. The utility functions for walk and bike only includes distance variables. These have been modeled with different sensitivity with distances larger or smaller than five kilometer. It also includes some calibration parameters to recompose the travel distribution, which is collected from a travel survey. The generalized cost for mode choice includes a mutual log sum parameter for all starting zones for all travelers. The generalized cost for trip generation also consists of a mutual log sum parameter for each starting zone. The value of the log sum parameter is constant for each travel mode with the purpose to scale the measure. To obtain the utility in the system, it weights the number of travelers that lives in respective zone.

The choice probabilities for the trip distribution are calculated based on the chosen travel mode. The choice probabilities for mode choice is calculated separately, first given that the traveler have access to a car and secondly that the traveler does not have access to a car. Thereafter, these choice probabilities of choosing a no car mode, public transport, walk and bike, are summarized into three separately probabilities. Thereafter, the choice probabilities for the trip generation are calculated based on the generalized cost for making a trip.

The total number of trips are then calculated by multiplying the three probabilities mentioned above with the origin for work trips or destination for other trips in order to receive an OD-matrix for each mode. Finally LuTrans uses Emme to perform the route choice in order to decide how the trips will be distributed on the network, based on travel time. Since LuTrans consider congestion, the process will be performed for a number of iterations until convergence is obtained.

4.2.3 Comparison of Sampers and LuTrans

Sampers and LuTrans are quite similar and have the same structure and uses the same input data. Furthermore, both models uses Emme to perform the route choice step. The difference between Sampers and LuTrans is that Sampers considers more purposes than LuTrans and it also considers another mode, commuter train.

Hence, the demand functions used by LuTrans was therefore chosen as a foundation for building a simplified demand model which will be used in this thesis.

5

Model Description and Implementation

From this chapter and now on the model developed for the purpose of the thesis is discussed and referred to as ”the developed model”.

The developed model have a set up time of around five hours or longer and is based on the structure and generalized costs used in LuTrans. This chapter presents how the model was implemented and how the matrices were obtained from the network. It also presents the structure of the code and the manual changes made in Emme. For an overview of the inputs and outputs of the developed model, see Figure 6.

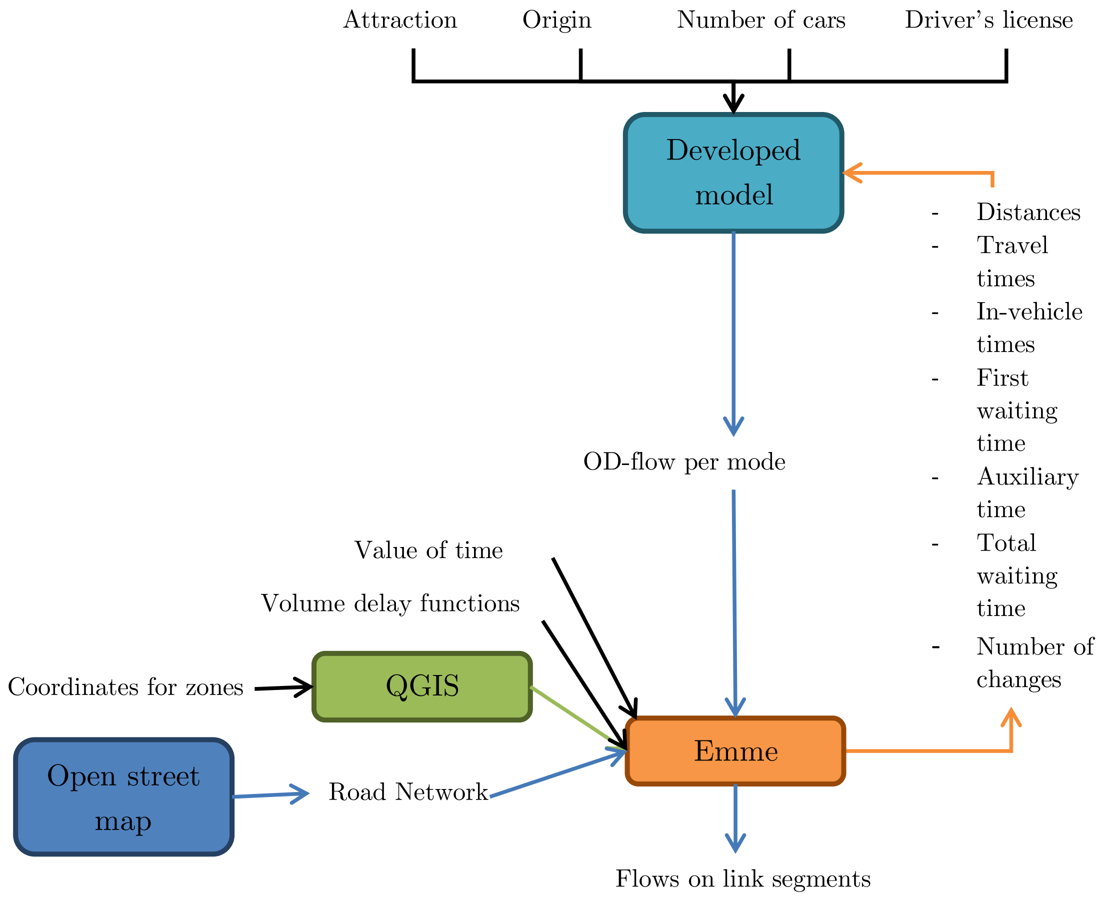

FIGURE 6: The main and sub program inputs and outputs and associated relationship of the developed model.

The developed model is built on the four step model where the first three steps were implemented. The developed model requires input matrices such as travel times and distances between every zone pair. These matrices are firstly produced from the network in Emme with the assumption that no congestion occurs. It also requires input data such as population and car accessibility in each zone. The developed model results in an OD-matrix for each travel mode where the OD-matrix for public transport and is imported into Emme where a transit assignment is performed, in order to complete the final step of the four step model.

5.1 Implementation in Emme

This section presents how the model was implemented into Emme. It describes the road network, the socio-economic data and adjustments made to make the model suitable for the purpose of the thesis.

5.1.1 Socio-economic and transit lines data

As mentioned in Section 1.3 the socio-economic data originates from SCB (2011). An example of the coordinates for a zone can be seen in Table 5.

Table 5: The coordinates for one zone in Örebro.

Zone ID	**X**	**Y**
18800003	1466212	6572957

Table 5 shows the coordinates for a zone located in Örebro. The column Zone ID is the identification for the zone where the two first digits represent the county, the second two digits the municipality and the final four tells which area in the city the zone belongs to. The coordinates for X and Y are in the reference system RT90, Rikets koordinatsystem 1990. Since the road network from OpenStreetMap (2015) is in the reference system WGS84 the zones have to be transformed into the same coordinate system before importing them to Emme. This was done using an open source program called QGIS where the coordinates of the zones were transformed from RT90 to UTM Grid Zone 33N, in WGS84, where 33N is the grid zone for Sweden. The zones in the network used for Örebro can be seen as the red circles in Figure 7.

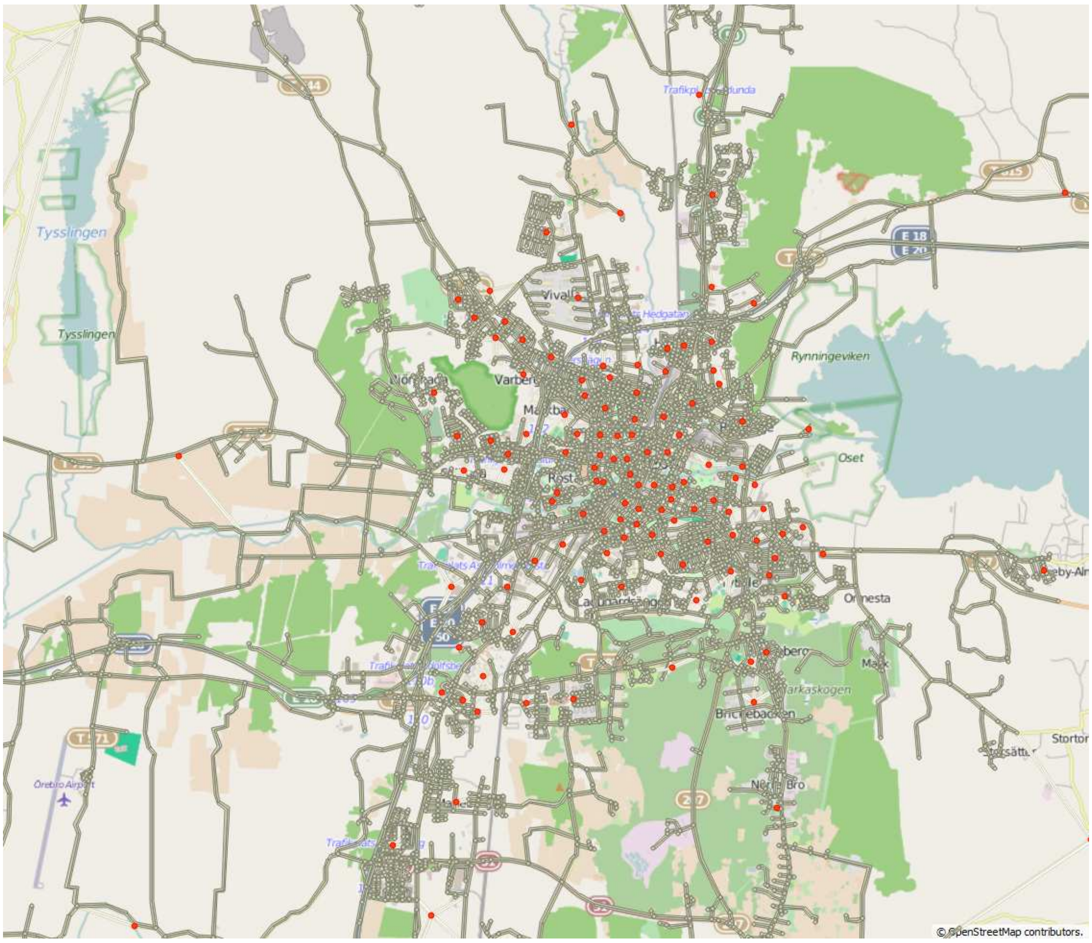

FIGURE 7: An overview of the links and zones in the network for Örebro.

5.1.2 The road network

The road network of Örebro was obtained using OpenStreetMap (2015), OSM, which holds open source maps. The map of Örebro was exported into an OSM-file which was imported into Emme, see Figure 7 for the road network. The background map in Emme is also from OpenStreetMap (2015) which made it easier to follow the road network when the bus transit lines were implemented. The OSM-file contains the nodes, links, road types, and coordinates for where they are located.

When the road network had been imported, the modes for car and bus were added and the allowed modes for certain road types were decided. Also a few links were added for the streets where only buses are allowed that did not exist in the imported network. Then the zones with positions too far away from the network area were removed since the residents are more likely to use the country buses and thereafter they were connected to the adjacent nodes. One zone represent an entire area and should therefore be connected several surrounding nodes. The links that connects the zones to the nodes are called connectors and are assigned a new link type making it easy to distinguish them from the rest of the links. Finally the transit lines for the city buses were added into the network.

The volume delay functions, VDF, are the functions that calculate the travel time for traveling by car on the links depending on the congestion. The functions used here are the same as Sampers and LuTrans uses for conducting the route choice. Different functions are used depending on the road classification. The functions and links, together with a classification used for the Örebro network, can be seen in Table 6. After the volume delay functions were added, the links were adjusted to correspond to the same unit, kilometers, which is used in Sampers for the volume delay functions. The volume delay functions are only used for making the intial traffic assignment.

Table 6: The different road types together with the description and the chosen VDF for each link type.

VDF for link type	**Description**
1	Motorway with 2 lanes, 90km/h
2	Motorway with ramps, 90 km/h
3	Links located in the city, 70 km/h
4	Links located in the country side, 70 km/h
5	Links located in the city, 50 km/h
6	Links located in the country side, 50 km/h
7	Links located in the city, 30 km/h
8	Streets designed primarily for pedestrians
9	Connectors, 30 km/h

The data for the transit lines contain the bus routes during the period of October 2010 – April 2011 and the timetables were received from Länstrafiken Örebro AB. The lines as well as the headway were coded into Emme. An overview of the bus lines can be seen in Figure 8 and the full list of headways can be found in Table 7. The headways have been calculated by looking at the departure schedule and divide the number of departures per day with the time interval of 1 050 minutes which is the total number of minutes from 5:30 AM to 11:00 PM.

FIGURE 8: The transit lines in 2010 within the city of Örebro.

Table 7: The headway in minutes for each bus line in the base scenario of Örebro 2010.

Line	**Origin - Destination**	**Headway**
1a	Lundby - Universitetet	21.43
1b	Universitetet - Lundby	20.59
2a	Lundby - Brickebacken	21
2b	Brickebacken - Lundby	21.43
3a	Mellringe - Brickebacken	20.59
3b	Brickebacken - Mellringe	21
4a	Mellringe - Universitetet	21.43
4b	Universitetet - Mellringe	21
5a	Björkhaga - Hovsta	21.43
5b	Hovsta - Björkhaga	21.88
6a	Björkhaga - USÖ	21
6b	USÖ - Björkhaga	21.43
7a	Karlslund - USÖ	21.43
7b	USÖ - Karlslund	21.43
8a	Karlslund - Hovsta	21.43
8b	Hovsta - Karlslund	20.59
21a	Berglunda - Rynninge	33.87
21b	Rynninge - Berglunda	32.81
22a	Marieberg-USÖ	25.61
22b	USÖ - Marieberg	24.42
23a	Mosås - USÖ	35
23b	USÖ - Mosås	35
24a	Adolfsberg - Lillån	25
24b	Lillån - Adolfsberg	20.19
25a	Adolfsberg - Wadköping	25.61
25b	Wadköping - Adolfsberg	30.88
26a	Tybble - Hjärsta	26.25
26b	Hjärsta - Tybble	25

To obtain the average speed on the city buses for different areas of Örebro, Örebro Municipality and Region Örebro County have collected data from the reality control system installed in the buses and the result can be seen in Figure 9.

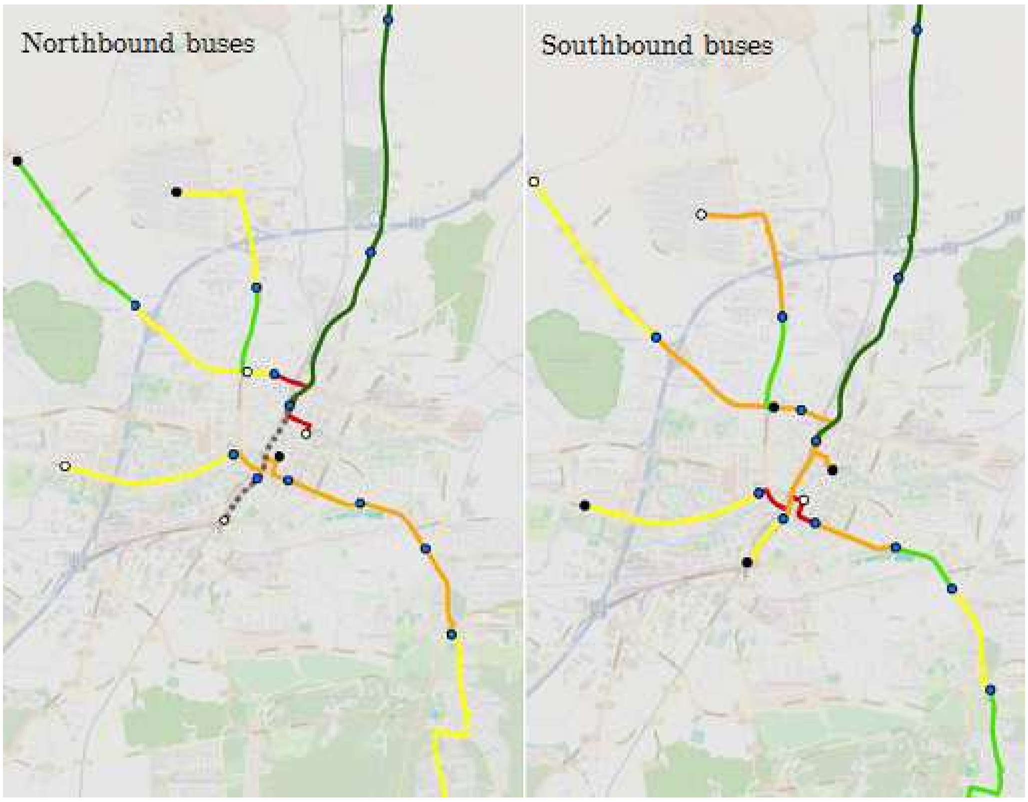

FIGURE 9: The average speed on the city buses in Örebro obtained from Region Örebro County and the municipality (Eliasson & Emilsson, 2015).
Red = lower than 10 km/h, orange = 10-15 km/h, yellow = 16-20 km/h, green = 21-25 km/h, dark green = higher than 25 km/h, grey dots = missing speed data.

Figure 9 shows that the most common speeds for the buses in the central areas of the city range between 10-15 km/h and 16-20 km/h. Kottenhoff et al. (2009) expresses in an article that the average speed for a city bus in Stockholm is 15 km/h but the speed for the buses was selected to be 18 km/h for the transit assignment since the measured speeds for Örebro are assumed to be a better estimation than speeds for another city. The speed for pedestrians was chosen to be 5.0 km/h since this was the value measured by Vägverket (2002) for the Swedish roads.

5.1.3 Traffic and transit assignments

A start matrix with an equal small demand was created in order to obtain the required start matrices which are used as input data in the developed model. The demand is chosen to be low to avoid congestion in the network and to receive a relationship between every zone pair in the system. When all settings have been adjusted in Emme, a traffic and a transit assignment was performed using a single iteration. The assignments were performed with the same value of time parameters that are used in Sampers, previously shown in Table 3, with the exception of the headway fraction. The headway fraction is set to 0.3 since the field study showed that most passengers are aware of the timetable when there is a 20 minutes interval between the buses. See Table 8 for the values used in the traffic and transit assignment.

Table 8: The assignment parameters used in the transit assignment for obtaining the start matrices.

Boarding time	5
Boarding time perception	1
Headway fraction	0.3
Wait time perception	1.5
Auxiliary perception	2

When both assignments have been performed, the matrices in Table 9 are stored for further use in the developed model.

Table 9: Output from the intial traffic and transit assignments performed in Emme

Name	**Description**	**For travel mode**
Distance	Distance in kilometers	Car, Car passenger, Walk and Bike
Travel time	Travel time in minutes	Car, Car passenger
In-vehicle time	In-vehicle time required for a trip	Public transport
First waiting time	Waiting time at the first stop	Public transport
Auxiliary time	Walking time	Public transport
Total waiting time	Total waiting time for a trip	Public transport
Number of changes	Total number of changes	Public transport

5.2 Implementation of the developed model

The developed model is based on LuTrans, which is implemented in the programming language Fortran 90, and has therefore inherited many properties. One important property is that the developed model, like Lutrans, only handles two purposes, working trips and other trips. They have been modeled quite similar, but some changes have been made in the utility functions and when calculating the total number of trips. This is done since the behavior for working travelers and other travelers differ. Also, the parameter values are the same as used by LuTrans. The LuTrans code includes variables which have been excluded in the developed model, for instance local residents' parking fees, tolls and the income is not considered. A trip is modeled as a one way trip, and is then transposed to correspond to a round-trip which gives a symmetric OD-matrix. The model forecast trips for all age groups, but for people between zero and six, the model make allowances that they only do half as many trips as the other age groups. The model considers a weekday and according to the travel survey the average trip independent of the travel mode is 6.6 kilometers in Örebro. The calibration parameters used derive from the calibration parameters used in LuTrans when the average trip length is five kilometers.

The growth factor for 2010 is calculated using Equation (13) where n stands for n years after 2001, 2001 is the year the parameters are calibrated for in LuTrans, and 1.02 stands for the yearly economic growth.

$$\tau_n = \frac{1.02^n - 1}{2} + 1 \tag{13}$$

But since 2010 has already occurred, the actual outcome for 2010, 1.0921, was used in the developed model. An overview of the input and output variables in the model can be seen in Figure 10.

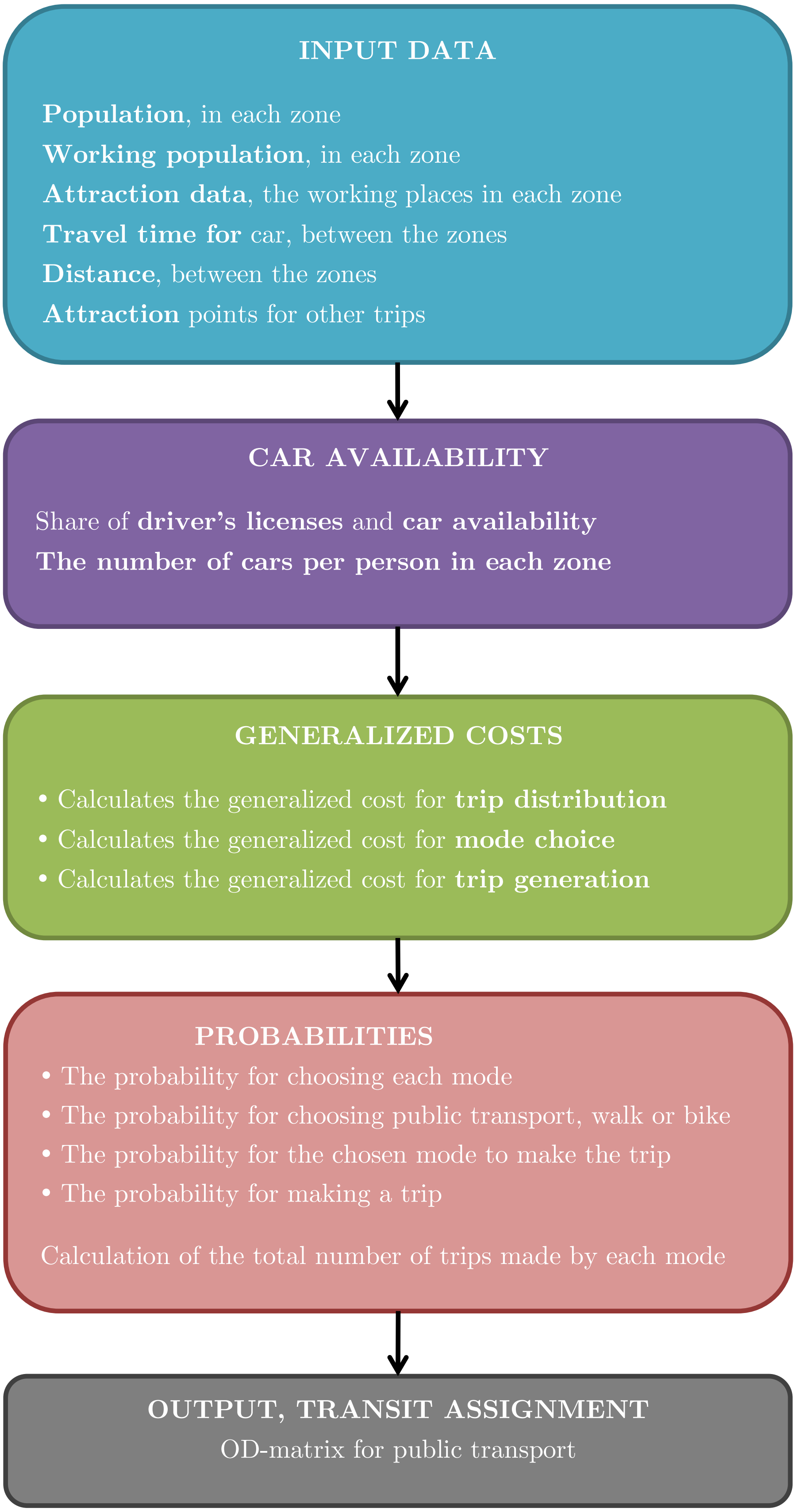

FIGURE 10: The main modules that the developed model consists of.

A full description of the developed model showed in Figure 10 is presented below.

1. Calculate the shares of driver's licenses, car availability, and the number of cars per person in each zone.
2. Trip distribution: Calculates the generalized cost by determining the utility for each mode using the utility functions.
    - Car driver: depends on the travel time, a car cost, the number of people in the car and how attractive the destination is.
    - Car passenger: depends on the same variables as car driver but it also contains a parameter for traveling as a car passenger multiplied by the distance.
    - Public transport: depends on the in-vehicle time, total waiting time, first waiting time, the auxiliary time to the bus stop, the cost for traveling by bus, and how attractive the destination is.
    - Walk: contains a weighted function which is based on specific equilibrium distances which represents how likely it is for the traveler to walk. It also includes how attractive the destination is. The assumption is that if the distance is more than 7.5 kilometers, the traveler chooses not to walk.
    - Bike: contains a weighted function based on specific equilibrium distances which represents how likely it is for the traveler to ride a bike. It also includes how attractive the destination is. The assumption is that if the distance is more than 12.5 kilometers, the traveler chooses not to travel by bike.
3. Mode choice: The generalized costs obtained from the utility functions are transformed into a log sum. The generalized cost in every originating zone for each travel mode is defined using the utility functions.
4. Trip generation: Calculates the generalized cost for making a trip from the originating zone to the zone at the travelers' destination.
5. The mode choice probabilities are then calculated:
    - Firstly the model decides the probability for each travel mode, from origin to destination.
    - Secondly it calculates the probability that a traveler chooses to travel from its origin with a non-car mode such as public transport, walk or bike.
    - Thirdly it calculates the probability for traveling by car as a driver, car as a passenger, by public transport, by walking or by bike.
    - Finally, it calculates the probability for making a trip.

6. The total number of trips from origin to destination for each travel mode is then calculated and the matrix containing the total number of trips made by public transport for an entire day is obtained.

7. Finally, the OD-matrix containing the total number of trips made by public transport is inserted into Emme and a stochastic transit assignment is performed with the standard values used by Emme and Sampers with the exception of the headway fraction which is 0.3. No random distribution or perception factors were used.

A tree structure illustration of the model can be seen in Figure 11.

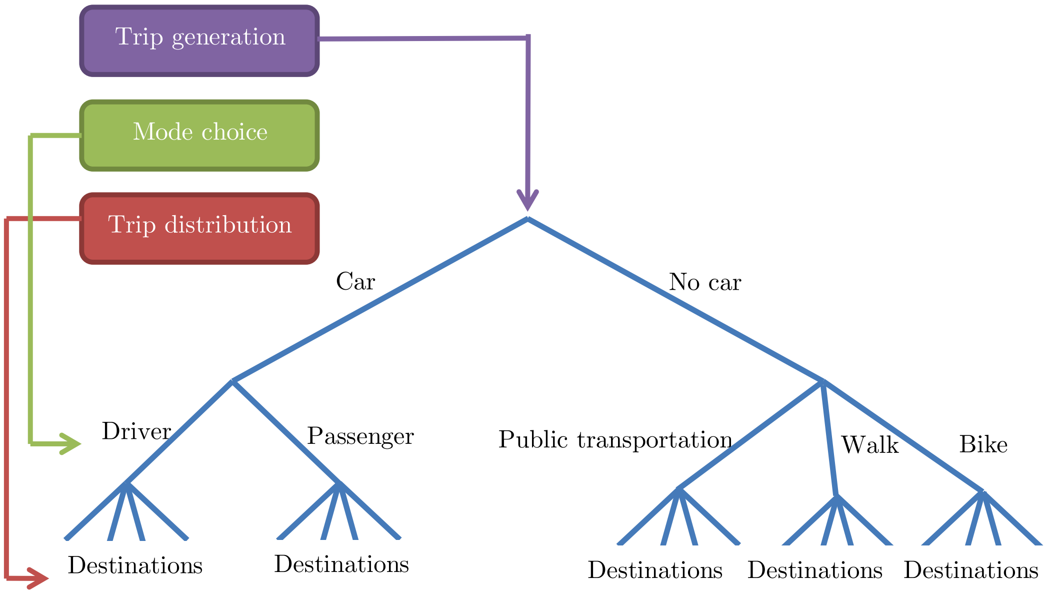

FIGURE 11: The tree structure of the developed model.

5.2.1 Car ownership and driver's licenses

The developed model uses the data for car availability, the number of cars, the number of driver's licenses and the population in each zone to calculate the shares for car availability, driver's licenses (which only uses the part of the population that are 18 years and older) and for car competition. An overview of the pseudo code for this sub model can be seen in Listing 5.1

```
if  Population = 0
    ShareOfDriversLicenses = 0
    CarCompetition = 0
else
   ShareOfDriversLicenses = NoOfDriversLicenses/Population>18
```

```
   CarCompetition = CarDisposal/Population
end

if NumberOfCars = 0
   CarCompetition = 0
else
   CarCompetition = NumberOfDriversLicences/NumberOfCars
end
```

LISTING 5.1: The pseudo code for the car sub model.

5.2.2 Working trips

The total number of trips for each travel mode are calculated using the population in the origin and the probability for making a trip. The attraction data used for working trips contains the number of working places in each zone. For working trips, the cost for traveling by public transportation is assumed to be a monthly cost i.e. no one pays for a one way ticket. The generalized costs among others, originates from LuTrans but they are modified and simplified by the authors and are shown as the pseudo code in Listing 5.2. A full description of the matrices can be found in Table 10 and a full description of the parameters can be found in Table 11.

```
%GENERALIZIED COST, TRIP DISTRUBUTION
%CAR
if 0 < Distance < 10000 & WorkingPlaces > 0
$GCDest_C$ = $t_C\cdot$ TravelTime · 2 + c · CarCost + log(WorkingPlaces) + $dcal_C$
else
$GCDest_C$ = -50
end
ExpsumCar = ExpsumCar + $e^{GCDest_C}$

%CAR PASSENGER
if 0 < Distance < 10000 & WorkingPlaces > 0
$GCDest_{CP}$ = $t_C\cdot$ TravelTime · 2 + c · CarCost + $d_{CP}\cdot$ Distance · 2 + log(WorkingPlaces)
     + $dcal_{CP}$
else
$GCDest_{CP}$ = -50
end
ExpsumCarPassenger = ExpsumCarPassenger + $e^{GCDest_{CP}}$

%PUBLIC TRANSPORTATION
if 0 < InVehicleTime < 10000 & WorkingPlaces > 0
$GCDest_{PT}$ = $t_{PT}\cdot$ (InVehicleTime + TotalWaitingTime - FirstWaitingTime) · 2 + $fwt_{PT}\cdot$
    FirstWaitingTime · 2 + $t_w\cdot$ WalkingTime · 2 + c · PTCost + log(WorkingPlaces) +
    $dcal_{PT}$
else
$GCDest_{PT}$ = -50
end
```

```
ExpsumPT = ExpsumPT + $e^{GCDest_{PT}}$

%WALK
if 0 < Distance < 7.5 & WorkingPlaces > 0
$GCDest_W$ = $d_{<5,W}\cdot$ min(Distance · 2,5) + $d_{>5,W}\cdot$ max (Distance · 2 · -5,0) + log(WorkingPlaces) + $dcal_W$
        if StartZone = EndZone
        $GCDest_W$ = $GCDest_W$ + $\varrho_W$
        end
else
$GCDest_W$ = -50
end
ExpsumWalk = ExpsumWalk + $e^{GCDest_W}$

%BIKE
if 0 < Distance < 12.5 & WorkingPlaces > 0
$GCDest_B$ = $d_{<5,B}\cdot$ min(Distance · 2,5) + $d_{>5,B}\cdot$ max (Distance · 2 · -5,0) + log(WorkingPlaces) + $dcal_B$
        if StartZone = EndZone
        $GCDest_B$ = $GCDest_B$ + $\varrho_B$
        end
else
$GCDest_B$ = -50
end
ExpsumBike = ExpsumBike + $e^{GCDest_B}$

%GENERALIZIED COST, MODE CHOICE
$GCMode_C$ = cc · CarCompetition + dl · ShareOfDriversLicences + $\beta_1\cdot$ log(ExpsumCar)
$GCMode_{CP}$ = $\theta_{CP}$ + $\beta_1\cdot$ log(ExpsumCarPassenger) + $mcal_{CP}$
$GCMode_{PT}$ = $\theta_{PT}$ + $\beta_1\cdot$ log(ExpsumPublicTransport) +$mcal_{PT}$
$GCMode_W$ = $\theta_W$ + $\beta_1\cdot$ log(ExpsumWalk) + $mcal_W$
$GCMode_B$= $\theta_B$ + $\beta_1\cdot$ log(ExpsumBike) + $mcal_B$

ExpNoCar = $e^{GCMode_{PT}}$ + $e^{GCMode_W}$+ $e^{GCMode_B}$
ExpAllModes = ExpNoCar + $e^{GCMode_{CP}}$ + $e^{GCMode_C}$

%GENERALIZIED COST, TRIP GENERATION
GCTrip = $\beta_2\cdot$ log(ExpAllModes) + tgcal

%PROBABILITIES
$pDest_C$ = $e^{GCDest_C}$/ExpsumCar
$pDest_{CP}$ = $e^{GCDest_{CP}}$/ExpsumCarPassenger
$pDest_{PT}$ = $e^{GCDest_{PT}}$/ExpsumPublicTransport
$pDest_W$ = $e^{GCDest_W}$/ExpsumWalk
$pDest_B$ = $e^{GCDest_B}$/ExpsumBike

$pMode_C$ = CarCompetition $\cdot e^{GCMode_C}$/ExpAllModes
$pMode_{CP}$ = CarCompetition $\cdot e^{GCMode_{CP}}$/ExpAllModes
$pMode_{PT}$ = (1-CarCompetition) $\cdot e^{GCMode_{PT}}$/ExpNoCar + CarCompetition $\cdot e^{GCMode_{PT}}$/ExpAllModes
$pMode_W$ = (1-CarCompetition) $\cdot e^{GCMode_W}$/ExpNoCar + CarCompetition $\cdot e^{GCMode_W}$/ExpAllModes
$pMode_B$ = (1-CarCompetition) $\cdot e^{GCMode_B}$/ExpNoCar+ CarCompetition · $e^{GCMode_B}$/ExpAllModes
```

```
$pTrip$ = $e^{GCTrip}$/($e^{GCTrip}$ + 1)

%OD-MATRICES
if population > 0
CarODmatrix = Population · $pTrip$ · $pMode_C$ · $pDest_C$
CarPassengerODmatrix = Population · $pTrip$ · $pMode_{CP}$ · $pDest_{CP}$
PublicTransportODmatrix = Population · $pTrip$ · $pMode_{PT}$ · $pDest_{PT}$
WalkODmatrix = Population · $pTrip$ · $pMode_W$ · $pDest_W$
BikeODmatrix = Population · $pTrip$ · $pMode_B$ · $pDest_B$
end
```

Listing 5.2: The pseudo code for the working trip sub model.

As mentioned, the matrices that are used as input in the working trip sub model is presented in Table 10.

Table 10: Presents the matrices used in the developed model, their name, a short description and how the matrix is used.

Matrices used in working trips

Name	**Description**	**Exported from**	**For travel mode**
WorkingPlaces	No. of working places	Population data	All
CarDisposal	Percentage with availability to a car	Population data	All
Changes	Number of changes for a trip between one zone to another	Emme	PT
Distance	Distance in kilometers	Emme	Car, Walk, Bike
NoOfDriversLicenses	Amount of drivers licenses	Population data	Car
FirstWaitingTime	Waiting time at the first stop for a trip	Emme	PT
InVehicleTime	Time spent in vehicle	Emme	PT
NumberOfCars	No. of cars in a zone	Population data	Car
Population	No. of residences who starts their trip in each zone	Population data	All
TotalWaitingTime	Total waiting time for a trip	Emme	PT
TravelTime	Travel time in minutes	Emme	Car, CP
WalkingTime	Walking time to a bus stop	Emme	PT

As mentioned, the parameters that are used as input in the working trip sub model is presented in Table 11. The parameters have the same values as in LuTrans.

Table 11: A description of the parameters used for working trips.

Parameters used in working trips			
	Explanation	**Mode**	**Value**
t_{PT}	Walking time	PT	– 0.01342
cc	Car competition	Car	– 0.97395
θ_{CP}	Car passenger	CP	1.16383
θ_B	Bike	Bike	0.44716
θ_{PT}	PT	PT	0.46803
θ_W	Walk	Walk	– 0.31370
d_{CP}	Distance car passenger	CP	– 0.01466
$d_{<5,B}$	Distance less than 5 km	Bike	– 0.13402
$d_{>5,B}$	Distance larger than 5 km	Bike	– 0.15143
$d_{<5,W}$	Distance less than 5 km	Walk	– 0.19512
$d_{>5,W}$	Distance larger than 5 km	Walk	– 0.29276
t_C	Travel time in vehicle	Car, CP	– 0.02936
t_{PT}	Travel and waiting time, except first waiting time	PT	– 0.01763
dl	Share of driver's license	Car	3.19655
β_1	Log sum, destination choice	All	0.73273
β_2	Log sum, trip generation	All	0.29049
γ	Average travelers in a car	Car, CP	1.12
ϱ_B	Within zone distance	Bike	0.27617
ϱ_W	Within zone distance	Walk	1.79052
fwt_{PT}	First waiting time	PT	–0.02809
c	Cost	Car, CP, PT	-0.01999
$dcal_C$	Calibration, destination choice	Car	-0.1705
$dcal_{CP}$	Calibration, destination choice	CP	1.0719
$dcal_{PT}$	Calibration, destination choice	PT	0.3788
$dcal_W$	Calibration, destination choice	Walk	0.5757
$dcal_B$	Calibration, destination choice	Bike	-0.0442
$mcal_{CP}$	Calibration, mode choice	CP	-3.0668
$mcal_{PT}$	Calibration, mode choice	PT	-2.0812
$mcal_W$	Calibration, mode choice	Walk	-0.2063
$mcal_B$	Calibration, mode choice	Bike	-0.3954
$tgcal$	Calibration, trip generation choice	All	-0.7611

5.2.3 Other trips

The sub model for other trips is quite similar to the model for working trips. Instead of using the total number of working places as the attraction matrix, the other trip sub model divides, among others the attraction dependent on different working sectors. The working sectors used in this model are the trade, health care, hotel and restaurant, public and education sector. Together with a common parameter, it reflects the total number of people that want to visit the industry or sector. Since the other trips uses different attraction data, the utility functions for each travel mode differs from the utility functions used in working trips. The generalized costs among others originates from LuTrans but they are modified and simplified by the authors and are shown in the pseudo code presented in Listing 5.3. A full description of the matrices can be found in Table 12 and a full description of the parameters can be found in Table 13.

```
%CAR
if 0 < Distance < 10000
$GCDest_C$ = $t_C \cdot$ TravelTime · 2 + c · CarCost + log(Trade + $\rho \cdot$ HolidayCottage + hc ·
    HealthCare + $pop_{residence} \cdot$ Population + $pop_{work} \cdot$ Population + hr · HotelRestaurant
    + ps · PublicSector + ed · Education + s · Supermarket + $ca_C \cdot$ CentralDistrict +
    $dcal_C$
else
$GCDest_C$ = -50
end
ExpsumCar = ExpsumCar +$e^{GCDest_C}$

%CAR PASSENGER
if 0 < Distance < 10000
$GCDest_{CP}$ =  $t_C \cdot$ TravelTime · 2 + c · CarCost + log(Trade + $\rho \cdot$ HolidayCottage + hc ·
    HealthCare + $pop_{residence} \cdot$ Population + $pop_{work} \cdot$ Population + hr · HotelRestaurant+
     ps · PublicSector + ed · Education + s · Supermarket + $ca_{CP} \cdot$ Central District +
     $dcal_{CP}$
else
$GCDest_{CP}$ = -50
end
ExpsumCarPassenger = ExpsumCarPassenger + $e^{GCDest_{CP}}$

%PUBLIC TRANSPORT
if 0 < InVehicleTime < 10000
$GCDest_{PT}$ = $t_{PT} \cdot$ InVehicleTime · 2 + ch · Changes · 2 + $fwt_{PT} \cdot$ FirstWaitingTime  · 2
    + $t_w \cdot$ WalkingTime · 2 + c · 2 · owt · (1-cs) + log(Trade + $\rho \cdot$ HolidayCottage + hc
     · HealthCare + $pop_{residence} \cdot$ population + $pop_{work} \cdot$ Population + hr ·
    HotelRestaurant+ ps · PublicSector + ed · Education + s · Supermarket + $ca_{PT} \cdot$
    CentralDistrict+ $dcal_{PT}$
else
$GCDest_{PT}$ = -50
end
ExpsumPT =ExpsumPT +$e^{GCDest_{PT}}$

%WALK
```

```
if 0 < Distance < 7.5
$GCDest_W$ = $d_w\cdot$ Distance · 2 + log(Trade + $\rho\cdot$ HolidayCottage + hc · HealthCare +
    $pop_{residence}\cdot$ Population + $pop_{work}\cdot$ Population + hr · HotelRestaurant + ps ·
    PublicSector + ed · Education + s · Supermarket + $ca_W\cdot$ CentralDistrict + $dcal_W$
        if StartZone = EndZone
        $GCDest_W$ = $GCDest_W$ + $\varrho_W$
        end
else
$GCDest_W$ = -50
end
ExpsumWalk = ExpsumWalk + $e^{GCDest_W}$

%BIKE
if 0 < Distance < 12.5
$GCDest_B$ = $d_{<5,B}\cdot$ min(Distance · 2,5) + $d_{>5,B}\cdot$ max (Distance · 2 · -5,0) + $pop_{residence}\cdot$
     Population + $pop_{work}\cdot$ population + hr · HotelRestaurant + ps · PublicSector +
    ed · Education + s · Supermarket + $ca_B\cdot$ CentralDistrict + $dcal_B$
        if StartZone = EndZone
        $GCDest_B$ = $GCDest_B$ + $\varrho_B$
        end
else
$GCDest_B$ = -50
end
ExpsumBike = ExpsumBike + $e^{GCDest_B}$

%GENERALIZIED COST, MODE CHOICE
$GCMode_C$ = cc · CarCompetition/2 + dl · ShareOfDriversLicenses + $\beta_1\cdot$ log(
    ExpsumCar)
$GCMode_{CP}$ = $\theta_{CP}$ + $\beta_1\cdot$ log(ExpsumCarPassenger) + $mcal_{CP}$
$GCMode_{PT}$ = $\theta_{PT}$ + $\beta_1\cdot$ log(ExpsumPT) + $mcal_{PT}$
$GCMode_W$ = $\theta_W$ + $\beta_1\cdot$ log(ExpsumWalk) + $mcal_W$
$GCMode_B$= $\theta_B$ +$\beta_1\cdot$ log(ExpsumBike) + $mcal_B$

ExpNoCar = $e^{GCMode_{PT}}$ + $e^{GCMode_W}$ + $e^{GCMode_B}$
ExpAllModes = ExpNoCar + $e^{GCMode_{CP}}$ + $e^{GCMode_C}$

%GENERALIZIED COST, TRIP GENERATION
GCTrip = $\beta_2\cdot$ log(ExpAllModes) + tg + tgcal

%PROBABILITIES
$pDest_C$ = $e^{GCDest_C}/ExpsumCar$
$pDest_{CP}$ = $e^{GCDest_{CP}}/ExpsumCarPassenger$
$pDest_{PT}$ = $e^{GCDest_{PT}}/ExpsumPT$
$pDest_W$ = $e^{GCDest_W}/ExpsumWalk$
$pDest_B$ = $e^{GCDest_B}/ExpsumBike$

$pMode_C$=CarCompetition $\cdot e^{GCMode_C}$/ExpAllModes
$pMode_{CP}$=CarCompetition $\cdot e^{GCMode_{CP}}$/ExpAllModes
$pMode_{PT}$=(1-CarCompetition) $\cdot e^{GCMode_{PT}}$/ExpNoCar + CarCompetition$\cdot e^{GCMode_{PT}}$/
    ExpAllModes
$pMode_W$ = (1-CarCompetition) $\cdot e^{GCMode_W}$/ExpNoCar + CarCompetition$\cdot e^{GCMode_W}$/
    ExpAllModes
$pMode_B$ = (1-CarCompetition) $\cdot e^{GCMode_B}$/ExpNoCar + CarCompetition$\cdot e^{GCMode_B}$/
    ExpAllModes
```

```
pTrip = $e^{GCTrip}/(e^{GCTrip}$ + 1)

%OD-MATRICES
if Destination > 0
CarODmatrix = Destination· pTrip $\cdot pMode_C \cdot pDest_C$
CarPassengerODmatrix = Destination· pTrip $\cdot pMode_{CP} \cdot pDest_{CP}$
PublicTransportODmatrix = Destination· pTrip $\cdot pMode_{PT} \cdot pDest_{PT}$
WalkODmatrix = Destination· pTrip $\cdot pMode_W \cdot pDest_W$
BikeODmatrix = Destination· pTrip $\cdot pMode_B \cdot pDest_B$
end
```

Listing 5.3: The pseudo code for the other trip sub model.

The generalized cost for public transportation use a different cost than for working trips where the cost for a one-way ticket is used. Unlike the working trips, the other trip sub model calculates the total number of trips by multiplying the probabilities with the total number of working places in the zone. As mentioned, the matrices that are used as input in the working trip model are presented in Table 12.

Table 12: Presents the matrices used in the developed model, their name, a short description and how the matrix is used.

Matrices used in other trips

Name	**Description**	**Exported from**	**For travel mode**
CarDisposal	Percentage with availability to a car	Population data	All
Changes	No. of changes for a trip	Emme	PT
CentralDistrict	Binary: central zone or not	Population data	All
Distance	Distance in kilometers	Emme	Car, CP, Walk, Bike
NoOfDriversLicenses	Amount of drivers licenses	Population data	Car
Education	No. of people working with education	Population data	All
FirstWaitingTime	Waiting time at the first stop for a trip	Emme	PT
HealthCare	No. of people working with health care	Population data	All
HotelRestaurant	No. of people working with hotel & restaurant	Population data	All
HolidayCottage	Area of holiday cottage	Population data	All
InVehicleTime	Time spent in vehicle	Emme	PT
NumberOfCars	No. of cars	Population data	Car
Population	No. of residence	Population data	All
Public sector	No. of people working in the public sector	Population data	All
Supermarket	Binary: supermarket or not	Population data	All
Trade	No. of people working with trade	Population data	All
TravelTime	Travel time in minutes	Emme	Car, CP
WalkingTime	Walking time to a bus stop	Emme	PT

As mentioned the parameters that are used as input in the other trip model is presented in Table 13. The parameters have the same values as in LuTrans.

Table 13: A description of the parameters used for other trips.

Parameters used in Other trips			
	Explanation	**Mode**	**Value**
t_{PT}	Walking time to the bus stop	PT	–0.02751
cc	Car competition	Car	–0.93069
ca_C	Central area	Car	–0.64587
ca_{CP}	Central area	CP	–0.60284
ca_{PT}	Central area	PT	0.25426
ca_W	Central area	Walk	–0.00508
θ_{CP}	Car passenger	CP	3.66988
θ_B	Bike	Bike	3.55941
θ_{PT}	Public transport	PT	3.34393
θ_W	Walk	Walk	4.43088
$d_{<5,B}$	Distance less than 5 km	Bike	–0.27143
$d_{>5,B}$	Distance larger than 5 km	Bike	–0.10524
d_W	Distance walk	Walk	–0.19619
ρ	Size of holiday cottages	All	0.00572
t_C	Travel time in vehicle	Car, CP, PT	–0.01928
dl	Share of driver's license	Car	5.76899
β_1	Log sum, destination choice	All	0.87785
ch	Amount of changes	PT	–0.14235
owt	One way ticket	PT	21.815
cs	Card share	PT	23
hr	No. of employees working with hotel & restaurant	All	5.62989
ps	No. of employees working in the public sector	All	0.72579
ed	No. of employees within education	All	2.05853
hc	No. of employees within health care	All	0.18416
pop_{work}	Half of the working population	All	0.03442
pop_{res}	Half of the residence population	All	0.23878
s	Supermarket	All	0.87771
ϱ_B	Within zone distance	Bike	–0.57283
ϱ_W	Within zone distance	Walk	–0.82606
fwt_{PT}	First waiting time	PT	–0.03223
tg	Trip generation constant	All	–0.8519
β_2	Log sum, trip generation	All	0.4618
γ	Avg. travelers in a car	Car, CP	1.5
c	Cost	Car, CP, PT	-0.02324
$dcal_C$	Calibration, destination choice	Car	-0.3472
$dcal_{CP}$	Calibration, destination choice	CP	-0.1531
$dcal_{PT}$	Calibration, destination choice	PT	-0.5282
$dcal_W$	Calibration, destination choice	Walk	-2.4068
$dcal_B$	Calibration, destination choice	Bike	-0.1820
$mcal_{CP}$	Calibration, mode choice	CP	-1.1514
$mcal_{PT}$	Calibration, mode choice	PT	0.0054
$mcal_W$	Calibration, mode choice	Walk	0.4143
$mcal_B$	Calibration, mode choice	Bike	-0.4995
$tgcal$	Calibration, trip generation choice	All	-0.9701

5.2.4 The stochastic transit assignment

When a full OD-matrix has been generated for public transport by the developed model, the values that can be seen in Table 14 were used for a stochastic transit assignment which was performed in Emme.

Table 14: The transit assignment values used for a stochastic transit assignment.

Headway fraction	0.3
Spread factor	1
Waiting time perception	1.5
Boarding time	5
Boarding time perception	1
Boarding cost	2.5
Boarding cost perception factor	2
In-vehicle time perception factor	1
Auxiliary time perception factor	2

6

Numeric Results

This chapter presents the numeric results obtained from the execution of the developed model which is divided into three sections. The first section presents the calibration data, how the method was performed and the results. The aim of the calibration was to receive an OD-matrix that was applied to the future scenario. The second section presents the future scenario and the third section presents the sensitivity analysis.

6.1 Calibration

Different methods can be used for calibrating models, for instance it is possible to calibrate the developed model and the transit assignment separately or calibrate them together. It is common to adjust parameters in a demand model by increasing or decreasing them a few units in the utility functions. Otherwise, it is possible to add a calibration parameter to each utility function. For the transit assignment model, the assignment parameters, described in Section 3.2 should be calibrated to reflect the passengers' behavior in the current city. Although, calibration parameters have been used in this thesis in order to calibrate the developed model.

Two common data sources used in general are data from traffic counts and from travel surveys to calibrate the model. According to WSP (2013) calibration by using traffic counts ensure that the total number of trips, travel mode distribution and trip length distribution from the model coincide with the observed traffic in the reality. It gives good estimates of the current traffic flows for use in a short and medium term horizon. Calibrating a model by using travel surveys have both advantages and drawbacks.

It is important to make sure that the calibration data is comparable with the subset that the model covers, i.e. same age groups or geographical area. If that is not the case, the data needs to be adjusted to cover the same subset.

6.1.1 Presentation of the travel survey data

In 2011 a travel survey for Örebro municipality was conducted and the data from the survey was used to calibrate the model. The survey covers Örebro municipality, with a population of 107 698, for the ages 16 - 84. The population for these ages in the used data from SCB (2011) is 107 041 and the reason for the difference in the population is because the population data used covers the year 2010. This is realistic since the population in Örebro is increasing, and it is concluded that the survey data can be comparable to the population data. Since the travel survey data included ages between 16 - 84, the data must first be adjusted to cover the same age span as the developed model. Therefore, the percentage of people between 6 - 16 and the half of the percentage of people between $0 - 6$ years retrieved from the population data were added to the travel survey data. The travel survey data covers the whole municipality of Örebro and because some zones were uninteresting for the city buses they were removed. Therefore, the percentage of the people living in those zones were removed from the travel survey data. The travel survey consists of data collected during September and October and is divided between different weekdays. Since the developed model is based on a weekday, it is not a problem to compare the model with the survey data. The total numbers of trips for weekdays, Saturdays and Sundays are shown in Table 15.

Table 15: Adjusted total number of trips per weekday for all ages.

Weekday	295 214
Saturday	257 546
Sunday	221 270

The share between working and other trips in the survey are 35 % for working trips and 65 % for other trips, the share for each travel mode divided into working trips and other trips can be seen in Figure 12.

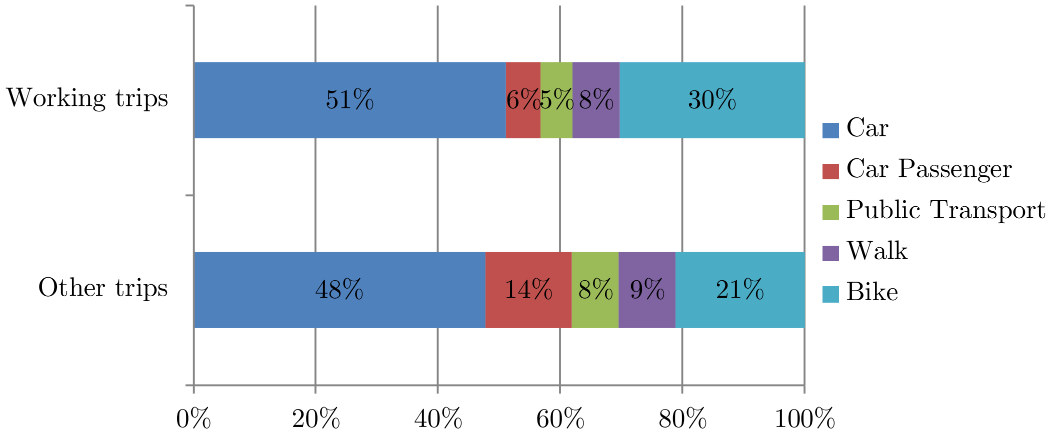

FIGURE 12: The mode choice for working trips and other trips for the survey data.

6.1.2 Presentation of data from Region Örebro County

The data received by Region Örebro County contains the total number of trips for each bus line per month during 2010. The data during September was chosen since September is assumed to be a good representative of an average month during a year. In addition, it is a suitable month since walking or taking the bike is still an attractive mode and vacations rarely occurs. The received data also included information for the school buses which have been excluded since the assumption is made that the majority of children go to school in the same zone they are living in. The total trips per line covers paying passengers in ages between seven and older. Also in this case, the half of the people between zero to six years were added in order to be comparable with the developed model.

The data collected by Region Örebro County covers an entire month and must therefore be adjusted to cover a weekday. This is done by finding the amount of passengers for each weekday based on the distribution over the week obtained from the travel survey. That gives that the total amount of bus trips per weekday for the city buses is estimated to be 21 871. This is obtained by using the Solver provided by Excel where the target value is the weekday value presented in Table 15. The same procedure were performed for each bus line and the complete data is presented in Table 16.

Table 16: The adjusted total number of trips per weekday for all ages.

Line	OD and vice versa	Total trips per line
1	Lundby - Universitetet	2 938
2	Lundby - Brickebacken	3 812
3	Mellringe - Brickebacken	2 729
4	Mellringe - Universitetet	2 002
5	Björkhaga - Hovsta	1 466
6	Björkhaga - USÖ	799
7	Karlslund - USÖ	947
8	Karlslund - Hovsta	1 766
21	Berglunda - Rynninge	247
22	Marieberg - USÖ	992
23	Mosås - USÖ	598
24	Adolfsberg - Lillån	1 405
25	Adolfsberg - Wadköping	1 193
26	Tybble - Hjärsta	978
	Total	**21 871**

6.1.3 Calibration of the developed model

The calibration process of the developed model is conducted in two steps. The first step is to ensure that the trip generation and mode choice correspond to the survey data while the second step adjusts parameters in Emme to change the trip destination distribution.

The number of trips for a weekday presented in Table 15 was used as a reference for the amount of trips the model should produce. This was done by changing the two parameters that affects the generalized cost for trip generation. The share of 35 % for working trips and 65 % for other trips received from the travel survey were used as a guideline during this process. When the outcome for the trip generation step was satisfying with the total amount of trips for a weekday according to Table 15, then the calibration parameters affecting the generalized cost for mode choice were adjusted in order to satisfy the shares in Figure 12. Since the purpose of the developed model is to generate an OD-matrix for public transport, the data from Region Örebro County is more reliable as it is collected directly from the bus system. Therefore, the data from Region Örebro County has higher priority than the public transport share retrieved in the survey in order to make the amount of bus trips generated by the developed model to coincide with the Region Örebro County data.

When the total number of bus trips generated by the developed model match the public transport data sufficiently well, the OD-matrix from the calibrated model was inserted into Emme where a stochastic transit assignment was performed in order to obtain how the passengers distribute over the bus lines. Since both the calibration data and the result from the stochastic transit assignment review each passenger for every bus line, passengers might be counted twice or even tripled if they need to change bus somewhere in the system. But since both data sets reckons every unique sub-trip, comparing them is not a problem.

In order to receive the optimal model parameters, two experiments have been conducted. One of the bus lines, 21, had a quite high error percentage compared to the public transport data. The route is in an industrial area represented by trade in the working sectors and therefore a trade parameter were added to the bus, bike and the walking mode in order to catch the behavior that shopping at trade areas are more likely to be performed by car. The conclusion was that a trade parameter of 0.5 gave the overall best results. The results from the experiment with the trade parameter can be seen in Table 17.

Table 17: The number of boardings and the difference compared to the county data in percent for different trade parameter, TP, values.

Line	**County data**	**TP = 1**		**TP = 0.75**		**TP = 0.5**	
1	2 938	3 174	8%	3 165	8%	3 175	8%
2	3 812	2 976	22%	2 960	22%	2 952	23%
3	2 729	2 023	26%	2 045	25%	2 064	24%
4	2 002	1 930	4%	1 937	3%	1 943	3%
5	1 466	1 299	11%	1 309	11%	1 314	10%
6	799	868	9%	874	9%	879	10%
7	947	860	9%	865	9%	867	8%
8	1 766	1 832	4%	1 840	4%	1 841	4%
21	247	804	226%	777	215%	745	202%
22	992	1 471	48%	1 443	45%	1 415	43%
23	598	784	31%	778	30%	775	30%
24	1 405	1 954	39%	1 961	40%	1 968	40%
25	1 193	1 087	9%	1 096	8%	1 104	7%
26	978	818	16%	824	16%	828	15%
Total	**21 871**	**21 880**		**21 874**		**21 870**	

A regression analysis was made for the three different parameter values that can be seen in Figure 13 - 15. The regression analysis was performed in order to receive the least square error. If the result for each bus line was equal to the calibration data from Region Örebro County the value of R^2 would be equal to 1, represented by the blue line seen in Figures 13 - 16. The relationship between the calibrated values and the actual values are represented by the black trendline seen in Figures 13 - 16.

Figure 13 shows the result for each bus line without any changes, i.e. a scale factor of 1 for the trade parameter and a spread factor of 1 was used which gives a least square error of 0.2388. This gives that the developed model can estimate trips on a bus line level with an accuracy of 76.12 %.

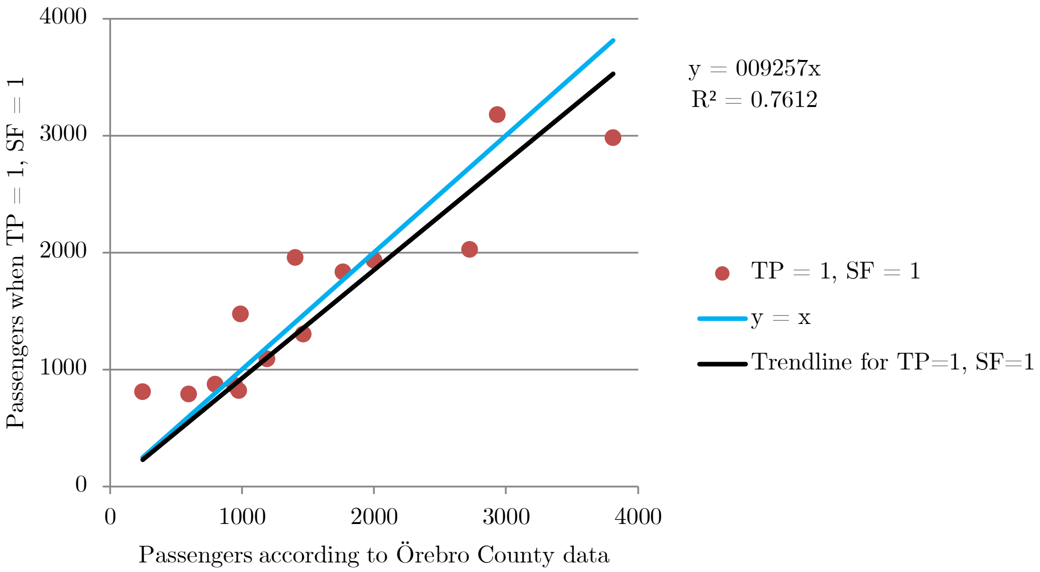

FIGURE 13: An regression analysis with a trade parameter of 1 and a spread factor of 1.

The first attempted value of the trade parameter was 0.75 and the result can be seen in Figure 14. The trade parameter of 0.75 gives a least square error of 0.2318, i.e. the developed model can estimate bus trips on a bus line level with an accuracy of 76.82 %. For this case, it is negligible compared to the square error received when using a trade parameter with the value of 1 presented in Figure 13.

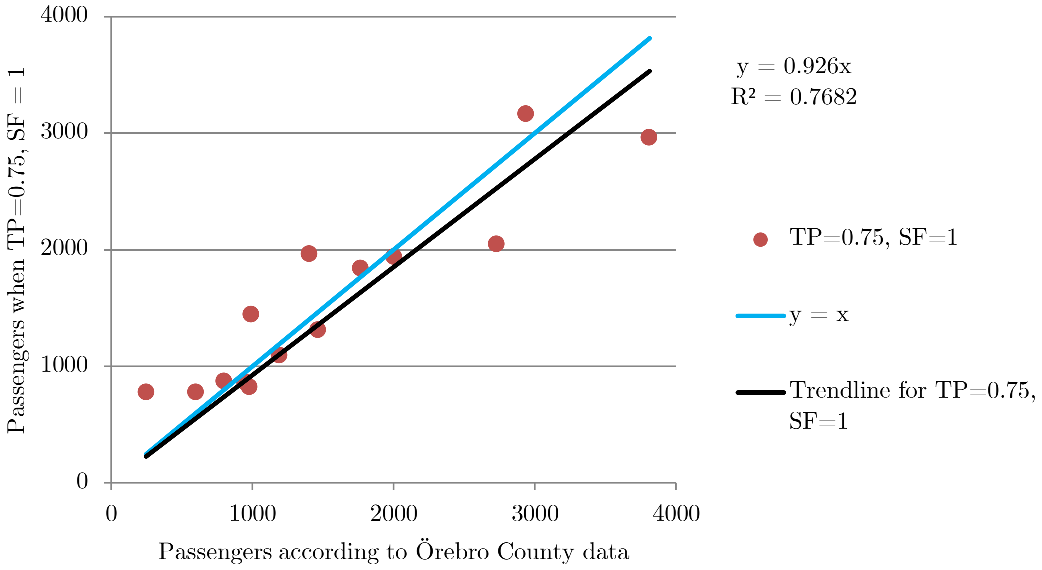

FIGURE 14: An regression analysis with a trade parameter of 0.75 and a spread factor of 1.

The result from Figure 14 made it interesting to change the value further. Figure 15 shows the result when the trade parameter is changed to 0.5 which gives a least square error of 0.2232. This gives that the developed model can estimate trips on a bus line level with an accuracy of 77.68 %, this is a better result than the ones given in Figure 13 and 14.

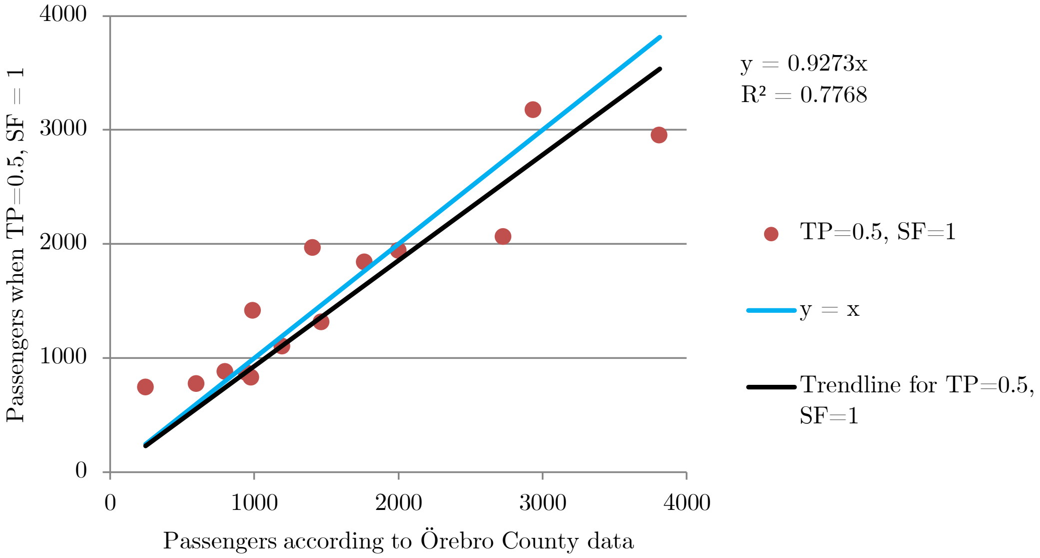

FIGURE 15: An regression analysis with a trade parameter of 0.5 and a spread factor of 1.

As mentioned, it was concluded that a trade parameter of 0.5 gave the best result according to the least square error. In addition, further decrease of the trade parameter is considered not to be realistic since it would practically eliminate the trade category from the public transport, walk and bike modes for other trips. Therefore the trade parameter of 0.5 was used in the second experiment where the spread factor for the waiting time was changed. When changing the spread factor, changes have been made in the network and therefore the new initial matrices have to be updated to correspond with the change which means that the calibration has to be performed iteratively, according to:

1. Perform a standard transit assignment with the chosen spread factor and a demand matrix containing a low demand in order to receive: in-vehicle time, auxiliary time, waiting time etc.
2. Insert the initial matrices into the demand model and execute it to receive an OD-matrix.
3. Insert the OD-matrix into Emme and perform a stochastic transit assignment.

This was done in order to obtain how the passengers will distribute over different lines when the passengers are inclined to consider several attractive lines at the bus stops. The process of testing several spread factors is very time consuming and therefore only one spread factor, 1.5, was selected and the result can be seen in Table 18.

TABLE 18: The number of boardings and the difference compared to the county data in percent for different spread factor, SF, values.

Line	**County data**	**SF=1**		**SF=1.5**	
1	2 938	3 175	8%	3 377	13%
2	3 812	2 952	23%	3 209	16%
3	2 729	2 064	24%	2 241	18%
4	2 002	1 943	3%	1 639	18%
5	1 466	1 314	10%	1 308	11%
6	799	879	10%	861	8%
7	947	867	8%	895	5%
8	1 766	1 841	4%	1 983	12%
21	247	745	202%	523	112%
22	992	1 415	43%	1 498	51%
23	598	775	30%	832	39%
24	1 405	1 968	40%	1 816	29%
25	1 193	1 104	7%	1 019	15%
26	978	828	15%	739	25%
Total	**21 871**	**21 870**		**21 867**	

Aside from the default value of 1, another spread factor was investigated. As mentioned in Section 3.2, a spread factor adjusts the waiting time in order to give the passengers fewer or more alternatives at a bus stop. The result of the regression analysis when the trade parameter was 0.5 and the spread factor was changed to 1.5 can be seen in Figure 16. This gave a lower least square error of 0.1474. This gives that the developed model can estimate trips on a bus line level with an accuracy of 85.26 %. Therefore, it can be concluded that changing the spread factor affected the least mean square error significantly compared to changing the trade parameter.

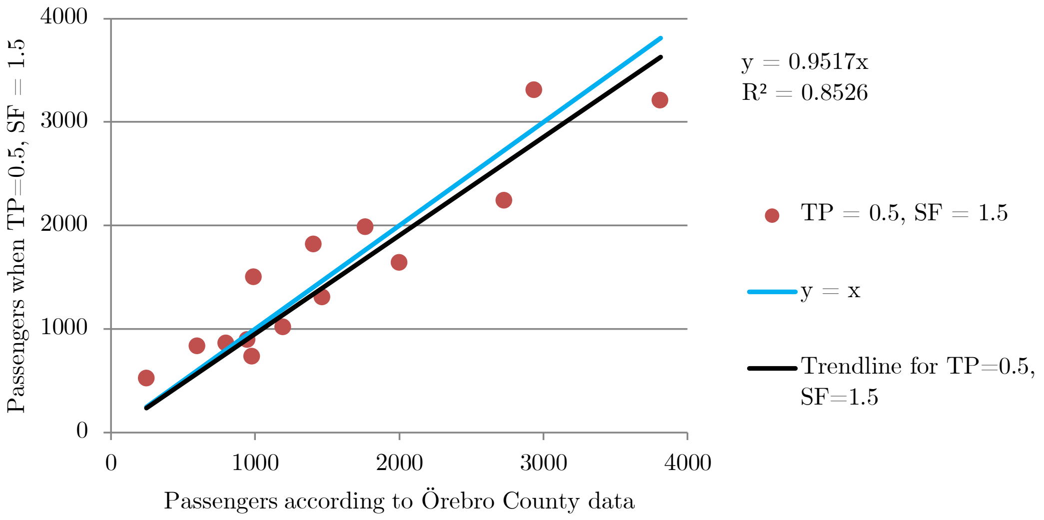

Figure 16: An regression analysis showing regression with a trade parameter of 0.5 and a spread factor of 1.5.

By comparing Figure 15 and 16 it can be seen that a spread factor of 1.5 gave the best result. Therefore a spread factor value of 1.5 has been chosen as the final parameter value regarding the spread factor. As the least square error limits to zero, the black trendline tend to tangent the blue line. According to Nilsson (2015), based on working experiences within this area and other analyses on a strategical level, it desirable to maintain a square error of 50 % or less on a bus line level.

The final values for the calibration parameters can be seen in Table 19. A calibration parameter for the mode choice of car in working and other trips was added to the model since it was the only mode that did not contain a calibration parameter initially. Also, not including one for the car mode as a driver made it difficult to calibrate the developed model so it would correspond to the share together with the remaining modes according to Figure 12.

Table 19: The final values of the calibration parameters used for working and other trips.

	Working trips	
$mcal_C$	Mode choice for car driver	0.385
$mcal_{CP}$	Mode choice for car passenger	-2.8
$mcal_{PT}$	Mode choice for public transport	-2.032
$mcal_W$	Mode choice for walk	-1.1
$mcal_B$	Mode choice for bike	-0.03
$tgcal$	Trip generation	-0.67
	Other trips	
$mcal_C$	Mode choice for car driver	0.73
$mcal_{CP}$	Mode choice for car passenger	-0.63
$mcal_{PT}$	Mode choice public transport	-0.4025
$mcal_W$	Mode choice for walk	-0.4
$mcal_B$	Mode choice for bike	-0.45
$tgcal$	Trip generation	-5.096

A visualization of the final route choices when a transit assignment with a trade parameter of 0.5 and a spread factor of 1.5 was performed can be seen in Figure 17.

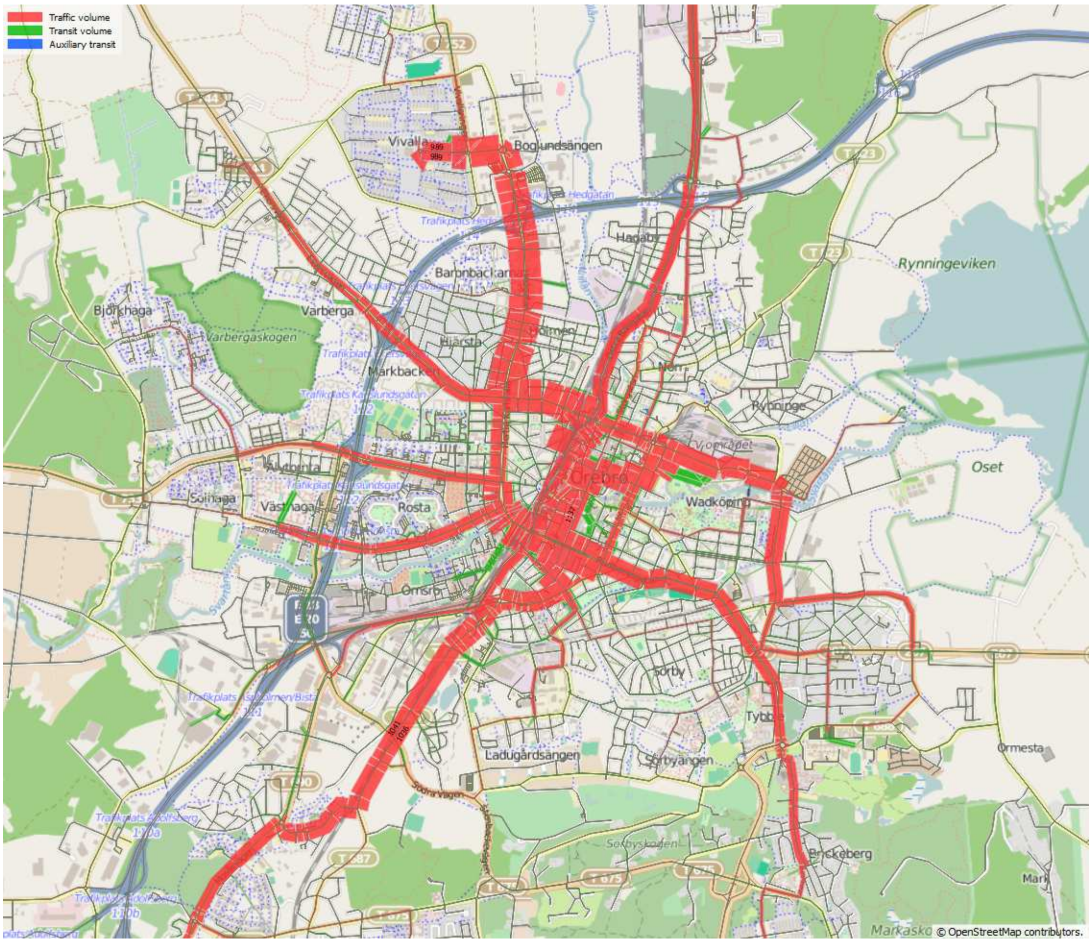

FIGURE 17: The public transit assignment for the calibrated developed model.

6.2 Forecast of Örebro in 2025

When estimating future trips, it is important to investigate how different districts in a city will evolve since the districts in a city may evolve in different rates. Therefore it is of great importance when conducting a thorough forecast that the change in population for each zone over different years is investigated. Other aspects that are important to consider is political changes such as changes in the infrastructure and taxes but also international changes, for instance the current price for the crude oil. Although, since the focus of this thesis is to develop a demand model and not to estimate an accurate forecast for a specific city, some of these factors mentioned above have not been taken into consideration. Therefore, the fuel and fare prices are assumed to be real unchanged and the population growth for all zones is assumed to be constant over time.

For the infrastructure changes, Region Örebro County has planned to forbid car traffic on a couple of streets in the city core but apart from that no major infrastructure changes seems to be planned. Since it is not decided yet which streets that will be affected, the road network used in the scenario for 2025 is the same as the one used for 2010. Region Örebro County has also made investigations on whether it is of interest to introduce bus rapid transit lines to the city. This is something that is still undecided and is therefore not considered in this scenario. Therefore the current bus line network in use, which was introduced in 2012, was used. The bus transit system can be seen in Figure 18 and the full list of the headways for the bus transit lines can be seen in Table 20. The headways have been calculated by looking at the departure schedule and dividing with the number of departures per day with the time interval of 1 050 minutes which is the total number of minutes from 5:30 AM to 11:00 PM.

FIGURE 18: The transit lines in 2025 within the city.

Table 20: The headway in minutes for each bus line in the future scenario of Örebro 2025.

Line	**Origin – Destination**	**Headway**
1a	Lundby - Mosås	22.83
1b	Mosås - Lundby	22.83
2a	Lundby - Brickebacken	22.83
2b	Brickebacken - Lundby	22.83
3a	Mellringe - Brickebacken	22.83
3b	Brickebacken - Mellringe	22.83
4a	Mellringe - Adolfsberg	22.83
4b	Adolfsberg - Mellringe	22.83
5a	Hovsta - Adolfsberg	21.88
5b	Adolfsberg - Hovsta	22.34
6a	Hjärtsta - Tybble	25
6b	Tybble - Hjärtsta	25.61
7a	Lillån - Björkhaga	23.33
7b	Björkhaga - Lillån	23.33
8a	Björkhaga - Bettorp	23.33
8b	Bettorp - Björkhaga	22.83
9a	Björkhaga - Universitet	22.83
9b	Universitet - Björkhaga	22.34
10a	Lundby - Universitet	22.34
10b	Universitet - Lundby	22.34
20a	Resecentrum - Universitet	65.63
20b	Universitet - Resecentrum	65.63
21a	USÖ - Berglunda	210
21b	Berglunda - USÖ	131.25
22a	Törsjö - Naturens hus	35
22b	Naturens hus - Törsjö	58.33
28a	Rynninge - Slottet	262.5
28b	Slottet - Rynninge	262.5

As seen in Table 20, the bus lines 21 and 28 have large headways and are therefore chosen to be excluded from the future scenario since the model will not provide a plausible result for those lines.

The forecasts made by Örebro municipality (2014) for 2024 gives a population of 162 635 people which correspond to a compound average annual growth, CAAG, of 1.322 % between 2014-2024. Between the years 2010 and 2014 the actual population increased by 1.296 % for each year. Therefore, the forecast made by the municipality is considered to be realistic which gives Örebro to have a population of 164 785 in 2025. Population data for 2025 was available but it had to be adjusted using the Fratar method to correspond better with the forecasts made by Örebro municipality (2014). Also the population data for 2025 only predicted an increase in the population of 0.629 % compared to the actual population in 2010 which was considered to be too low. An adjustment factor was calculated and applied to the population data. By using Equation (13) the growth factor, τ_{24}, for 2025 is estimated to 1.3042 and is used in the developed model for this scenario.

The result obtained from Emme for the future scenario was that the number of trips made by public transport will increase from 21 871 trips to 25 170, which gives a yearly percentage increase, CAAG, of 0.94%. This can be compared to the percentages for the years 1998-2014 and 2010-2014 which were 1.26% and 1.31% and were calculated using the received data from Region Örebro County. An article by Nilsson et al. (2013) presents a forecast conducted from Trafikverket for calculating the evaluation of passenger transport from 2010 to 2030 in Sweden. The article compares the amount of traveled person kilometers and concludes that trips will increase by 1.4 % per year regionally regardless of the transportation mode and by 0.2 % yearly for bus. The passenger distribution for the bus transit lines for the scenario of 2025 can be seen in Table 21

TABLE 21: Boardings per line in 2025.

Line	**OD and vice versa**	**Boardings**
1	Lundby - Mosås	3 412
2	Lundby - Brickebacken	3 071
3	Mellringe - Brickebacken	2 309
4	Mellringe - Adolfsberg	2 840
5	Hovsta - Adolfsberg	2 617
6	Hjärtsta - Tybble	865
7	Lillån - Björkhaga	1 959
8	Björkhaga - Bettorp	1 698
9	Björkhaga - Universitet	2 855
10	Lundby - Universitet	2 511
20	Resecentrum - Universitet	376
22	Törsjö - Naturens hus	657

A visualization of the transit assignment can be seen in Figure 19.

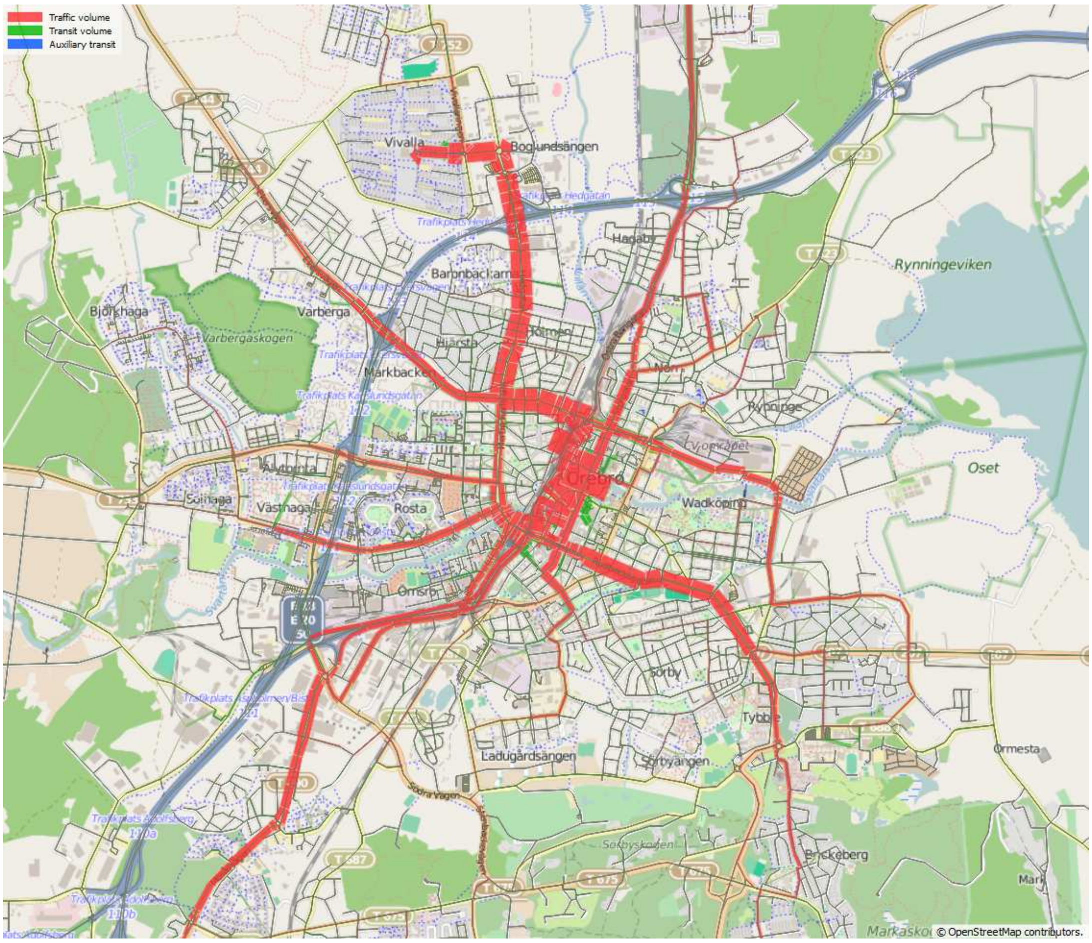

FIGURE 19: The public transit assignment for the future scenario of 2025.

The result produced by the developed model shows a realistic increase of passengers traveling by bus in 2025. The increase is lower than the previous years which could depend on the fact that two lines were excluded. Although, the developed model would not have performed a higher increase since the model is not suitable for large headways. If it is important that such lines are included in the forecast they could be included afterwards for instance by making general assumptions or research on those lines.

Table 22 shows a comparison of the most interesting factors for the base and future scenario.

Table 22: Comparison of different factors for the years 2010 and 2025.

	2010	**2025**	**Difference**	**CAAG**
Input				
Population	125 980	152 425	20.99 %	1.28 %
Fuel price (SEK)	9.75	9.75	0.00 %	0.00 %
Public transport fare, monthly (SEK)	387.21	387.21	0.00 %	0.00 %
Public transport fare, one way (SEK)	19.2	19.2	0.00 %	0.00 %
Output				
Total trips	293 270	328 430	11.99 %	0.76 %
Vehicle kilometers	1 612 644	1 844 786	14.40 %	0.90 %
Trips made by car	177 310	199 950	12.77 %	0.80 %
Number of boardings	21 871	25 170	15.08 %	0.94 %
Trips made by public transport	20 670	24 141	16.79 %	1.04 %
Trips made by bike	71 136	77 897	9.50 %	0.61 %
Trips made by walking	24 159	26 447	9.47 %	0.61 %

As Table 22 shows, most factors are different for the future scenario compared to the base scenario. Factors that do not change are the fuel price, the monthly and one way public transport fares. This is due to the fact that the developed model, like LuTrans, uses the same costs for traveling by car or public transport for both scenarios, instead different growth factors are used.

In order validate the developed model, data from a LuTrans model for Örebro is presented in Table 23. The actual output from LuTrans considered the years 2020 and 2030. Therefore, the average values between 2020 and 2030 were calculated to represent 2025.

Table 23: The output from a LuTrans model for Örebro 2010 and 2025.

	2010	**2025**	**Difference**	**CAAG**
Car driver	71 212	84 371	18.48 %	1.14 %
Car passenger	23 425	26 736	14.13 %	0.89 %
Public transport	12 823	15 196	18.51 %	1.14 %
Walk	44 903	55 759	24.18 %	1.45 %
Bike	30 043	38 004	26.50 %	1.58 %
Total	182 406	220 065	20.65 %	1.26 %

When comparing Table 22 and Table 23 it can be seen that the the number of trips for each mode differs greatly. This is because the developed model and the LuTrans model are calibrated against different data sets which make it difficult to compare them. As seen in Table 22 and Table 23 the CAAG for the total trips are higher for the LuTrans model than the developed model. Although, the purpose of the developed model is to predict the number of trips made by public transport and by comparing the result from the LuTrans model in Table 23 with the result from the developed model in Table 22 it can be seen that the CAAG for both models are quite similar and both values are close to one percent. This gives the conclusion that the developed model can perform forecasts on a similar level as LuTrans.

6.3 Sensitivity analysis

A sensitivity analysis describe how the travel behavior is changed when changes are made to different variables that affect the traveling. Such variables can be the price, the waiting time and the bus headway. An article by Holmgren (2007) presents a summary of different elasticity for public transport where Holmgren (2007) states that many studies have a large variation for elasticity which makes it difficult to conclude if the correct relationship between the travel demand and other variables has been found. A common used measure is the price elasticity which describes how sensitive the passengers are to changes in the price. Holmgren (2007) mentions that the value of -0.3 is often used as a rule of thumb. Studies regarding other variables for instance the waiting time have not been conducted in that wide of spread.

From an operator's point of view, it is interesting to investigate which factors that will increase the public transport trips in the future. Therefore, a sensitivity analysis was performed to analyze factors that can be controlled by the operators, for instance the headway or the fare, as well as to observe how the model reacts to changes. According to Stadsbyggnadskontoret (2014), Örebro municipality has a goal that the trips made by public transportation, walking or by bike shall increase and therefore another sensitivity analysis was performed with factors that the municipality is able to change. To compare if the results are plausible, elasticity constants for the given change have been calculated.

First, an analysis was performed where it was investigated how the trips made by public transportation are affected by changes in the population. The result given by the model is presented in Table 23.

Table 24: The sensitivity analysis for changes in the population. The changes in percent are calculated compared to no changes in the population.

	Boardings	**Percentage**	**Elasticity**
Increase of population with 15 %	29 458	17.0%	1.135
Increase of population with 10 %	28 021	11.3 %	1.132
Increase of population with 5 %	26 592	5.6%	1.129
Decrease of population with 5 %	23 754	-5.6%	-1.126
Decrease of population with 10 %	22 352	-11.2%	-1.120
Decrease of population with 15 %	20 952	-16.8%	-1.117

The result presented in Table 23 shows that the elasticity have an average value of 1.1, which is larger than 1 and means that the public transport trips increase more than the actual population increases.

Secondly, it was investigated how changes in the public transportation fare would affect the number of public transport passengers, the result given by the model is presented in Table 25.

Table 25: The sensitivity analysis for changes in the public transport fare. The changes in percent are calculated compared to no changes in the fare.

	Boardings	**Percentage**	**Elasticity**
Increase in public transport fare with 5 %	24 716	-1.8%	-0.362
Increase in public transport fare with 10 %	24 271	-3.6%	-0.358
Increase in public transport fare with 15 %	23 830	-5.3%	-0.355

Holmgren (2007) found a large number of studies regarding the price elasticity and the variation ranges from -0.009 to -1.32 with a mean value of -0.38. The elasticity presented in Table 25 shows that the elasticity varies around -0.36, which lies close to the mean value observed by Holmgren (2007) and quite close to the rule of thumb. This strengthens the assumption that the price elasticity given in Table 25 is reasonable.

Thirdly, it was investigated how changes in the headways would affect the number of public transport passengers. Also, as mentioned in Section 6.1.3, if changes have been made in the network the new initial matrices have to be updated to correspond with change according to:

1. Perform a standard transit assignment with the changed headways and an demand matrix containing a low demand in order to receive: in-vehicle time, auxiliary time, waiting time etc.
2. Insert the initial matrices into the demand model and execute it to receive an OD-matrix.
3. Insert the OD-matrix into Emme and perform a stochastic transit assignment.

The result given by the developed model is presented in Table 26.

Table 26: The sensitivity analysis for changes in the headways. The changes in percent are calculated compared to no changes in the headways.

	Boardings	**Percentage**	**Elasticity**
Decrease of headway with 50%	30 451	21.0%	0.420
Decrease of headway with 20%	26 862	6.7%	0.336
Decrease of headway with 10%	26 006	3.3%	0.332

The result presented in Table 26 shows that the elasticity lies within the interval of 0.3 - 0.4 which can be compared with the elasticity for changes in the transport fare presented in Table 25.

Since Region Örebro County is considering instating bus rapid transit it is of interest to investigate how changes in the bus speed would affect the number of public transport passengers. This is due to the fact that bus rapid transit may drive on special lanes which could give the buses a higher average speed. When changing the bus speeds the initial matrices needs to be updated according to the same method mentioned earlier. The results can be seen in Table 27.

Table 27: The sensitivity analysis for changes in the bus speed. The changes in percent are calculated compared to no changes in the bus speed.

	Boardings	**Percentage**	**Elasticity**
Increase of bus speed with 30%	27 974	11.1%	0.371
Increase of bus speed with 20%	27 104	7.7%	0.384
Increase of bus speed with 10%	26 174	4.0%	0.398

The elasticity presented in Table 27 can be compared to the elasticity presented in Table 25 and Table 26 since it lies within the same interval.

A factor that the operators' cannot control is the fuel prices which is considered to have a great influence for the mode choice. The developed model uses a common distance based cost where costs such as fuel price, taxes and wear are included. To obtain how many percent that is composed by the fuel price, the fuel price per ten kilometer was compared to the common cost. With an average petroleum driven car that consumes 0.83 liters per ten kilometers according to Energimyndigheten (2013) and with a fuel price of 13.74 SEK per liter according to St1 (2015), the share of the fuel price corresponds to 75 % of the common cost. The result for when the share of the fuel price was increased by 10, 20 and 50 % can be seen in Table 28.

Table 28: The sensitivity analysis for changes in the fuel price. The changes in percent are calculated compared to the original common cost.

	Boardings	**Percentage**	**Elasticity**
Increase of fuel price with 50%	25 419	1.0 %	0.020
Increase of fuel price with 20%	25 266	0.4 %	0.019
Increase of fuel price with 10%	25 219	0.2 %	0.019

The elasticity presented in Table 28 is extremely low which means that changes in the fuel price would generally not affect the behavior of people using the car mode.

The studies found by Holmgren (2007) showed that the elasticity with respect to the fuel price ranges between 0 to 1.04 with a mean of 0.38. Since the elasticity for the fuel price have a wide range the result in Table 28 clearly showed that the trips made by public transport was not significantly affected by changes in the fuel price. Therefore, it was also investigated how the change in fuel prices affects the other modes and the result can be seen in Table 29.

TABLE 29: The sensitivity analysis for elasticity for changes in fuel price.

	Car	**Car Passenger**	**Public Transport**	**Walk**	**Bike**
Increase of fuel price with 50%	-0.030	-0.027	0.018	0.020	0.020
Increase of fuel price with 20%	-0.029	-0.026	0.018	0.019	0.020
Increase of fuel price with 10%	-0.029	-0.026	0.018	0.020	0.020

Even for this case, the elasticity was extremely low for all modes and two conclusions can be drawn from this. Either it is a correct result and the peoples' behavior is not affected by changes in the fuel price or the parameter for the common cost must be adjusted.

Also, since Örebro municipality has a goal of increasing the number of travelers using public transportation, walking or using a bike it is interesting to study the outcome for the modes if car traffic is prohibited in the city core. The area in which car traffic is prohibited can be seen in Figure 20.

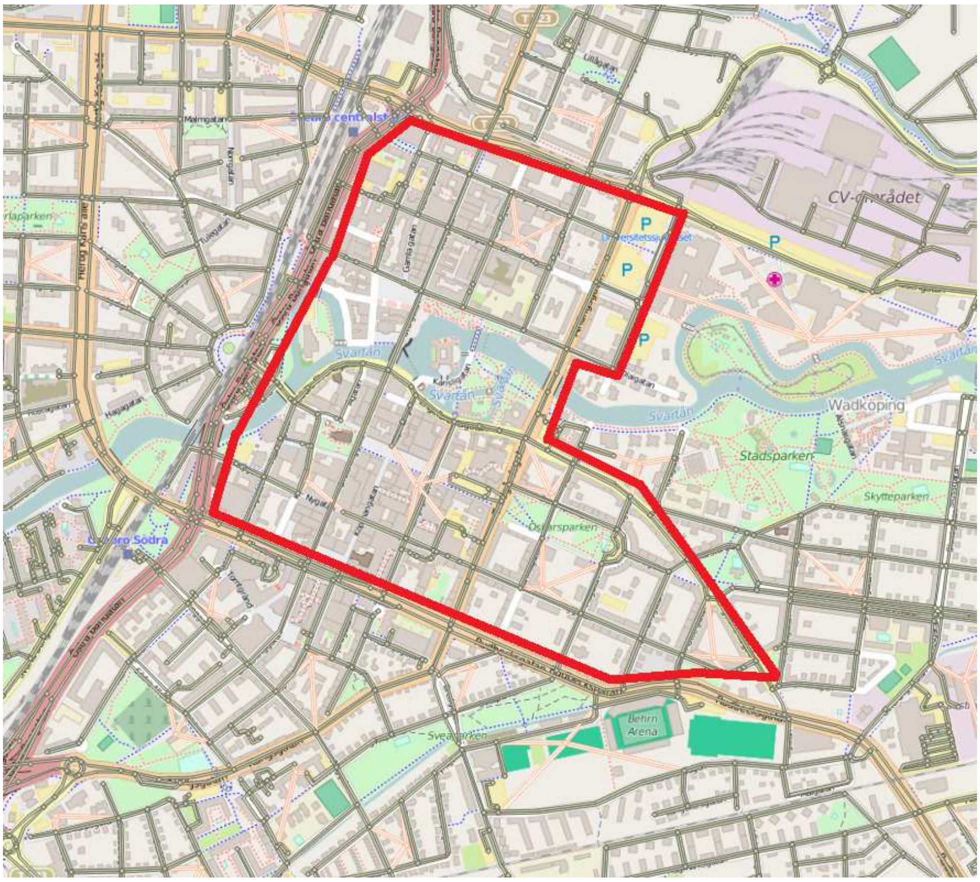

FIGURE 20: The area within the red lines shows the part of the city core where car traffic is prohibited.

For this analyis, a new traffic and transit assignment were performed to receive the new matrices and the result received directly from the model without any implementation in Emme can be seen in Table 30.

Table 30: The sensitivity analysis when car traffic is prohibited in the city core. The change in percent is compared to no prohibition of the car traffic in the city core for the scenario of Örebro 2025.

Mode	**Difference**	**Change**
Car	-31 780	-18.8%
Car Passenger	-7 216	-23.1%
Public Transport	1 343	5.7%
Walk	2 127	8.0%
Bike	6 522	8.4%

The OD-matrix received from the developed model was also inserted into Emme and gave the result that the trips made by public transport will increase by 5.7 %. As can be seen in Table 30, many travelers decide to abstain from traveling. This could be due to the fact that the area, seen in Figure 20, where car traffic is prohibited is quite large.

It was also investigated how the new bus transit lines for 2025 and headways differ from the bus transit lines in use 2010. This was done by applying same OD-matrix, public transport trips in Örebro 2025, for all zones to the scenario for 2010 and for 2025. This gave that the result for Örebro 2010 was 25 610 trips and for Örebro 2025 it was 25 170 trips. This means that the bus line network with the headways in use for 2025 gave a passenger rate of -1.72 % for this matrix i.e. a lower amount of total trips, than the bus lines and headways in use during 2010. This may be reasonable since the total amount of bus departures for Örebro 2025 is perceived to be lower than the total amount of bus departures for Örebro 2010.

7

Analysis and Discussion

According to the results received from the future scenario, the trips made by public transport will increase in average by 0.94 % for each year, which is a realistic increase of passengers for 2025. This result is lower than the actual outcome for the years between 1998 and 2014. But at the same time, two bus lines were not considered which may have contributed to a higher increase and these numbers can vary much from year to year depending on different things such as socio-economic and infrastructure factors. Therefore, the actual changes for previous years may not be considered as good estimates for the future. This is due to fact that the fuel prices, the public transport fare, the total length of the bus lines and the bus frequencies might have gone through major changes during the past years compared to the forecast year. Changes in costs, such as fuel and public transport fare are not considered in the developed model.

The forecast described by Nilsson et al. (2013) is developed by Trafikverket and showed that the yearly increase for the years 2010 to 2030 in public transport is 0.2 %. This shows a lower yearly increase than the result produced by the developed model but it is difficult to relate to this result without any knowledge for how the forecast was produced and which assumptions that were made. 0.2 % is a general change for regional trips in Sweden and the change may be small or even negative for smaller regions with a negative growth in population. A result from this may be that the average value is forced down. For Örebro, which has an increase in population one might think that the yearly increase of passenger trips would be higher than 0.2 %. Since the result produced by the developed model, 0.94 %, lies within the interval of 0.2 % to 1.3 %, the result is considered to be a good estimate.

Another factor that the model cannot capture in a satisfactory way is if there are large variations in the headways and if some of the bus transit lines in the network have an apparent lower headway than the other lines. Since Örebro 2010 did not have large variations in headways, it can be difficult to prove that the model has problem performing a good forecast for such bus lines. For instance, in the scenario for 2025 there were two excluded bus lines, 28 and 21, with a low amount of departures per day. This gives a very unattractive headway for those lines compared to the others and would therefore affect the result for the number of passengers on those lines, since it may not reflect the true number of passengers. It is most likely a bus line that the passengers choose to travel by in the morning to spend the day in the city core before they have to take the bus back home later during the day. If there is a city containing multiple bus lines like, 21 and 28, it could be interesting to investigate a method for how the model could be adapted to take large headways into consideration. A suggestion is to use a node specific waiting time for bus lines that have large variations in the headways.

Another model limitation is that the model is not able to consider non-employees such as children going to school and retired people. Instead, an assumption was made that younger children go to school in the same zone they live in. This was assumed since the location of the schools are easy to find but it can be more difficult to obtain how many children there are in each school online and may require some more research such as contacting the municipality. Also, the population data does not contain information about where the children go to school. Therefore, it can be concluded that the developed model have a number of limitations compared to for instance, Sampers and LuTrans which both consider a larger amount of factors such as toll, parking fees, congestion, income etc.

The developed model was applied to the urban area of Örebro and therefore only trips within the city were considered. Although, in reality travelers may start their trip in a nearby city or area and travel to, for instance Örebro. Therefore, the developed model could be improved by representing such trips in form of large hubs if such trips are considered to be of interest. Since Örebro is the largest nearby city in the county it is a city that most likely have commuters coming from the nearby cities or areas.

It was difficult to find information regarding the pedestrian free flow speed but the speed of 5 km/h, as noted by Vägverket (2002), was selected since it was considered to be the most realistic value for a Swedish city. Although, it could be interesting to make a field study to observe the free flow speed in smaller cities to obtain a suitable auxiliary speed. Another factor regarding the speed is that it would have been interesting to apply a different speed for the city buses depending on where in the network they are located. As of now, the buses have the same speed for the entire network which does not reflect the reality well since buses travel by a higher speed outside the city core and they travel by a lower speed inside the city core, see Figure 9. This makes it less attractive in the developed model to travel outside the city core by bus. This could be enhanced by assigning a travel time function for every transit segment which can be connected to the car flows which would result in a more realistic model.

An additional factor, affecting the result is the transit assignment performed in Emme. Since the focus of this thesis lies within the first three steps of the four step model and not the final step, route choice, no further consideration of the selected transit assignment was made. A stochastic transit assignment was selected since it was assumed that it would represent the reality better since it is more complex and consider additional strategies apart from only minimizing the expected travel time. A deeper analysis of the selected transit assignment might have been appropriate since it is possible that the model could be improved by using a different transit assignment.

The current time period modeled was 24 hours since the received calibration data consisted of this time period. It is possible to split the time period into high, medium and low demand traffic during the day by assuming different percentages of the total traffic volume during these time periods. This is of interest to investigate from an operator's point of view since they want to estimate how many buses they should invest in, in order to operate the system. Although in order to model different time periods it is desirable that data for certain time periods are available. Otherwise, the user is forced to make several assumptions which might provide an incorrect image of reality. Another factor that should have been taken into consideration is the variations of passengers for different seasons. For instance winter, summer and spring/fall could have been modeled as different scenarios where the utility functions take the different seasons into consideration.

The reliability of a forecast depends on how the changes have been made. It is difficult to evaluate how reliable a forecast is since the future has not occurred yet. It is more common that the growth occurs in different parts of a city or municipality over different time periods and is not constant as assumed in the scenario of Örebro 2025. Therefore, when estimating a thorough forecast, different growth factors should be applied to different zones or areas in the city for different periods of time. In order to acquire the most suitable growth factors for each zone, a number of data sources should be compared. The municipality often provides forecasts regarding their urban planning, although since the forecasts made by the municipality tend to be optimistic, the forecasts made by the municipality should be compared to forecasts regarding the same area from different data sources. It is important to compare the forecast data with historical data in order to receive an apprehension if the forecast made by the municipality is reasonable. The focus in this thesis has not been to obtain a thorough forecast for Örebro but to develop a forecast model. If the developed model was to be used in practice, more focus should lie on this process.

By comparing the developed model with LuTrans, it was showed that the number of trips for each mode differs greatly. This is because the developed model and the LuTrans model are calibrated against different data sets which make it difficult to compare them. Although, it is possible to compare the changes for the different years. Since the purpose of the developed model is to predict public transport trips, it can be seen that the CAAG for both models are quite similar and both values are close to one percent, which shows that the developed model can perform forecasts on a similar level as LuTrans.

By looking at the sensitivity analysis, it can be seen clearly that an increase in the population have the highest impact for traveling by public transport. Since this is something that the operators cannot control, factors that are controllable by the operators were investigated. It is very difficult to assume how much it will cost the operators to instate the investigated changes since some changes may cost more to instate than others. Reducing the fare might be a backlash for the operators if the amount of passengers falls below the amount the fare is decreased by. But at the same time, it should be noted that operators might receive subventions from the government and therefore a decrease of the fare might not lead to any major losses in the revenue. Changing the bus headways by 50 %, i.e. doubling the frequency would give an increase in passengers by 21.0 %. Doubling the frequency will probably result in doubling the costs which is probably more expensive that it is worth. Although, it is up to the operators to do a further research of the costs involved and thereafter judge if it is worth to instate. Increasing the speed within the city core is assumed to be the most difficult and expensive change to instate. This is due to the fact that the operators have no control regarding changes in the infrastructure such as instating bus priorities on lanes and changing the speed limit. It might be reasonable to increase the speed by 20 % but since it only gives a change of 7.7 % the investments might not pay off. It was proven that a change in the fuel price would barley affect the trips made by public transport.

Since the sensitivity analysis showed that the bus lines used in 2010 produced a better result than the new bus lines it may be difficult to fulfill the goal set by the municipality to increase the public transport. In this case, it might be realistic to implement a network with higher bus frequencies for the future scenario than the one in use during 2025 and 2010. Another improvement of the developed model could be to contact the responsible regarding the public transport system and ask if they are planning to redo the bus lines or increase the bus frequency, hence decreasing the headways.

A wider field study could have been performed in order to find more appropriate assignment parameters. Also, a deeper analysis of the headway fraction including more observations, for different days and bus stops would have been desirable.

Regardless of the inadequacies, the developed model possesses many advantages since it is fast to set up and run while presenting satisfactory results. The total set up and running time is estimated to be around five hours or longer which is an apparent improvement compared to the models available as of today. As mentioned in Section 4.2, LuTrans requires a set up time of around 100 hours or more and can therefore be expensive to conduct for an operator. This shows that the developed model can save a great amount of working time and costs which is suitable if there is a limited budget for placing a tender for a smaller city. Another advantage is that the road network can be imported directly into Emme from OpenStreetMap (2015) which saves a great deal of set up time. Additionally, it is simple to perform different types of sensitivity analyses on the developed model in order to receive information for how the trips will change depending on changes in different factors.

8

Conclusion and Further Work

8.1 Conclusion

This thesis has showed that it is possible to simplify an existing intricate model and receive a plausible result. The developed model was simplified by removing less necessary parameters for smaller cities, e.g. parking fees and tolls, and only keep the essential data. It is concluded that the essential data needed to build a simple model that produces a plausible result requires travel time, distances and socio-economic data. The travel time data can consist of in-vehicle time, auxiliary time and waiting time. The distance data consist of the distance between zones depending on the travel mode. The socio-economic data can for instance be population, driver's licenses, car availability, car competition, and zoning. The zoning decides how deeply and detailed the OD-matrix is which also determines the accuracy for the result. For instance, if the zoning is too large, it might be difficult to determine how the travelers distribute on the routes.

The value that should be used for the parameters in the transit assignment is concluded to be specific for each city or region and to receive the most accurate value it might be of interest to conduct measurements for the city being investigated.

The final conclusion is that the developed model is quite easy to adapt to different cities in order to predict a forecast for public transport trips. The developed model estimated the trips for each individual bus line for the base scenario of Örebro 2010 with an accuracy of 85 %.

8.2 Further Work

The developed model can be changed in two directions depending on how accurate the model should be. It can either be simplified or more detailed. For instance, one simplification could be to make the developed model a solid three step model. That is, removing the transit assignment and use the Euclidean distance between each zone pair to calculate the distance and use a common speed which is multiplied with the distance matrix in order to get the travel time matrix.

The aim of the developed model was that it should be a simple model requesting the minimum amount of input data. Therefore, it would be interesting to perform a deeper sensitivity analysis in order to investigate how the passengers would change when excluding some of the initial matrices such as the number of changes, auxiliary time etc. This would give a result of which matrices have the largest impact for traveling by public transport.

In order to make the performance of the model more accurate it is possible to focus more on the public transit assignment and the related parameters. To make the model easier to handle, it is possible to integrate the developed model and the transit assignment by translating the MATLAB code into Python scripts which can be used directly in Emme. Furthermore, it might be of interest to simplify the calibration by implementing a support tool. This would be much easier to interpret if the developed model is integrated into a single program, for instance Emme.

The developed model should be applied on different cities to confirm that the developed model produces good forecasts. As mentioned in Chapter 7, the model could be adapted to take large headways into consideration by for instance applying a node specific waiting time when performing the transit assignment. This is can be applied for different cities in order to confirm if it is a suitable solution for headways with large variations. The model is easy to recreate for another Swedish city since population data is available at SCB (2011) for every municipality or region and the developed model is independent regarding of the city it is applied to. The developed model itself requires barely any time to produce a result, it is the processing of input data that may require some time. Also, time should be spared to acquire surveys or input data from the operators or municipality for the cities that the model might be applied to.

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