Thesis 238

Evaluating a simplified process for developing a four-step transport planning model in VISUM

–Application on the capital area of Reykjavik-

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LTH, Institutionen för Teknik och samhälle
CODEN: LUTVDG/(TVTT-5204)/1-79/2013
ISSN 1653-1922

Tryckt i Sverige av Media-Tryck, Lunds universitet
Lund 2013

Examensarbete CODEN:LUTVDG/(TVTT-5204)/1-79/2013

Thesis / Lunds Tekniska Högskola, ISSN 1653-1922
Instutionen för Teknik och samhälle,
Trafik och väg, 238

Author(s):	Albert Skarphedinsson
Title:	Utvärdering av förenklade processer för att utveckla fyrstegsmodell i VISUM –Fallstudie Reykjavik huvudstadsodsområde–
English title:	Evaluating a simplified process for developing a four-step transport planning model in VISUM –Application on the capital area of Reykjavik-
Language	Engelska
Year:	2013
Keywords:	Four-step model; Trip generation; Trip distribution; Mode choice; Traffic assignment; VISUM
Citation:	Albert Skarphedinsson, Evaluating a simplified process for developing a four-step transport planning model in VISUM – Application on the capital area of Reykjavik-. Lund, Lunds universitet, LTH, Institutionen för Teknik och samhälle. Trafik och väg 2013. Thesis. 238

Abstract:

A four step transport planning model was built for the greater Reykjavik area in Iceland and the process validated to find out if greater simulation accuracy can be acquired than for other models built for the area. Simulation of the public bus system in the greater Reykjavik area was also included in the process which has not been done before.

A method was used that breaks the population in the study area down into groups with similar travel behaviour and different trips they do within the day where simulated separately. With this method more information can be extracted from available data in Iceland than previous models are capable of.

The results are found by comparing the traffic estimated by the model with the observed traffic. The average percentage deviation for this model is 17% and the RMS error is 0,973 while the older model has 32% respective 0,960 in RMS error.

Simulations for the public bus system where not close enough to the reality; estimation of coefficients that simulate road user's preferences for mode choice was based on outdated data and was therefore unsuccessful. Better results could be achieved with travel behaviour survey where these preferences are measured and to account for whether the road user has access to passenger car or not.

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Preface

I would like to thank my instructors Thomas Jonsson at the department of technology and society, Lunds Tekniska Högskola and Karin Brundell Freij at WSP engineering consultants for support and guidance during this project.

I would like to thank Brynja Þorsteinsdóttir at Samsýn for all the help on providing geographical data and Björg Helgadóttir at Reykjavik city for providing traffic counts relative for the project. I would also like to thank the staff at PTV traffic for providing me a VISUM license and software support necessary for the project.

Last but not least I would like to thank my spouse Anna Björg Guðmundsdóttir for all the help and support.

Lund 2009

Albert Skarphedinsson

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Summary

The introduction of the passenger car and its road network has had a huge effect on the development of cities. A few examples of these effects are sparse city structure, segregation of homes and work and generally larger distances for the inhabitants. The capital area of Iceland is not an exception from this development with sparse city structure and among the highest rates of car ownership in the world. The car ownership in the end of year 2007 was 0.8 cars for every person in Iceland. Therefore the transportation within the area is highly dependent on the passenger cars. This has lead to heavy traffic congestion during peak hours and the noise and air pollution is a growing concern.

The connection between land use and transportation is well known and therefore it is possible to influence travel behaviour with different city planning strategies. Traffic forecasting models such as the four step transport planning model can evaluate what effects different city planning proposals will have on the transport network. Today one of Reykjavík city's goals is to be the most sustainable city of all the Nordic cities. A good transport planning model could be a powerful tool to help the city officials to achieve this goal.

Four step transport planning models have been built before for the capital area of Iceland. However, there has been discontent with their results, that the simulated traffic was not close enough to the reality and that the models do not simulate public transport. Four step models are always just a simplification of the reality and their results are highly dependent on their input data. The goal of this project is to build a four step transport planning model for the base year 2008 while validating the process to see if a better result could be achieved than before with current available data in Iceland, and possibly some additional data, or other methods. No model in Iceland has included public transport in its simulation but this model will additionally include public transport to find out if reasonable results can be found with available data in Iceland. The software PTV VISUM is used for the modelling. VISUM was chosen because according to its description and trial demo it would suit this study very well and it is also widely used in Sweden.

The report is divided into three parts; the first one is a literature study where a general overview is given for all aspects of the study area, data used and the theory behind four step models. The second part of the report includes an evaluation of the four steps in a four step transport planning model. Finally the last part of the report is the overall model validation. In this part the performance of the model is validated by comparing the simulated traffic volumes to observed volumes.

The modelling process starts by splitting the population in the study area into groups based on similar traffic behaviour. These groups are called mobility groups and includes for this study, employees, not employed, primary school students and higher education students. Furthermore are the trips that these mobility groups do in one day classified into trips according to purpose. Trip purposes used are, to school, to work and other trips. When the mobility groups are joined with the trip purposes we have particular population segments going to particular destinations. This is called demand stratums and seven of them are used. These are; employee going to work, employee going to other locations, primary school student going to school, primary school student going to other locations, higher education students going to school, higher education students going to other locations and not employed inhabitants going to other locations. These demand stratums are carried

out throughout the whole modelling process. In the first step productions and attractions are generated for each demand stratum separately. In the second step a gravity model is used to distribute trips amongst the zones, for each of the demand stratum. For the third step trips are split into two modes, public and private transport, for each of the demand stratums. Finally in the fourth step these demand stratums are joined for each of the two modes and assigned to the road network separately. With this method more information can be extracted from available data such as travel survey, demographical, and land use data.

Now when the model has been built and input data, calculation methods and simulation performance have been evaluated the main conclusion is that the model has a better performance than previous models that have been used in Iceland, when estimated volumes are compared to the exact same observed screen lines counts. Screen lines are lines across a study area that often follow natural realities and give a good idea of the amount of traffic expected and the traffic displacement over the study area.

Included in this project is a test whether mode choice could be simulated with acceptable results in the study area. The main conclusions are that mode choice can be simulated but the results were not close enough to the reality. The main reason is that estimation of coefficients that simulate road user's preferences for mode choice was based on outdated data. To fully implement this step to the four step model new travel survey is highly recommended. It is also recommended to further split demand segment into population segment with access to car or not since that is the single most important factor influencing people's choice of mode.

During validation of each step some comments were made on how a better accuracy can be achieved. Three most important of them are listed below:

- Attraction/generation for jobs is estimated in a process where the accuracy depends on how good the match is between categories at two government agencies. By studying what is included in each of those categories, a better match could be found and thereby better results. An even better solution would be to have spatial data with number of jobs connected to address or geographical location, like the population data used.
- One more purpose category could be included, that is shopping trips. This could simulate 8% of the trips with better accuracy.
- More work is needed on assigning right volume/delay functions to road classes and roads need to be checked if they are in the right category.

One thing to keep in mind is that this model is calibrated and validated against the same data. This limits the possibility to draw any conclusion on the models real reliability. This is common practise since the data availability limits the possibilities. This model has reached the stage where it can be used for guidance in the city planning, however the results will always have to be looked at with this fact in mind.

1. Introduction

The introduction of the passenger car and its road network has had a huge effect on the development of cities. A few examples of these effects are sparse city structure, segregation of homes and work and generally larger distances for the inhabitants. This development has caused the public transport to become a less attractive choice for travellers and made people more car dependent (Holmberg, B., Hydén, C. et al, 1996). The capital area of Iceland is not an exception from this development with sparse city structure and among the highest rates of car ownership in the world. The car ownership in the end of year 2007 was 0.8 cars for every person in Iceland (statistics Iceland, 2009). Therefore the transportation within the area is highly dependent on the passenger cars. This has lead to heavy traffic congestion during peak hours and the air pollution is a growing concern.

1.1 Background

The connection between land use and transportation is well known and therefore it is possible to influence travel behaviour with different city planning strategies (O'Flaherty, CO., 1997). Transport planning models can therefore evaluate what effects different city planning proposals will have on the transport network. Transport planning models could evaluate what effect planning proposal would have e.g.; on accessibility of different transport modes, travel lengths by vehicles and thereby calculate the environmental impact such as noise and air pollution, or be used for cost benefit analysis of different transport improvements. Today one of Reykjavik city's goals is to be the most sustainable city of all the Nordic cities (The Icelandic environment page, 2009). A good transport planning model could be a powerful tool to help the city planners to achieve this goal.

Four step models are not new in Iceland. The first model is from the year 2001 with data from the year 1998. This is a simple four step model and there has been discontent with the result, because the estimated traffic was not close enough to the reality (Sigurðsson, H., 2004).In the year 2005 a new model was made for the base year 2004. Most of the same concepts where used in this one, except a travel survey was used to strengthen the calculations and a method called a Multiple Path Matrix Estimation was used to calibrate the model. The main conclusions from this work were that this model gave better results than the first one although the gravity models trip distribution matrix was still not good enough. The main reason given was that the land use data used for attraction generation was unsatisfactory (VSÓ Consultant Engineers, 2005).

1.2 Purpose

Four step models are always a simplification of the reality and their results are highly dependent on their input data. The purpose of this report is to build a four step transport planning model for the base year 2008 while validating the process to see how good result can be achieved with the current available data in Iceland, and possibly some additional data or other methods. No model in Iceland has had mode choice before, or where road users can choose to travel by other modes than just the passenger car. This model will include mode choice to find out if reasonable results can be found with the current available data (in Iceland). The software PTV VISUM is used for the modelling. VISUM was chosen because according to its description and trial demo it would suit this study very well and it is also widely used in Sweden.

1.3 Method and setup of the report

The report can be divided into three parts; literature study, model evaluation and finally the validation part.

The first part is the literature part and includes the chapters;

- The greater Reykjavik area (chapter 2)
- Data(chapter 3)
- Four step models (chapter 4)

The purpose of chapter 2 is to: give a general overview of the city structure, describe what is special about the study area, describe the traffic and what influences it and finally describe the general travel behaviour in the study area. The purpose of chapter 3 is to; generally describe the data used, describe what information can be used from the data and to find out its reliability. The purpose of chapter 4 is to: generally describe four step models, describe the four step model approach used in previous models in Iceland and then finally describe the approach used in this report.

The second part of the report includes evaluation of the four steps in a four step transport planning model. Each chapter describes one step and the common approaches for carrying it out, then what approach was chosen to use in VISUM, then what data was used and how it was implemented into the model. If any particular problems where encountered, they are specially discussed, and then finally if there are any remaining issues with the step they are listed in the end. By this chapter setup possible weaknesses can be better distinguished for the later validation of the overall model performance.

The last part of the report is the overall model validation (chapter 9). In this part the performance of the model is validated by comparing the simulated traffic volumes to counted volumes. The results will show how close the simulation is to the reality, potential weaknesses of the model and what can be done to strengthen the model.

1.4 Delimitations

To be able to finish this project within a reasonable time following delimitation are made.

- Mode choice is only between passenger car respective public transport (by bus or by foot), the transport mode bicycle is not included.
- Validation of the overall model performance are focused on the Reykjavik city region.

2. The greater Reykjavik area

The greater Reykjavik area is the capital area of Iceland. However, Reykjavik city is only one of seven cities that constitute the capital area. The cities are so interconnected that their boundaries are more political than geometrical (See Figure 1).

The greater Reykjavik area has a total population of 202.000 inhabitants with Reykjavik city being the biggest with about 120.000 (see Table 1). About 64% of Iceland's total population lives in the metropolitan area.

City	population
Reykjavík city centre area	65.712
Reykjavik city suburbs	54.453
Kópavogur	29,886
Hafnarfjörður	25,726
Garðabær	10,331
Mosfellsbær	8,625
Seltjarnarnes	4,437
Álftanes	2,487
Total	**201,847**

Table 1) Population in the greater Reykjavik area cities (Official homepage of Statistics Iceland, 2009)

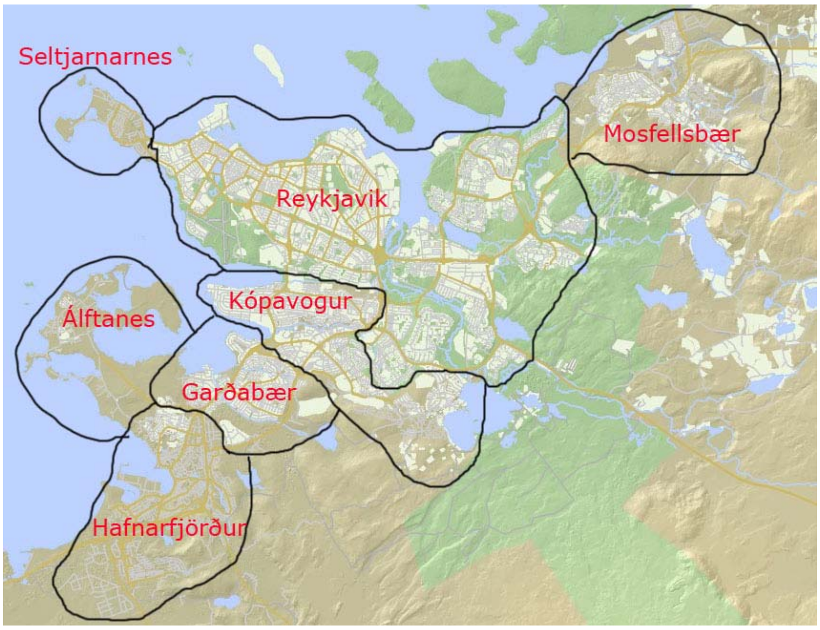

Figure 1) Map of the cities that are included in the greater Reykjavik area(Borgarvefsjá Reykjavíkur, 2009)

2.1 City structure

Reykjavik city can furthermore be divided into two areas or Reykjavik city centre area and Reykjavik city suburbs. In between the Reykjavik city centre area and the surrounding suburbs and neighbouring cities are valleys, green zones, ocean or rivers and therefore there are very few road connections (see Figure 2).

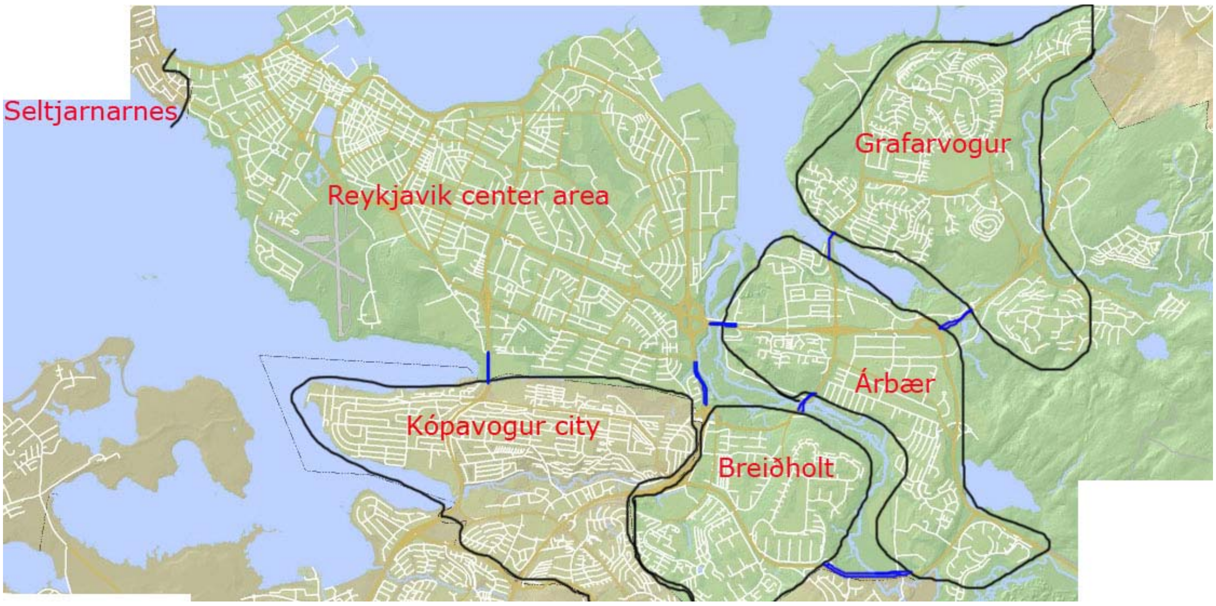

Figure 2) Map of Reykjavik'smain districts (**Borgarvefsjá Reykjavíkur,** 2009)

The suburbs are(Official homepage of Statistics Iceland, 2009):

- Breiðholt, the most dense suburb with 21.089 inhabitants
- Árbær, suburb with 9.886 inhabitants
- Grafarvogur and Grafarholt, the least dens of the suburbs with 23.478 inhabitants

Reykjavík has most of the jobs of the capital area and is also mostly dense. Seltjarnarnes is located northwest of Reykjavik and is a dense residential district and includes almost no workplaces. Kópavogur lies south of Reykjavik and consists mainly of residential and commercial areas. Garðabær, lies south of Kópavogur and is mostly a residential district with very widespread houses. Hafnarfjörður is the southernmost and has many jobs as well as residents. North of Hafnarfjörður lays a low populated town called Álftanes with only one road connecting it to the metropolitan area. To the northeast of Reykjavik is Mosfellsbær. Mosfellsbærs has not yet grown together with the capital area and is considered an individual town.

2.2 Main attractions

Reykjavik centre area (see Figure 2) is the centre for the greater Reykjavik area and in certain aspect for the whole country. Therefore Reykjavik has many major attractions that a normal city of this size would not have. In Reykjavik is(see figure 3);

- the University hospital with over 5000 jobs and over 100.000 arrivals a year (Official homepage of Landspítali, 2009),
- the University of Iceland with about 14.000 students and over 2000 employees(Official homepage of the University of Iceland, 2009),
- the domestic airport with 420.000 arriving and departing passengers per year (Flugstoðir, 2009),
- the Reykjavik city centre area with a large variety of shops and recreations,

- Kringlan a large shopping centre with almost 60.000 m^2 of shops and services (Borgarvefsjá Reykjavíkur, 2009)
- and large industrial and commercial areas like the harbour area and Suðurlandsbraut.

Outside Reykjavik centre area the biggest attraction is Smáralind, a big shopping mall with over 60.000 m^2 of shops and services (Borgarvefsjá Reykjavíkur, 2009).

With the Reykjavik centre area having such a large supply of work and service and while many live outside the city centre area (see chapter 2.1) it obviously causes rather long travel distance for a large proportion of the population.

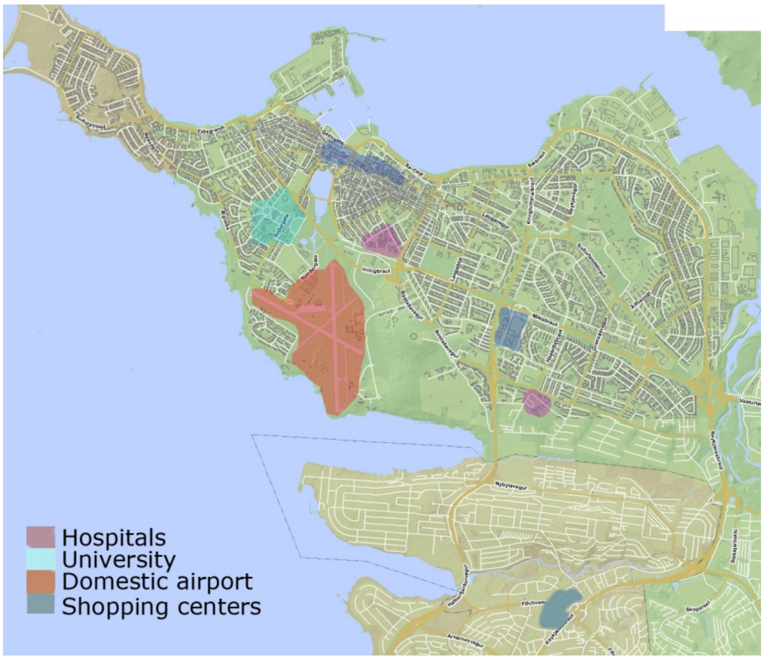

Figure 3) Some of the main attractions in the greater Reykjavik area (Borgarvefsjá Reykjavíkur, 2009)

2.3 Usage of different transport modes

The sparse structure of the city has caused that the travel time ratio between passenger cars and public transportation is too high and thereby travellers tend to favour the passenger car (Bjarnasson, H., 2006). When looking at the use of different transportation modes in the greater Reykjavik area this fact becomes even clearer. A travel survey was performed 2002 in the greater Reykjavik area where among other factors the use of different modes where studied. According to the study 76% of all trips were done by passenger car while only 4% with public transportation and 20% by foot or bicycle (Gallup, 2002). Of those who use passenger car, 56% drove alone and 28% had only one passenger. For comparison these proportions are, 53% by passenger car and 14% by public transportation, in Sweden. This high usage of cars in Reykjvik apparently increases as further away travellers live from the Centrum (see Figure 4).

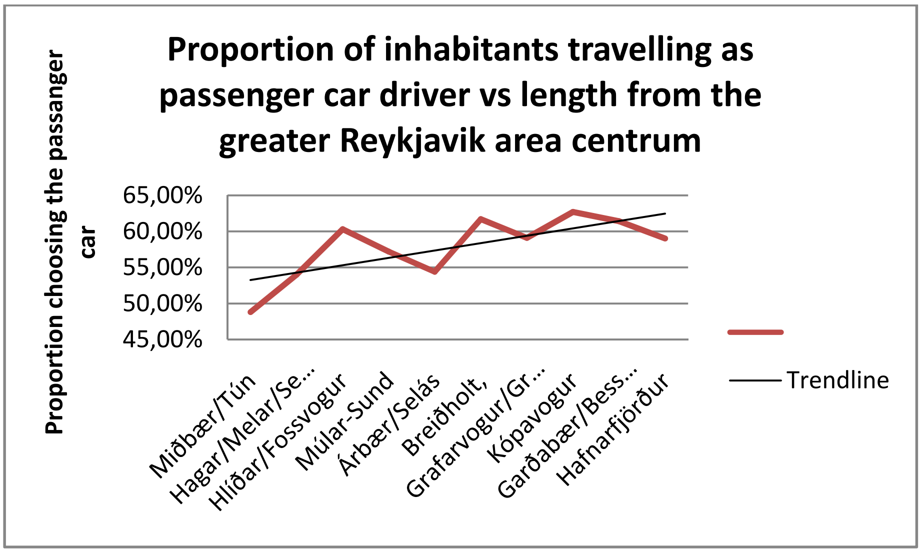

Figure 4) Graph showing proportion of inhabitants travelling as passenger car driver were, Miðbær/Tún is the district closest to the centrum and Mosfellsbær the district furthest from the Centrum (Gallup, 2002)

Car ownership in Iceland is also amongst the highest in the world (Statistics Iceland, 2009). Of all people living in the greater Reykjavik area, seventeen and older, 96% have driving license and 93% have access to car (Gallup, 2002). For comparison one fourth of all households in Sweden do not have a car (SIKA Statistik, 2007). This shows that the greater Reykjavik area is a highly car dependant society.

2.4 Current road network and main traffic flows

The road network is composed of three motorways. First there is Vesturlandsvegur/Miklabraut (line 1inFigure 5) that connects Mosfellsbærand the major residential areas to the east ofReykjavik centre, as well to the rest of the road network. Secondly there is Reykjanesbraut/Sæbraut (line 2 in Figure 5) and third there is Hafnarfjarðarvegur/Krimglumýrarbraut (line 3 in figure 5). The two latter connect Hafnarfjörður, Kópavogur, Garðabær and Álftarnes to Reykjavik.

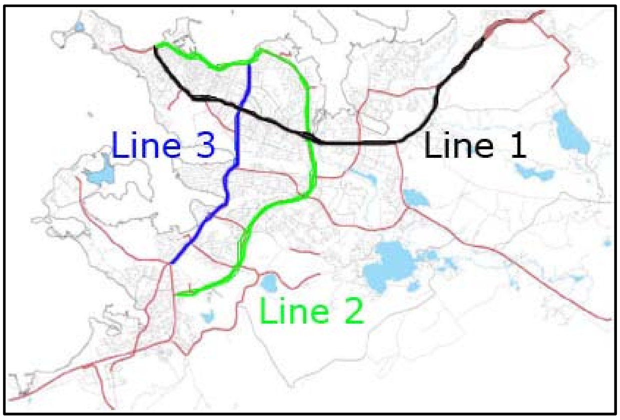

Figure 5) Traffic on main roads (Image source: Almenna Consultants Engineers, 2007)

The traffic volume on these roads is:

- 22 to 72 thousand cars per day on Vesturlandsvegur/Miklabraut (Almenna Consultants Engineers, 2007),
- 23 to 61 thousand cars per day on Reykjanesbraut/Sæbraut (Almenna Consultants Engineers, 2007),
- and21 to 72 thousand cars per day on Hafnarfjarðarvegur/Krimglumýrarbraut (Almenna Consultants Engineers, 2007).

Remaining roads with traffic higher than 10 thousand a day are marked with red in Figure5.

As discussed in previous chapter the car dependency is high in Reykjavik which results in a quite higher traffic than expected from a city with 200.000 inhabitants. Additionally only three roads connect the centre area with the most attractions to the remaining road network (see figure 6). These connections yield the highest traffic. Although having such a high amount of traffic the greater Reykjavík area is not severely affected by traffic congestion (Almenna Consultants Engineers, 2007). To be able to handle all this traffic these main roads are usually 2 to 3, even 4 lanes in each direction with many grade separated intersections.

2.5 Reykjavik bus system

Public transportation in the greater Reykjavik area consists only of one bus system called Strætó bs. Although only a small proportion of travellers choose public transport (see chapter 0) the public bus system has a reasonably good cover over the greater Reykjavik area.

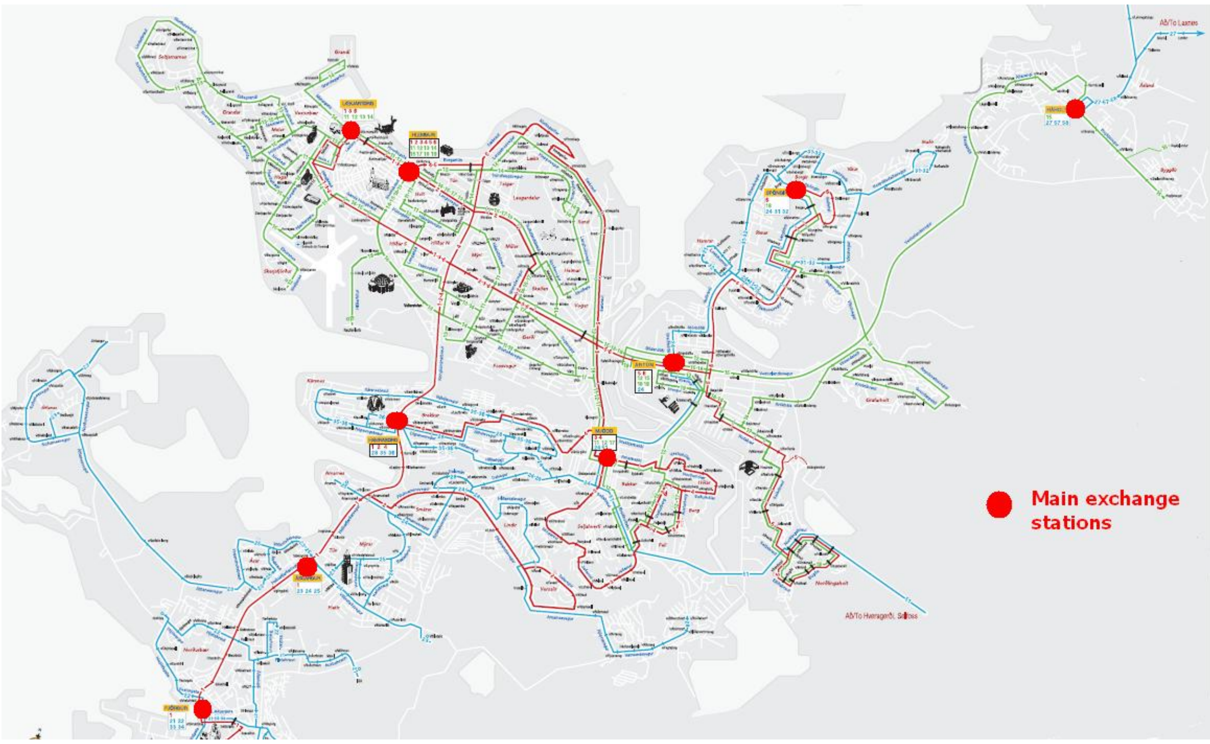

Figure 6) The Reykjavik public bus system and the main exchange stations (Image source: Strætóbs, 2009)

The public bus system has thirty bus lines divided into three categories. Red lines (see Figure 6) drive mainly on the main roads and serve as commuter lines. Green lines' (see Figure 6) main purpose is to go into the neighbourhoods and connect them to the red lines. Blue lines' (see Figure 6) main purpose is to serve passenger travelling inside the neighbourhoods as well as to connect them to the red lines (Strætó bs, 2009).

3. Data

In this chapter a general overview is given for all aspects of currently available data in Iceland.

3.1 Traffic survey

A travel survey was carried out for the study area in January and February 2002. Participants where first sent a letter with a questionnaire and then where called by phone for the results. They were asked about the trips done the day before and in all cases was that a week day (Tuesday, Wednesday or Thursday) (Sigurðsson, H., 2004).

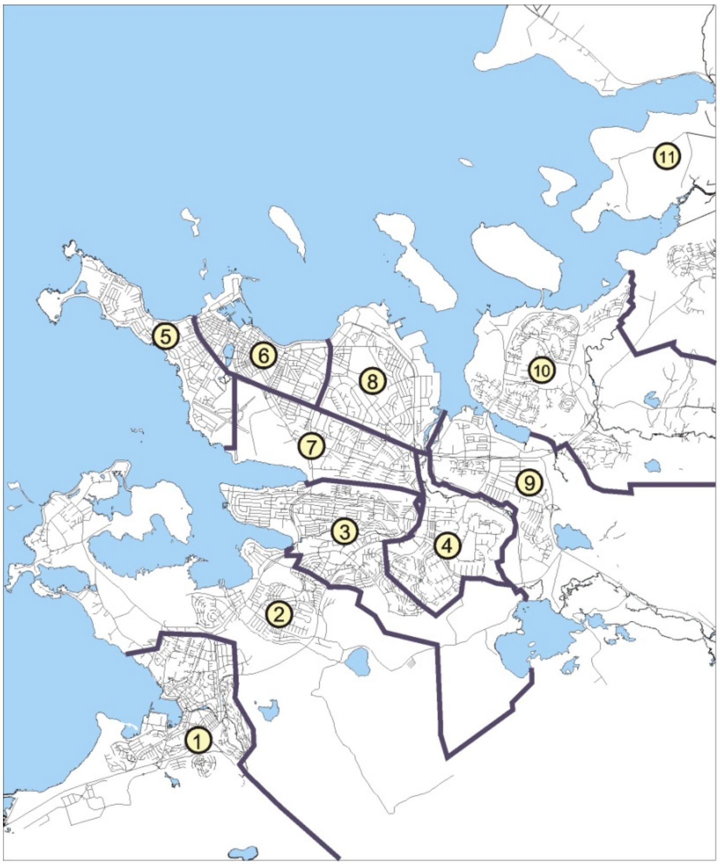

Figure7) Traffic survey zones

The whole capital area was surveyed but divided into eleven survey zones (see Figure 7). The zones where carefully placed to be as homogenous as possible in travel behaviour. Sample sizes where 750 participants for every zone with an answer rate of 64% (Sigurðsson, H., 2004).

This was a very detailed survey where the participants were asked about all their trips the day before. The sample was based on people aged 6 to 80 years, and divided into age groups. Professional drivers were not asked. Travel information gathered can be viewed in Table 2.

The type of this travel survey could be classified as a household survey. Recommended sampling size for that kind of surveys for study area with around 200.000 inhabitants is 10% of households and with minimum of 3% (Ortúzar, J. De D., Willumsen, L.G., 2001). Therefore the sample size used, 4,7% of all inhabitants, was sufficient though not optimal. When looking at accuracy of information one major conclusion from the analysis of the survey was that trips done by car are underestimated and trips done by public transport are overestimated (Baldvinsson, B., 2002).

Question	Options
Age	5 categories
Number of trips	8 categories
Mode used	5 categories
Number of passengers	6 categories
Purpose of trip	9 categories
Access to car	yes/no
Has driver license	yes/no
Type of household	4 categories
Owner of household	3 categories
Number of residents	5 categories
Employed or in school	Work/both/school
Type of job	9 categories
Family income	4 categories
Number of cars at household	5 categories
Usage of bus discount cards	Use/do not use
Marital status	3 categories

Table 2) Traffic survey questionnaire (Gallup, 2002)

3.2 Demography

The demography data used is spatial information extracted from LUKR or the Land Information System of the Reykjavík Area (*Þorsteinsdóttir, B., 2009)*. The data is linked to 239 polygons covering all the capital area of Iceland. These polygons will be the traffic zones used in the model (see Figure 8).

Figure 8) Traffic zones used for the modelling (Aerial photograph source: *Þorsteinsdóttir, B., 2008)*

Zone data for the base year 2008 was extracted from the LUKR database and includes number of inhabitants divided into eight age groups (same groups as in the travel survey), and a gross floor area divided into nine business categories. Information about inhabitants is a point data or addresses that are cross referenced with the national register of persons to get a number of inhabitants per age group per zone. Information on a gross floor area is polygon data that could be extracted right from the database. The data is considered very reliable, especially the person data.

3.3 Traffic counts

Traffic counts used are annual average weekly traffic (AAWT) from Reykjavik municipality (*Helgadóttir, B., 2009)*. These counts are for the year 2008.

The counts from Reykjavik municipality are two-folded; one set of counts is so called screen line counts where all traffic crossing an imaginary boundary is counted simultaneously (see Figure 9); the other set are various counts spread throughout all kinds of roads in the municipality. Number of AAWT counts used is 205 including these 6 screen-lines.

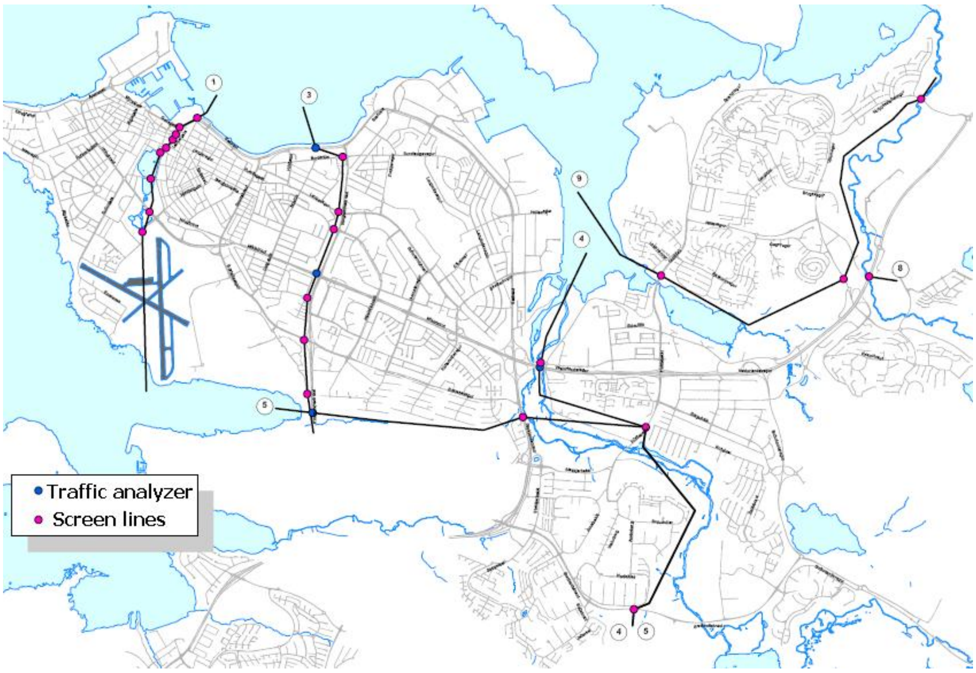

Figure 9) Map over screen line count done by Reykjavik municipality (Official homepage of Reykjavík, 2009)

All these counts have been done in several years with fixed counting instruments and have been reviewed by analytics before being published. The reliability of the counts should therefore be good.

3.4 Road network

Like the demographical data the road network is also spatial data acquired from The Land Information System of the Reykjavík Area (Þorsteinsdóttir, B., 2009). The last update of the network was done in April 2004. The network is built up by links, where every link represents a road segment. Associated with the links are information such as road ID, name, road class, speed limit and length. All road constructions and changes in the road system done from April 2004 to this year is not included in the data. The most important changes was manually drawn and registered to the road network database.

4. Four step transport planning models

In this chapter the theory behind four step models and its purpose is explained. In the following subchapter the common four step model approach is explained first then the model approach used in previous models in Iceland and finally the approach used in this study.

The four step transport planning model executed for a specific study area, for example a city or a region, calculates with given conditions the expected amount of traffic by different modes of transport on the road network within the area. Calculations can be done for a specific period of the day or the whole day.

These four step models are simplified representation of reality which can be used to explore the consequences of particular policies or strategies. They are deliberately simplified in order to keep them manageable and avoid irrelevant detail while hopefully encapsulating the important features of the system of interest (O'Flaherty, CO., 1997).

The reason for using four step models is that estimates can be made of likely outcome more quickly and at lower cost and risk than would be possible through implementation and monitoring.

Models can be used in a variety of ways:

- To predict future conditions in the absence of a policy intervention or designs and find which road facilities are likely to prevail at some future date.

- To obtain results from cost-benefit analysis, environmental and social impact assessments for new road facilities or new planning proposal.

- To test what effects a policy intervention such as lowering or raise gasoline taxes or bus fares would have.

4.1 Common four step models

A study area in question is first divided into zones, the number of zones and their size is determined by the purpose of the model and what precision is feasible. For every zone, information on the demography and land use is needed.

The model also needs a road network that resembles the current conditions. Exact geometrical layout is often discarded and the roads are expressed as simplified polygons and called links. Dead end streets, housing streets are normally discarded as well since the traffic on larger collecting roads are of much more importance.

The model calculation is done in four steps and is therefore called four step models. The role each step has in the model is expressed below and in figure 10.

Trip generation (step one) determines the frequency of origins or destinations of trips in each zone, as a function of land uses and demographics, and other socio-economic factors.

Trip distribution (step two) calculates how big proportion of the total traffic travels between each pair of the zones based on how good connection there is between the zones. The connection quality is often measured in travel time.

Mode choice (step three) computes the proportion of trips between each zone that use a particular transportation mode.

Trip assignment (step four) calculates how the traffic will distribute on the road network. Calculation methods often take delays caused by congestions into consideration. New travel time between zones is calculated with these traffic delays and step two is then repeated with the new travel time. This process is repeated until certain criteria are reached.

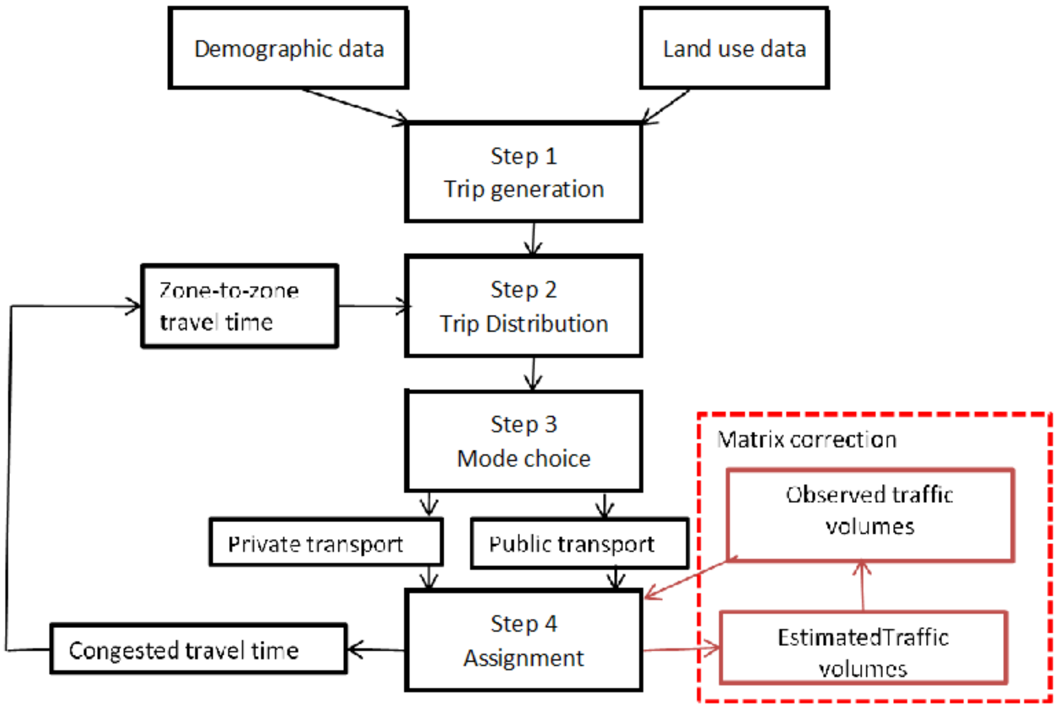

Figure 10)Schematic picture of common four step model

One essential element in four step models is the definition of production and attraction. Every trip goes between two points were the trip intentions is to do certain activity. The trip is said to be produced in the more permanent end, for example a residence, and attracted to the other end for example work.

4.1.1 Matrix corrections

Many four step models use so-called matrix correction (or matrix update) techniques. Matrix correction methods are used to adjust a given OD matrix in such away that the result of the assignment closely matches the latest traffic count figures (see red boxes in figure 10). Resulting trip distribution matrix from such adjustment is no longer based entirely on productions, attractions and connection quality between zones instead combination of these factors and traffic counts. Research has shown that these matrix corrections can provide a reliable correction if the initial demand estimate is affected only by generation errors, while distribution errors can hardly be reduced through the observation of link counts (Papola, A., Marzano, V., 2006).

4.2 Approach currently used in Iceland

Currently there are two four step models used in Iceland. One of them is from the year 2001 with data from the year 1998. This is a simple four step model and there was discontent with the result, because the estimated traffic was not close enough to the reality (Sigurðsson, H., 2004). In the year 2005 a new model was made for the base year 2004. Most of the same concepts where used in this one, except a trip rate from the travel survey was used for the trip generation, stochastic user equilibrium was used for the assignment step, and a method called a Multiple Path Matrix Estimation was used for matrix correction (see matrix correction in chapter 4.1.1). The main conclusions from this work were that this model gave better results than the first one, although the gravity models' trip distribution matrix was still not good enough. The main reason given was that the land use data used for attraction generation was unsatisfactory (VSÓ Consultant Engineers, 2005).

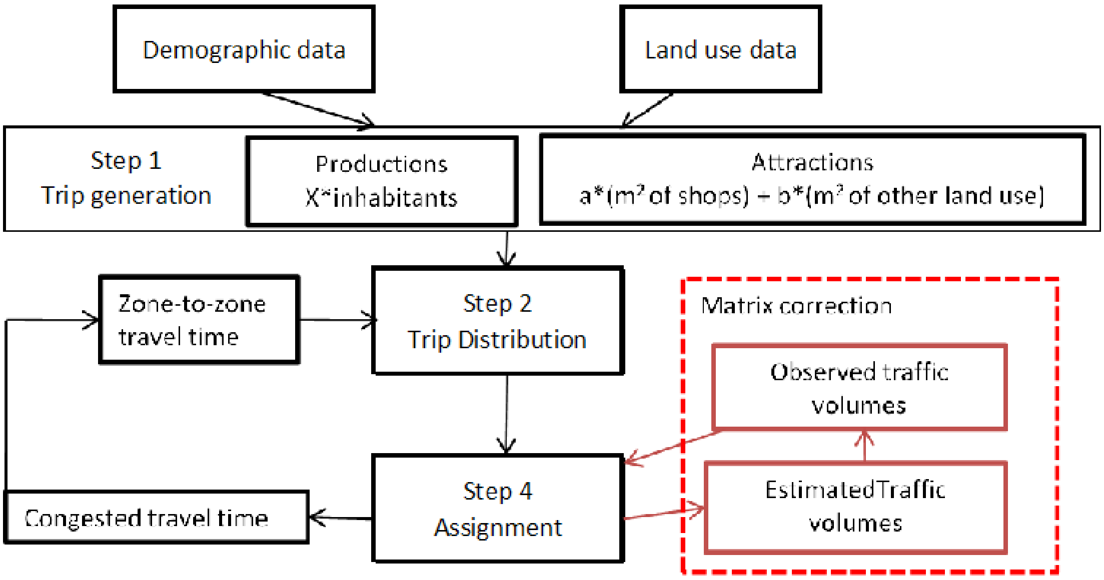

Figure 11) Schematic picture of the four step model structure currently used in Iceland

Figure 11 shows a schematic picture of the four step model structure currently used in Iceland. As one can see rather basic methods are used for trip generation a. For production generation all inhabitants are assumed to generate equal amount of productions and for trip attractions one square meter of different land use is assumed to generate equal amount of attractions. Finally the third step is not included in the model or the mode choice step.

4.3 Approach used in this study

The four step model built for this study is for the base year 2008. The model is validated against traffic counts on the annual average weekly traffic format because the travel survey used for the modelling was carried out on week days. Figure 12 shows a schematic picture of the model structure. The modelling process starts by splitting population in the study area into groups based on similar traffic behaviour. These groups are called mobility groups and includes for this study, employees, not employed, primary school students and higher education students. Furthermore are the trips that these mobility groups do in one day classified into trips according to purpose. Trip purposes used are, to school, to work and other trips. When the mobility groups are joined with the trip purposes we have particular population segments going to particular destinations. This is called demand stratums and seven of them are used. These are; employee going to work, employee going to other locations, primary school student going to school, primary school student going to other locations, higher education students going to school, higher education students going to other locations and not employed inhabitants going to other locations. These demand stratums are used throughout the whole modelling process. In the first step productions and attractions are generated for each demand stratum separately. In the second step gravity model is used to distribute trips amongst the zones, for each of the demand stratum. For the third step trips are split into two modes, public and private transport, for each of the demand stratums. Finally in the fourth step these demand stratums are joined for each of the two modes and assigned to the road network separately.

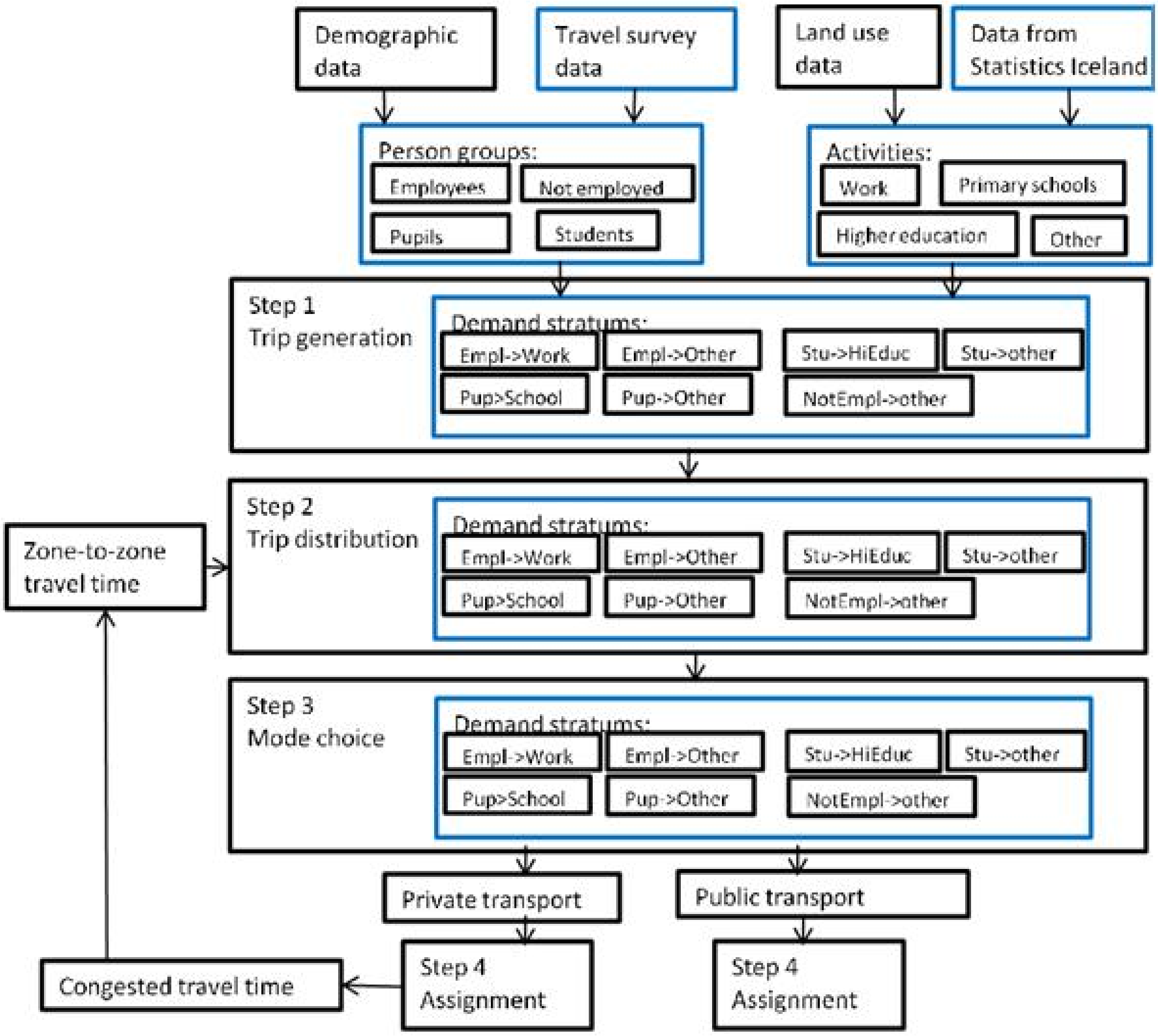

Figure 12)Scematic picture of the four step model structure used for this study

With this method more information can be extracted from available data such as travel survey, demographical, and land use data. This model structure is also essential for the mode choice step since people's willingness to use public transport differs significally between population segments.

5. Trip generation (step one)

The first step in four step transport planning model is determination of the trips currently undertaken in a planning region.

5.1 Common approaches in trip generation models

Trip generation is the process of determining the number of trips that begin or end in each traffic zone within a study area. Trips are determined without regard to certain destination, since that they are referred to as trip ends. Each trip has two ends, when the trip end is the origin of the trip it is called production and when the trip end is the destination of the trip it is called attraction. For example, a home to work trip would be considered to have a trip end produced in the home zone and attracted to the work zone.

Procedures have been developed to generate trips and they are, to some extent, all based on three factors that influence the demand for urban travel. The first one is the location and intensity of land use. Second are the socioeconomic characteristics of people living in the area. Third is cost, and quality of available transportation services (*Ortúzar, J. De D., Willumsen, L.G., 2001*). Two most popular of them are cross classification and rates based on purpose of trip.

Cross classification is a technique developed by the Federal Highway Administration to determine the number of trips that begin or end at the home. Significant proportion of all trips either start or end at home, so home-based trip generation is a very useful measurement. The first stage is to develop a relationship between socioeconomic factors and trip production. The three most commonly used variables are average income, household size, and car ownership (*Ortúzar, J. De D., Willumsen, L.G., 2001*).

Rates based on purpose of trips. Trip generation for the home end can be determined for residential zones where the basic units are households, persons, or mobility groups. Trips generated at the home end are referred to as productions, and they are attracted to zones for purposes such as work, shopping, going to school, and visiting friends (*Ortúzar, J. De D., Willumsen, L.G., 2001*). Trip generation rates for the productions are based on the purpose of the trip. For example, one persons group (called students) generate in one zone 100 home-to-school trips and 50 home-to-shop trips. The none home end units(or the attractions)can be described by measures such as square feet of floor space or number of employees. Trip generation rates for both productions and attraction in zones can be determined from survey data or external tabulated data found in relevant literatures (*Ortúzar, J. De D., Willumsen, L.G., 2001*).

5.2 VISUM approaches and concepts

The approach chosen in VISUM for the study is based on later procedure (Rates based on purpose of trips) described in the previous chapter. VISUM calculates Trip generation for a number of separate purposes – person group combinations. Attractions and productions per zone is calculated for each of these, on the basis of zonal characteristics.

Road users featuring comparable mobility behaviour are grouped together into groups. Mobility behaviour is very different between age groups as well as occupation and these key variables can easily be extracted from the available travel survey and the demographical data (see chapter 3.1 and 3.2). Based on the available data the mobility groups; employed (E), not employed (NE), students (Stu) and primary school pupils (Pup) have been chosen. The breakdown of students into two groups, students and primary school pupils is because the majority of students 17 and older have driving license and therefore have different mobility behaviour.

Activities are used to describe the location of the population in the course of the day. Activities used will be work, school, home and other. Activities are then paired up to describe purpose of trip. Trip purposes used for the study are Home-Primary School (HP), Home-Further education (HU), Home-Work (HW), Home-Other (HO). Further education is secondary schools and universities.

A combination of these mobility groups and purposes is called demand stratum. These demand stratums links a trip purpose with one or several mobility groups to form a basic demand object for calculation in the modelling process (see figure 13).

For example the demand stratum HW-E is an employee going to work. Seven demand stratums will be used for the model (see figure 13).

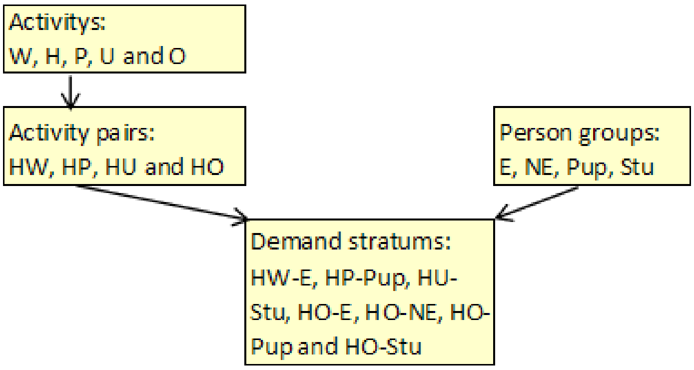

Figure 13) Flow chart showing how demand stratums are built-up (VISUM manual, 2007).

5.3 Data sources used

Productions and attractions are estimated using information from the travel survey and demographic data. Attractions and productions are calculated separately for seven demand stratums.

Purpose	Productions	Attractions
HW	E*trip rate*activity ratio	Jobs
HP	Pup*trip rate*activity ratio	Number of seats
HU	Stu*trip rate*activity ratio	Number of seats
HO	NE*t.r.*p.r. + E*t.r.*p.r. + Pup*t.r.*p.r. + Stu*t.r.*p.r	Other vehicle trips - Work vehicle trips
t.r= trip ratio		
p.r.=purpose ratio		

Table 3)Table showing how productions and attractions are calculated.

Table 3 above shows the results of the trip generation process that will be explained in the continuing chapters. The results can also be viewed in appendix A

5.3.1 Productions

The population living in the planning area will be grouped into mobility groups with help from the travel survey and demographical data. Spatial information from the travel survey is available on proportion of the population that is working, is in school or is neither in school or working. This information is given for 11 zones (red zones, see Figure 14). Information is also available for a number of people in 239 zones categorized into age (blue

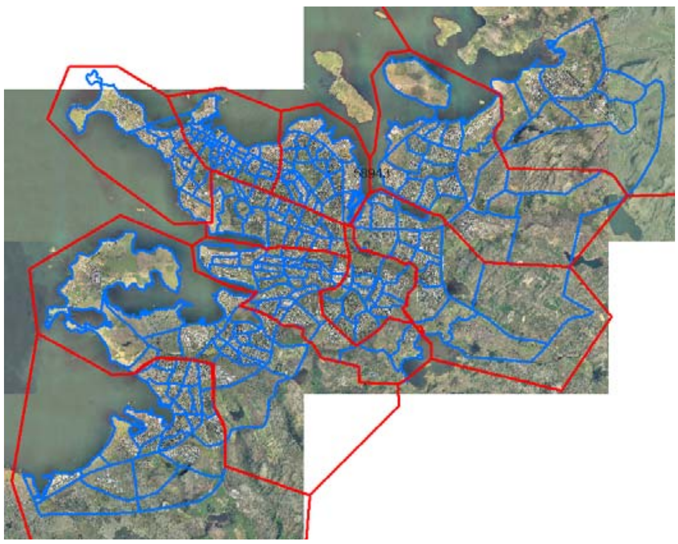
Figure 14)spatial data, red is the travel survey zones and the blue is the demographic zones

zones see Figure 14). When this data is merged the above mention mobility groups in each zone can be found. The software ArcGIS was used to merge the zones (SeeFigure 14). Since the travel survey data is from the year 2002 proportions probably have changed since then. Corrections on the total numbers of students were therefore performed based on registered students in the year 2008 (*Statistical Series, 2009*). The five mobility groups chosen for the study and their characteristics are;

Employees (E) are the workforce of the study area. These persons share the same travel behaviour group because the majority have access to passenger car, or 95% and low proportion of them share the lowest income category or 17,6% (Gallup, 2002). All inhabitants older than 16 years old can belong to this group. Total of 103.593 inhabitants belong to this group or about 55% of the total population.

Not employed (NE) are for example unemployed, pensioners or parents working at home. These people share the same travel behaviour group because lower proportion have access to passenger car, or 88% and high proportion of them share the lowest income category or 73,8% (Gallup, 2002). All inhabitants older than 16 years old can belong to this group. Total of 25.668 inhabitants belongs to this group or about 14% of the total population.

Primary school pupils (Pup) are all inhabitants in age groups from 6 years to 16 years old. These persons share the same travel behaviour group because they do not have driving license and their main purpose trip or, trip to school, is usually to the nearest primary school. Total of 26.053 inhabitants belongs to this group or about 14% of the total population.

Other students (Stu) are secondary school students and university students. These people share the same travel behaviour because they are all students that could have driver license. Of them 84% have access to passenger car (Gallup, 2002). Total of 34.157 inhabitants belongs to this group or about 18% of the total population.

After the mobility groups have been defined the travel survey trip rate is used to find out how many trips per day one person does to find out the productions. A production for this study is defined as one partial trip done by one person during the day. For example, one employee going to work is one production. Average trip rates were applied to the persons in the age groups 6-12 and 13-16 in each of the 11 travel survey zones to find the productions for primary school pupils (see table 4). Average trip rates over the whole travel survey area are used to find productions for employees, non employees and students (see table 4). This was done differently because standard deviation was lower when extracting trip rates per zone for the primary school pupils productions rather than the average over all the zones. On the other hand the same standard deviation was in average trip rates per zone and trip rates over all the zones for the other mobility groups.

	E	NE	Pup	Stu
Average trip rate	**4,63**	**3,15**	**3,7 to 5,9**	**4,65**
Total productions	**502104**	**95925**	**114896**	**163691**

Table 4) Trip rates and productions for different mobility groups

All locations a person could be at in one day were categorized into activity groups. Five activity groups are used and they are home (H), work (W), primary school (P), Secondary school and university (U) and other locations (O). Other locations are for example shops, government services, sport facilities etc. After that activities are paired up corresponds to the path between two successive activities in the daily routine. This will be called trip purpose.

Four trip purposes are used to simulate trips done in the study area and they are home-to-work (HW), home-to-primary school(HP), home-to-higher education(HU) and home-to-other location (HO). The proportion of activities different person group does in one day was studied in the travel survey (see chapter 3.1). These proportions are additionally given for the occupations, working, in school and neither in school. These proportions were then assigned to each person group (see Table 5). For example, 62% of all trips employees do in one day are either to work or going home from work.

	HW	HP	HU	HO
E	62%			38%
Pup		50%		50%
Stu			44%	56%
NE				100%

Table 5) Productions divided by purposes

These proportions are then multiplied with the productions given in table 4. This will give the productions for all of the seven demand stratums (see table 6).

	HW-E	HP-Pup	HU-Stu	HO-E	HO-NE	HO-Pup	HO-Stu	Total
E	311.304			190.800				502.104
NE					95.925			95.925
Pup		57.448				57.448		114.896
Stu			72.024				91.667	163.691

Table 6) Calculated production for all of the seven demand stratums

5.3.2 Attractions

To find out where the population in the study area is going some measurement of attraction per zone is needed. Today the best data available for this measurement, in Iceland, is the floor area of different business measured in square meters and divided into 8 categories. Additionally some information is available on total jobs divide into 15 job categories (Official homepage of Statistics Iceland (Hagstofa Íslands), 2009)and the number of students registered to secondary schools and universities (Statistical Series, 2009).

Furthermore to calculate the number of attractions these basic measurement units (jobs or floor area) needs to be multiplied with a trip rate. For example shops might generate one trip per2 m^2 while a factory generates one trip per 13m^2. Trip rates used are empirical data that have been use in previous four stage models in Iceland (Almenna Consultants Engineers, 2007).

For every zone, attractions for four different trip purposes are needed. The basic measurement unit used for calculating the attractions is the floor area of 8 different business categories. For the trip purposes some of the business categories are irrelevant. For example we do not need floor area for industry when working with home-to-primary school trips. Business categories used for each trip purpose is displayed in Table 7.

	Retail	Office	Industry	Warehouse	Primary schools	Higher education	Healthcare service	Other
Trip purpose	**m^2**	**m^2**	**m^2**	**m^2**	**m^2**	**m^2**	**m^2**	**m^2**
HW	x	x	x	x	x	x	x	x
HP					x			
HU						x		
HO	x	x		x			x	x

Table 7) Business category used for each trip purpose

By this way it is easier to distinguish where the population is going. One problem rises though when the business category attracts two types of trip purposes e.g. retail attracts both workers and shoppers. How to overcome this problem different approach is used to calculate attractions for each of the trip purposes and explained separately.

For the HW trip purpose attraction generation, information on number of jobs per job sector gathered from Statistics Iceland and m^2 per business category gathered from the Icelandic property registry is used. This information will be combined to calculate how many jobs each zone has. In each zone only m^2 of 7 different business categories are known so if total jobs in each of these categories were known, the jobs could be distributed among these zonal m^2 by assuming each m^2 includes equal amount of jobs. For example if there were 1000 jobs in the retail business and only two zones had retail stores, one 250 m^2 and the other one 750 m^2 then the first one is estimated to have 250 jobs while the other one 750 jobs. One problem is that these two government agencies do not have the exact same categories for their data, one agency has 15 categories while the other has only 8 categories. For example one agency has agriculture, fish industry ex. while the other one has just industry. For this reason an attempt will then be done to match these categories so their information can be combined (see Table 8).

		The Icelandic property registry business type categories						
Statistics Iceland job sectors	**No. of jobs**	**Industry**	**Other**	**Retail**	**Warehouse**	**Office**	**Schools**	**Healthcare**
Agriculture	**500**	500						
Fishing	**500**	500						
Fish industry	**600**	600						
Other industry	**9000**	9000						
Infrastructure	**1000**	1000						
Building industry	**10500**	10500						
Retail and maintenance service	**17100**			17100				
Hotels and restaurants	**4200**		4200					
Transport and postal	**7700**				7700			
Banking and insurance	**7000**					7000		
Real-estate jobs and other service	**15400**		15400					
Governmental jobs	**6300**					6300		
Educational	**7600**						7600	
Healthcare service	**17500**							17500
Other social services	**11500**		11500					
Sum:	*116400*	*22100*	*31100*	*17100*	*7700*	*13300*	*7600*	*17500*

Table 8) Match proposal of job sectors and business types

The result after this match will be number of jobs in 7 different business type categories. Now after the categorical job totals have been found the jobs will be rationally distributed between the zone values of m^2 according to the formula:

$$\frac{Total\ jobs\ in\ catagory\ x}{Total\ m2\ in\ catagory\ x} * zonal\ m2\ for\ catagory\ x \qquad \textbf{Equation 1}$$

The resulting attractions will be number of jobs in each zone.

For the HP trip purpose attraction calculation, information from Statistics Iceland on total number of registered primary school students (seats) and m^2 of primary schools in each zone is used. After that the calculation is done similar to the HW attraction pair by using equation 1. The resulting zonal attractions will be number of seats.

For the HU trip purpose attraction calculation, number of registered students in every secondary school and university is used from Statistics Iceland. Number of students for every school was manually written with its exact location into the database so the floor area was not needed in this case. The zonal attractions for this trip purpose will be number of students.

For the HO trip purpose attraction calculation, m^2 of all the business categories listed in Table 7without, industry, primary schools and higher education categories will be used. These zonal m^2 is then multiplied with vehicle trip rate per business category. Vehicle trips rates are empirical data that was used in previous four stage models in Iceland (Almenna Consultants Engineers, 2007). The trip rates are 0,16 trips per m^2 for shops and offices, 0,016 trips per m^2 for warehouses, 0,061 trips per m^2 for healthcare and 0,024 trips per m^2 for other. The resulting attractions will then be total vehicle trips in every zone. As mentioned before it varies between businesses the ratio between work trip/other trip attractions, e.g. a shop has a lot more of other trips then work trip compared to factory. To correct this ratio the work based attraction calculated earlier in each zone is subtracted from these HO attractions. But before this is done these attractions has to have the same unit. The other trip based attraction has the unit total vehicle trips per day but the work based attraction has number of jobs. The number of jobs is thereby transformed into vehicle trip by multiplying jobs first by trip rate per job and then divided by car occupancy (average number of people in cars). The resulting zonal attractions for this trip purpose will then be total vehicle trips done by shoppers or clients.

5.3.3 Balancing productions and attractions

The last step in the trip generation process is to balance trip productions and attractions. The estimated total trips produced should be equal to the total trips attracted. Each trip must have a beginning and an end. How the productions and attraction are balanced is based on the degree of confidence over the generation data. The productions have greater degree of confidence since it is based on travel survey done in the study area. The attractions are based on data from the study area and some external information. Therefore are the attractions balanced with regards to productions with the following equation:

$$BF = \frac{\sum P_Z}{\sum A_Z} \textbf{\textit{Equation}}\ \mathbf{2}\ (NCHRP\ Report\ 365, 1998\ )$$

Where the BF is the balancing factor found by dividing the sum of productions in all zones with the sum of attractions in all zones. This balancing factor is then multiplied with attractions in each zone according to the equation:

$$A'_Z = BF * A_Z\ \textbf{\textit{Equation}}\ \mathbf{3}\ (NCHRP\ Report\ 365, 1998\ )$$

This is done individually for the productions and attraction belonging to each of the trip purposes. Now since the attractions are balanced to the productions for every trip purpose the unit of the attraction is not relevant. The results from this step will be seven sets of productions and attractions, one for each demand stratum (see Table 9).

	HO		HW		HP		HU	
	Product.	**Attract.**	**Product.**	**Attract.**	**Product.**	**Attract.**	**Product.**	**Attract.**
E	**190800**	**190800**	**311304**	**311304**				
NE	**95925**	**95925**						
Pup	**57448**	**57448**			**57448**	**57448**		
Stu	**91667**	**91667**					**72024**	**72024**

Table 9) Total productions and attractions for all of the seven demand stratums

5.4 Problems encountered and solutions

Only the activity pairs HW, HP, HU and HO will be used but not the return trips WH, UH, PH and OH. The reason is that the data used for the production generation have much higher reliability then the attraction generation. Because of this the model can distribute trips done in the direction towards the attractions with much higher level of confidence then towards the productions. To make this possible two HX trips will be used instead of HX-XH and after the trip distribution matrix has been calculated the mean value of the upper and lower triangle will be taken. The upper triangle represents the trips going from the attractions to productions while the lower represents the opposite. When the mean value is taken then for example 1000 trips to work will be transformed into 500 going to work and 500 going home from work.

5.5 Remaining issues

Attraction generation for jobs is merely estimation where the accuracy depends on how good match is between categories at two government agencies. By studying what is included in each of those categories, better match could be found and thereby better results. Spatial information on jobs where number of jobs with connection to address or geographical location like the population data used is though always the best data.

One more purpose category could be included, that is shopping trips. Of all the trips done in the travel survey 8,1% was shopping trips which could be a big activity groups and attractions for it could be easily extracted since one of the land use category is retail.

Most model additionally to activity pairs form activity chain. Activity chain describes a sequence of activity pairs, for example the activity chain home - work - other - home (HWOH) to better describe a real trip pattern a road user would do in a day. Activity chains will not be used in this model since the travel survey used doesn't have enough information on trip ends or all destinations of a road user within the day.

6. Trip distribution (step two)

Trip distribution is the second major step in the four step transport planning model. Trip distribution is the process that links the trip productions to the trip attractions calculated in step one, for each zonal pair.

6.1 Common approaches in trip generation models

A mathematical model often referred to as a gravity model is the most common approach to calculating the trip distribution. Gravity model is based on the assumption that the trips made in a planning area are directly proportional to (VISUM manual, 2007)

-the relevant origin and destination demand in all zones and
-the functional values of the utility function between the zones.

The gravity model calculates a matrix of the origin-destination pairs from available matrix boundary sums (productions and attractions of the individual zones). The model determination of where trips are going is based on the destination zones attractiveness (attractions) and the connection quality between the zones. The underplaying formula for trip distribution is

$$T_{ij} = a_i b_j O_i D_j f(c_{ij})$$ **Equation 4** $(Ortúzar, J. De\ D., Willumsen, L. G., 2001)$

Where;
$T_{ij} = is\ the\ number\ of\ trips\ from\ zone\ i\ to\ zone\ j,$
$ai\ and\ bj = the\ ballancing\ factors$,
$O_i = the\ productions\ in\ zone\ i,$
$D_{ji} = the\ attractions\ in\ zone\ j,$ and
$f(c_{ij}) = the\ utillity\ function$

The variable c_{ij} inside the utility function is an indicator of connection between the zone i and j. Indicator of connection is often measured by travel time, distance or cost. The utility function on the other hand is a function of the connection indicator that describes people's willingness to do the trip based on that connection indicator.

6.2 VISUM approaches and concepts

VISUM uses the gravity model approach to calculate trip distribution with several choices of utility functions. From them the combined formulation is used, mainly because that its distribution curve has the closest fit to the surveyed trip length distribution (see description in chapter 5.4). As a indicator of connection, loaded travel time of passenger car is used. Loaded travel time is used since trip length distribution surveyed is measured with time. The program calculates these travel times and displays them in the form of skim matrices. Skim matrix is a matrix of all the travel times between all the zones. Loaded travel time is the travel time between two zones where the possible delays from traffic congestions is taken into account.
The combined formulation used can be written as:

$$f(c_{ij}) = a * b^{c*ij} e^{-c*c_{ij}}$$ ***Equation 5*** $(Ortúzar, J. De\ D., Willumsen, L. G., 2001)$

Where;
$a, b\ and\ c = friction\ coefficients$

The utility function works with friction coefficients, i.e. with values within the utility function, which map the reaction of road users to travel cost or time. When indicator of connection is a function of time, length or cost VISUM calls it impedance.

6.3 Data sources used

As described in chapter 5 productions and attractions for seven separate demand stratums where calculated. In this step a trip distribution matrix is calculated for each of these demand stratums using equation 4. Demand stratums react differently to travel times for example employee going to work has different reaction to travel time then a primary school pupil going to school. This behaviour is simulated in the model by using different friction coefficients for the demand stratums (see equation 5).

Additionally to the productions and attractions provided by step one, four external zones are added to the trip distribution matrix. External zones are used to include traffic going out of and inside the study area into the model calculation. Before the above mentioned seven trip matrices can be calculated productions and attractions for the external zones has to be estimated. This process will be described in the following sub-chapter.

6.3.1 External travel estimation

External trips are trips that have at least one end outside the study area. Usually the external trips have one end inside and one end outside the study area, those trips are called internal-external or external-internal trips. When both ends of a trip are outside the study area they are called external-external trips or through trips (*NCHRP Report 365, 1998*). The model manages these trips by adding imaginary zones where those external trip ends occurs. The study area will have four external zones that should cover all external trips between the capital area and the rest of Iceland (see Figure 15).

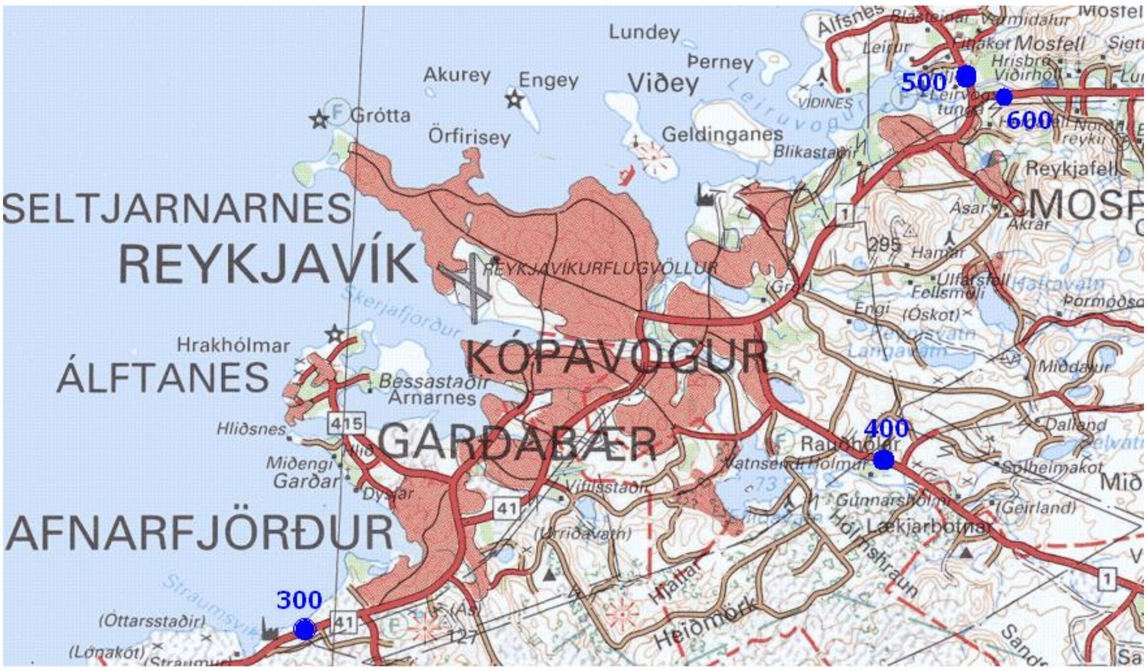

Figure 15) Map of the external stations used in the model (image source: National Land Survey of Iceland, 2002)

When the external zones have been decided few steps are required to develop the internal-external, external-internal and external-external volumes. These steps are:

- Estimation of through trips at each external zone,
- Distribution of through trips between the external zones,
- Estimation of external-internal trip production and attractions and
- Distribution of internal-external and external-internal trips between internal zones and external zones.

The NCHRP report is used as a guideline for these steps. The report's guideline is based on research that showed that through trips percentage was relative to the functional classification of the external highway, the connectivity of each external zone pair, daily volume at the external zone and the population size of the study area (*NCHRP Report 365, 1998*). The guidelines reliability is best with study area wit population up to 100.000. The guideline recommends a roadside survey otherwise. The study area in question has 190.000 inhabitants which is over this reliability limit. However to be able to use the guideline it is assumed that the study area is in the upper limits. For the first step zones 300, 400 and 500 were classified as principal arterial and zone 600 as a minor arterial. Principal arterial is assumed to yields 10% through trips while minor arterial only 1% through trips.

The process to distribute the through trips between external zones is shown in appendix 1. These through trips will be added to the final trip matrix before the assignment stage.

To estimate the external-internal trip production and attractions information is needed to find out whether the study area is an importer or an exporter of work force and by how much proportion. For this directed hourly traffic counts are evaluated. In Figure 16 one can see that there are more vehicles coming to the capital area during the morning peek hour then leaving. This indicates that more people are coming to the capital area for work and school then leaving.

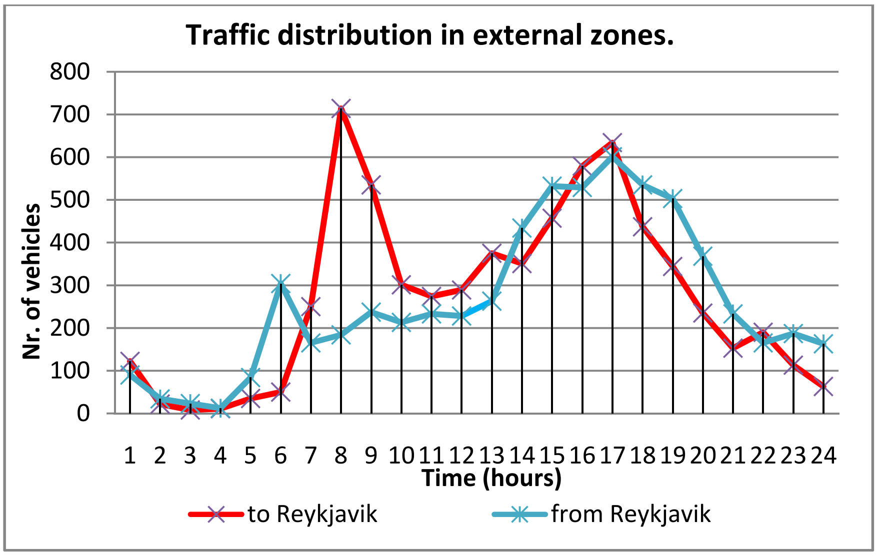

Figure 16) Traffic from and to the capital area (Brynjarsson, F., I., 2009).

To find out the net import of work/school trips the ratio of in- and outbound trips are taken during the morning (from 6:00 to 9:00). The ratio yields 65% net import of trips. This kind of counts where only available for one of the external zones in question or zone 300 so the same proportion is assumed for the other external zones.

The distribution of internal-external and external-internal trips between internal zones and external zones is done in the distribution stage of the model where the external zones are assumed to be regular zones in the model.

6.3.2 Trip matrix adjustments

The last step of the trip matrix calculation is the balancing of the matrix. The goal is the same as in the earlier mentioned, balancing of productions and attraction (see chapter 5.3.3), to get the total “to” trips as many as total “return” trips. The balancing process is though a bit more advanced. The matrix is balanced with the factors a_i and b_j (see equation 4) over and over again until certain convergence is met. As we are focusing on the “to” trips (see chapter 5.4) the distribution process is more accurate in the direction towards the attractions. For this reason the matrices will be single constrained balanced. Single constrained balance simply means that only one of the two balancing factors are used which is in this case a_i, the other on is set to one. The formula for balancing is;

$$\mathrm{a_i} = 1/\sum_j D_j f(c_{ij}) \quad \textbf{\textit{Equation}}\ \mathbf{6}\ (NCHRP\ Report\ 365, 1998)$$

The results of this steps calculation will be seven trip distribution matrixes, one for every demand stratum, showing person trips in the direction towards the attractions. To correct the matrix of having two trips going to the attraction instead of towards and a return trip mean value is taken of the matrix upper triangle and the lower triangle.

6.4 Problems encountered and solutions

The gravity models uses utility function with friction coefficients (see equation 5) that determines the distribution of trips among the attractions available based on indicator of connection, which is in this case travel time. The utility function can be expressed as a distribution curve where the friction coefficients determine its shape (see Figure 17).

From the travel survey average travel time of all trips done in the study are extracted (see curve market travel survey in Figure 17). As mentioned in chapter 6.3 population segments react differently to distance, travel time or cost e.g. employee going to work has different reaction to travel time or cost then primary school pupil going to school. This behaviour is simulated by using different friction coefficients for each of the demand stratums (see $a, b\ and\ c$ in equation 5). An attempt is made to simulate this behaviour by having different friction factors for each trip purpose. For this few assumptions are set:

- Workers and students travel generally further than the average and therefore have longer average travel time.
- Primary school students are assumed to go to the nearest school.
- Other trips are equal to the average travel time.

These coefficients are then revised after the assignment step, when the simulated traffic is compared to observed traffic. The best solution found can be viewed in figure 16.

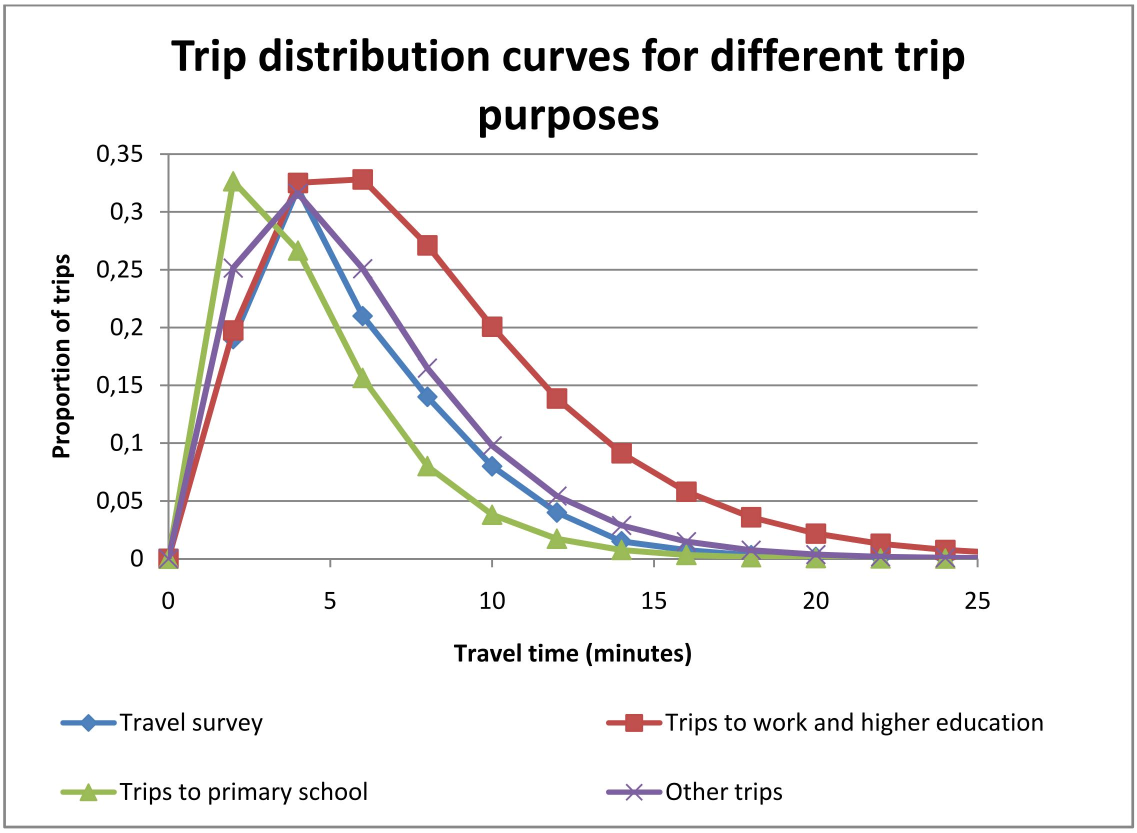

Figure 17) Graph showing different travel length distribution for trip purposes.

6.5 Remaining issues

People base their choice of destination on more factors then just the travel time by passenger car. Amongst these factors is what other modes are available, for example if it is more convenient to take the bus to go shopping in zone x then to drive the car to zone y, the road user will choose the first option. Trip distribution models usually take this factor into account. Why this is not included is because of the limited time given for this project.

7. Mode choice (step three)

Mode choice analysis is the third major step of the four step modelling process. In this step zone to zone person trips calculated in the previous step is split into trips using public transport and private transport. In this study private transport is the car and public transport is the public bus system as is described in chapter 1.4. Seven trip matrices calculated in the previous step (one for each demand stratum) will be split into 14 trip matrices or seven for each mode. These matrices will then be joined for each mode before the assignment stage.

7.1 Common approaches in mode choice models

The most common approach in mode choice models is the generalized logit model. The model estimates the probability for road user of choosing a specific mode (*NCHRP Report 365, 1998*). The generalized logit model is given with the equation.

$$P_i = \frac{e^{u^i}}{\sum_{i=1}^{k} e^{u^i}} \boldsymbol{Equation\ 7} \text{ (NCHRP report 365, 1998)}$$

Where

P_i = the probability of a traveller choosing mode i,

U_i = a linear function of the attributes of mode i that describe its attractiveness, also known as the utility of mode i or impedance, and

$\sum_{i=1}^{k} e^{u^i}$ = the sum of the linear functions of the attributes of all the alternatives k, for which a choice is available.

The linear function of the attributes, or impedance u_i, is composed of

$$u_i = a_i + b_i * IVTT_i + c_i * OVTT_i + d_i * COST_i \boldsymbol{Equation\ 8} \text{ (NCHRP report 365, 1998)}$$

Where

$IVTT_i$= the in-vehicle-travel-times for mode i,

$OVTT_i$= set of variables measuring the out-of-vehicle-travel-time for mode i,

$COST_i$ = the cost of mode i,

a_i= mode specific coefficient (constant) to account for mode bias not measurable with level of service variables,

b_i = coefficient for the IVTT variables of mode i,

c_i = coefficients for the OVTT variables of mode i, and

d_i = coefficient for the COST variables of mode i,

7.2 VISUM approaches and concepts

Among many approaches the program provides the generalized logit model has been chosen for this study. The decision was based mainly on its popularity and easy access to information. Trips will be split for every demand stratum into two modes: private transport and public transport. The private transport are passenger car trips and the public transport are trips done by the public bus system or by foot. The transport mode bicycle is not included

To be able to calculate what mode road user will choose, comparable unit of mode attractiveness is needed. The unit of attractiveness or impedance will be function of cost, out-of-vehicle-time and in-vehicle-time (see equation 8). The program calculates this impedance between all the zones for the modes in question and presents them in a skim matrix. Two skim matrices will be calculated, one for each mode. Timetable approach is used to calculate impedances for the public transport. With timetable approach every bus line with all their journeys are needed in the model. This gives the program what it needs to calculate all variables for the in-vehicle-time such as travel time in the busses, and the out-of-vehicle time such as walking time, waiting time and bus exchange waiting time.

7.3 Data sources used

The complete bus network introduced in chapter 2.5 is implemented into VISUM. All information for the system are taken from the Reykjaviks bus networks winter time schedules and route maps (Official homepage of Strætó bs, 2009). First all the 30 bus lines are drawn with all their bus stops and time between stops where set. This gives the time for a route to do one trip. After that different headway for various periods of the day were set to generate timetables for the route. Most common is 15 minutes headway in the morning and evenings with 30 minutes during the day and 60 minutes during the night. There are more than 2000 individual time tables (bus trips) in the model. With such detailed information the program can tell where every bus is every second of the day.

7.3.1 Private transport impedance

Attributes needed to calculate the impedance for the private transport is loaded travel time and cost. Skim matrix for loaded travel time has already been calculated (see chapter 6.2). Information on The cost of travel for a private car is estimated as a function of length. Information on what medium prised car with average fuel consumption costs per kilometre is found from the Icelandic car association (Official homepage of the Icelandic car association, 2009). The cost was estimated to be 51 IKR per kilometre. New skim matrix with the impedance of already available loaded travel time and cost per kilometre was then calculated.

7.3.2 Public transport impedance

Attributes needed to calculate the impedance for the public transport is cost, in-vehicle-time, out-of-vehicle-time. The only cost attribute is the bus fare and the fares are based on the travellers age. Additionally there is currently a government policy that allows all students to travel with busses free of charge. Based on this the cost attributes for different demand stratums are 227 ISK for employed, 80 ISK for not employed and free for pupils and higher education students. In-vehicle-time is the time spent in the bus in case if the journey involves taking two busses, the time spent on the second bus is added. Out-of-vehicle-time is the sum of walk time, access time, egress time, transit exchange walking time, transit exchange waiting time. Access and egress time is the time spent in zone connectors (more information in chapter8.3). Walk speed used is 5km/h. New skim matrix with the impedance of these attributes is then calculated.

7.4 Problems encountered and solutions

Two problems where encountered during this step, they will be explained individually in the following sub-chapters.

7.4.1 Travel behaviour

The coefficients a_i, b_i,c_i, and d_i (see chapter 7.1) describe how much different attributes effects people's choice of mode. For example, if a road user values cost over time he's more leaning towards the public transport, respectively if he values time over cost he will probably favour the passenger car. No direct studies on travel behaviour have been carried out in Iceland to find out these coefficients. Furthermore are these coefficients very different between different study areas so direct use of other set of coefficients is not possible. For the model to work some preliminary coefficients still has to be set. So to start with coefficients from 13 cities in the United States are studied. Then simulations are done with few combinations of those coefficients and then the results are compared to the travel survey. The travel survey gives proportion of travellers using different modes for two purposes, going to work and going to school also proportion over all the trips are available. Each of the demand stratum is compared to these surveyed proportion (see table 10). Adjustments had to be made on the coefficients. General trends where used for the adjustments. Widely known trend is that with increased income people get less affected by cost of travel (NCHRP report 365, 1998). Also the effect described earlier with longer distance from the Greater Reykjaviks central areas people tend to favour the passenger car (see chapter 0). The following table show the proportion of trips done by public transport surveyed compared to simulated proportion. The coefficients chosen can also be viewed in the table.

Demand segment	Trip Purpose	Proportion choosing public transportation		Travel behaviour coefficients				
		Estimated	observed	a (constant)		b	c	d
				Private	public	In-vehicle-time	Out-of-vehicle-time	Cost
HW-E	To work	8%	11%	-2	-0,5	-0,13	-0,27	-0,002
HP-Pup	To school	31%	49%	-2	-0,5	-0,1	-0,21	-0,003
HU-Stu	To school	19%	49%	-2	-0,5	-0,08	-0,18	-0,004
HO-all	all	14%	24%	-2	-0,5	-0,1	-0,21	-0,003

Table 10) Proportion of different population segments choosing public transport (data source: Gallup, 2002)

These coefficients are found after simulated travel is compared to passenger counts from 2008. The passenger count is given as number of passengers entering and leaving the bus on every bus stop.

7.4.2 Timetables

For the bus system to keep an even service level throughout the day, shorter headway is needed during the peak traffic hours. To simulate this, the program distributes traffic load differently over the time periods (see Figure 18).

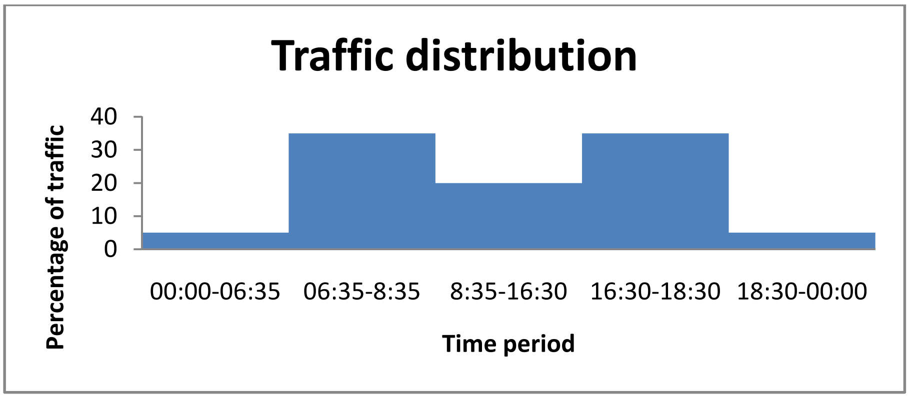

Figure 18 Public transport traffic distribution used for this study.

No information is available on actual traffic distribution during the day in the study area. Therefore is the traffic distribution taken from a German demo model provided by the software.

7.5 Remaining issues

The travel survey used for this study is outdated for this step of the model. Government policies such as students ride for free have been implemented since the survey was made in 2002. Additionally to that travel behaviour coefficients are estimated. New travel behaviour study would drastically strengthen this step.

Probably the single most important factor that has to say what mode a road user would choose is whether he has access to car or not. This would be implemented by breaking all the demand stratums in two parts for example employee going to work that has access to car (HW-E+car), or student going to school that doesn't have access to car (HU-Stu-car). Information to do this is ready available from the travel survey but working with 14 demand stratums before the mode choice step was too time consuming for this project. On the other hand this can easily be added afterwards.

The mode bicycle is not included in the calculation. To include this mode more complicated methods need to be implemented to the model. One popular method is nested mode choice. This method involves adding a second choice of mode after the first one.

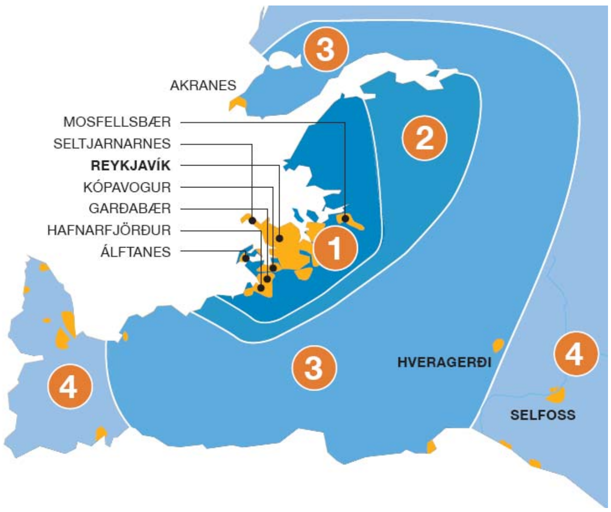

Figure 19 Bus system fare zones (Official homepage of Strætóbs, 2009)

The bus system serves much larger area then the greater capital area. The whole system is split into four fare zones (see figure 19**Error! Reference source not found.**). The study area is all inside the first are zone and the model will thereby not be able to account for additional cost outside the study area.

8. Assignment (step four)

The assignment step is the fourth and last major step of the traditional four-step process. This includes both private car and public transportation of vehicle and person trips, respectively. The assignment of trips to the network is the final output of the modelling process and becomes the basis for validating the models ability to replicate observed travel in the base year as well as to evaluate changes in the transportation system in the future (NCHRP report, 1998).

8.1 Common approaches in assignment procedures

Three basic approaches can be used for traffic assignment purposes:

All-or-nothing assignment. The simplest assignment method is “all-or-nothing” assignment. This method assumes that there are no congestion effects, that all drivers consider the same attributes for route choice and that they weigh them in the same manner. The absence of congestion effects means that link cost or time is fixed. The assumption that all drivers perceive the same cost or time means that every driver from i to j chooses the same route. Therefore, all drivers are assigned to the same route between i and j and no driver is assigned to other, less attractive, routes. (*Garber, N.J., Hoel, L.A., 2002*)

Stochastic user Equilibrium assignment. Stochastic methods of traffic assignment emphasise the variability in driver’s perception of travel time or cost and the urge they seek to minimise it. Stochastic methods need to consider second-best routes (in terms of cost or time).This generates additional problems as the number of alternatives second-best routes between each O-D pair may be large. Several methods have been proposed to incorporate these aspects. Of them the proportion-based methods has relatively widespread acceptance. The proportion-based methods allocate flows to alternative routes from proportions calculated using logit-like expressions. (*Garber, N.J., Hoel, L.A., 2002*)

Equilibrium assignment. Different from the stochastic method the equilibrium assignment methods concentrates on capacity restrains as generator of a spread of trips on a network. For a start, capacity restraints models have to make use of functions relating flow to the cost, or time of travel on a link. These models usually attempt to approximate to the equilibrium conditions as formally enunciated by Wardrop 1952:

> *Under equilibrium conditions traffic arranges itself in congested networks in such a way that no individual trip maker can reduce his path cost by switching routes.*

If all trip makers perceive cost in the same way (no stochastic effects):

> *Under equilibrium conditions traffic arranges itself in congested networks such that all used routes between an O-D pair have equal and minimum cost while all unused routes have greater or equal costs.*

This is usually referred to as Wardrop’s first principle, or simply Wardrop’s equilibrium. (*Ortúzar, J. De D., Willumsen, L.G., 2001 “Modelling Transport*)

Equilibrium assignment process can be divided into three simple steps: First traffic is assigned onto the network based on the initial travel time calculated according to free flow speed. In the second step the number of trips assigned to each link is compared with the capacity of the link to determine the extent to which link travel time have been reduced. With relationships between volume and travel time (or speed) it is possible to recalculate the new link travel time. Finally a reassignment is made based on these new values. The iteration process continues until an equilibrium balance is achieved.

Most common relationships between volume and travel time used is the speed-volume relationship expressed in the following formula:

$$t = t_0 \left[1 + \alpha(\frac{V}{C})^{\beta}\right]$$ **Equation 9** (*Ortúzar, J. De D., Willumsen, L.G., 2001 "Modelling Transport)*

Where

t = loaded link travel time,

t_0 = free-flow travel time,

V = volume on the link,

C = capacity of the link, and

α, β = volume/delay coefficients.

8.2 VISUM approaches and concepts

Before the actual assignment the fourteen person trips matrices calculated in the previous step, seven for each mode, are joined by mode. The trip format of these two matrices is person trips. The private transport person trip matrix has then to be transformed into vehicle trip matrix, that's done by divide the matrix with car occupancy factor. Car occupancy factor used to start with is 1,34. The public transport matrix will be assigned as person trips. VISUM assigns these matrices, one for private transport and the other for public transport, separately. Out of six types of assignment methods VISUM offers, including those listed in the previous chapter, the equilibrium method and the stochastic user equilibrium method where tested. The later one gave much better results and was therefore chosen for the study. For the public demand timetable based assignment with shortest path search option will be used. This method is believed to give the best results compared to the information used. In timetable based assignment it is assumed that the passengers have timetable information available and can find the shortest path to their destination. Having this information available all passengers are assumed to take the shortest path between zone i and j in means of journey time.

8.3 Data sources used

Few adjustments were made to the road network illustrate in chapter 3.4 before it was imported into VISUM. In addition to the information provided with the network data for each link, number of lanes, free flow speed, capacity, new link classification, and one way streets, had to be added. VISUM splits up each link by direction. Thereby, all link attributes that were not symmetrical by direction had to be more or less manually configured. Number of lanes was assigned to links based on aerial photographs. One way streets are set by the program by prohibiting all modes except walking in one direction, this had to be manually configured in the model. Speed limits that where provided by the network where changed to free-flow speed. Since free-flow speed is usually higher than the speed limits (*HCM, 2000*), 5km/h was added for the lowest speed limit and other roads 10km/h

For the stochastic user equilibrium assignment process to work properly all links in the above discussed road network had to be classified. Each link group could have as similar function in the network as possible. Each group would then be assigned with its own capacity and volume/delay parameters (see α, β in equation 9). How the capacities and the new link classification where found will be described in chapter 8.4.

To connect the travel demand, calculated in the previous steps, to the supplying road network zone connectors had to be assigned. All trips generated in one zone will start and end in one particular spot in the zone, called centroid. Zone connectors are imaginary roads connecting this centroid to the road network. Furthermore the length of the zone connector has to serve as a mean travel distance inside the zone. All zone centres and connectors had to be carefully placed with that in mind.

8.4 Problems encountered and solutions

Following problems were encountered in this stage. First one was how the road network links should be classified and second one is what capacities should be used.

8.4.1 Link classification

The current network was already classified into three classes. Those initial classes had various speed limits and in some cases links with grade separated intersections were classified into same class as link with signalized intersection. The road network was further classification into 5 classes based on the initial classes, speed limits, and intersections density. The classes could be called; housing streets, minor collector, major collector, multilane urban street, and multilane highway (see Figure 20).After that volume/delay coefficients had to be assigned to each class. The volume/delay coefficients controls how the traffic reacts to congested conditions (see equation 9). The highway capacity manual provides some guideline on how to choose volume/delay coefficients (*HCM, 2000*). In the manual urban streets are classified into 4 classes and the volume delay coefficients are assigned to each class based on the signal density. If the signal density is not known the manual recommends using some default values. Data to calculate signal density was only available for one municipality of the study area so default values were used. For multilane highways the manual gives volume/delay coefficients for four different free-flow speeds. Volume/delay coefficients for the free-flow speed 96 km/h were chosen.

	Free flow speed	Signal spacing	Free flow capacity (LOS E)			Volume/delay parameters		Capacity 24h per lane		
	km/h	signals/km	cp/h/ln	cp/h/ln	cp/h/ln			cp/day/ln	cp/day/ln	cp/day/ln
			1 lane	2 lanes	3 lanes	α	β	1 lane	2 lanes	3 lanes
Multilane urban	80	1	1110	2120	3040	0,74	5	11100	21200	30400
Major collector	60	2	860	1650	2370	1	5	8600	16500	23700
Minor collector	60	4	840	1610	2310	1,4	5	8400	16100	23100
Housing street	40	6	790	1520		1,5	5	7900	15200	0
Multilane highway	90		2100			0,08	6	21000	42000	63000
Connectors	50					0	0	99999		

Table 11) Road classification used for the model

Table 11 shows the classes chosen with all their parameters needed for the assignment calculation. How the capacities were found will be described in the following chapter.

8.4.2 Link capacity

Link capacity is the maximum traffic flow obtainable on a given roadway using all available lanes; usually expressed as the number of vehicles per hour (vph) per lane or as directional capacity per hour (*HCM, 2000*).The preferred method for deriving link capacity for a travel demand model is to use the procedures containing in the 1994 Highway capacity manual (*HCM, 2000*) and calculate capacities specific to the physical limitations in each link. This is often not feasible because many parameters have to be measured for every link in the model. The alternative method is to use link capacities that reflect average conditions for various link types. Tables in HCM will provide initial capacities that can be used for building the network. These capacities are based on the service volumes for level of service E and are given for the four urban street classes mentioned in the above chapter. LOS E capacities are given as number of vehicles per hour per direction. However, the model being built is based on 24 hour traffic. To transform the hourly traffic into daily traffic common practise is used that assumes peak hour traffic is 10% of the total daily traffic.(*Árnadóttir, A., Þ., 2009*) The capacity for multilane highway is calculated using formula 30-2 in the highway capacity manual with heavy-traffic 5% (*HCM, 2000*).

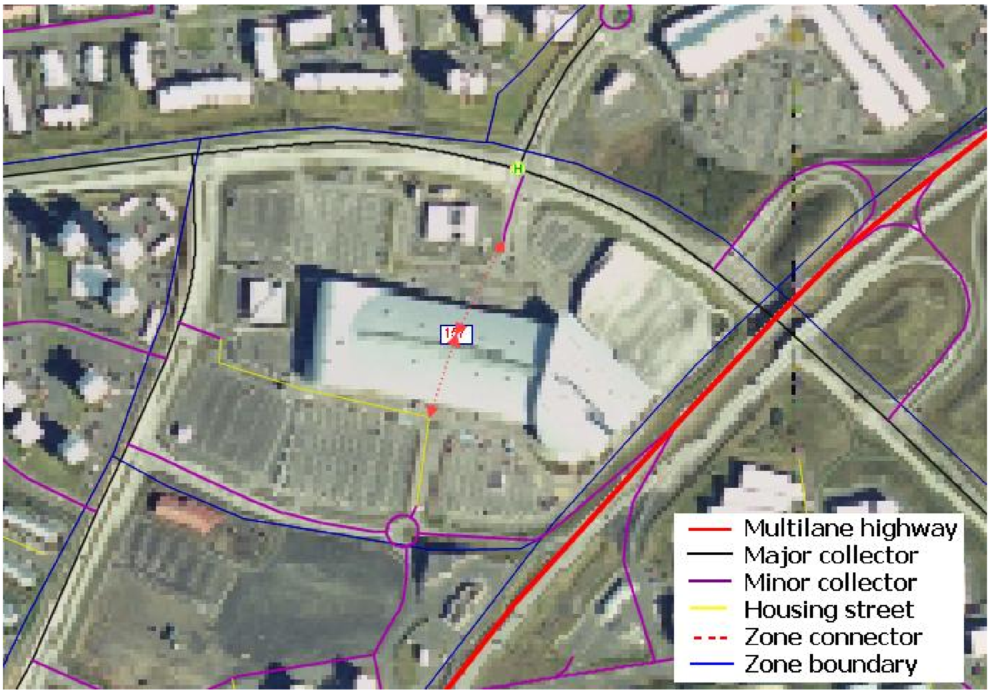

Figure 20) Example of the road classification and zone connectors (Aerial photograph: *Þorsteinsdóttir, B., 2008)*

8.5 Remaining issues

Speed limits provided with the road network turned out to be inaccurate. This applies mainly to streets with 35 km/h and is registered with the speed limit 50 km/h. This can result in streets being assigned to wrong link class with wrong capacity and volume/ delay function. This has been corrected for many streets but not all. During the validation process this will be kept in mind.

Trips that have their origin and destination in the same zone are called intra-zonal trips. They are not loaded to the network since they move from a centroid to itself. This could cause a problem when zones cover large area where the intra-zonal trips are large proportion of a road connection being studied. VISUM provides solution to this by dividing zones into subzones that will not be studied further in this report.

9. Overall model validation

In this stage of the process the overall model performance is validated. One disadvantage with four step models is that it is hard to distinguish how much each step contributes to the overall model inaccuracy. Therefore is the model validation performed at three levels to pinpoint where potential errors can be found. First, system wide performance is reviewed to determine if regional inputs or parameters should be changed. For example, given that the assignment volumes appear to be slightly lower than the observed volumes, changes in demography or land use data, trip generation rates, car-occupancy factors, or travel length distribution coefficients could be used to increase volumes throughout the study area. Second, if the assigned volumes in different road class categories are estimated less accurate than in others, the default speed or capacities on the various road class categories could be modified in order to balance the results. Third, problem on specific links confined to small area of the network could indicate network coding errors (NCHRP Report 365, 1998).

The mode choice step is believed to be built on possibly outdated data (see chapter 7.5). Therefore is the validation split into two parts. One part is validation of the model without the mode choice and the second is with mode choice. By doing this it is possible to estimate how much the mode choice step adds to the overall error. Furthermore by doing this it is possible to compare this model with older ones, since they do not have mode choice.

9.1 Validation without mode choice

The validation process on three levels is applied for this part. Calculated traffic volumes are compared to observed volumes on so called screen lines discussed in chapter 3.3. Screen lines are lines across a study area that often follow natural realities. In this case a river, the ocean and roads that cuts the area (see black lines in figure 20). Screen lines give a good idea of the amount of traffic expected and the traffic displacement over the study area.

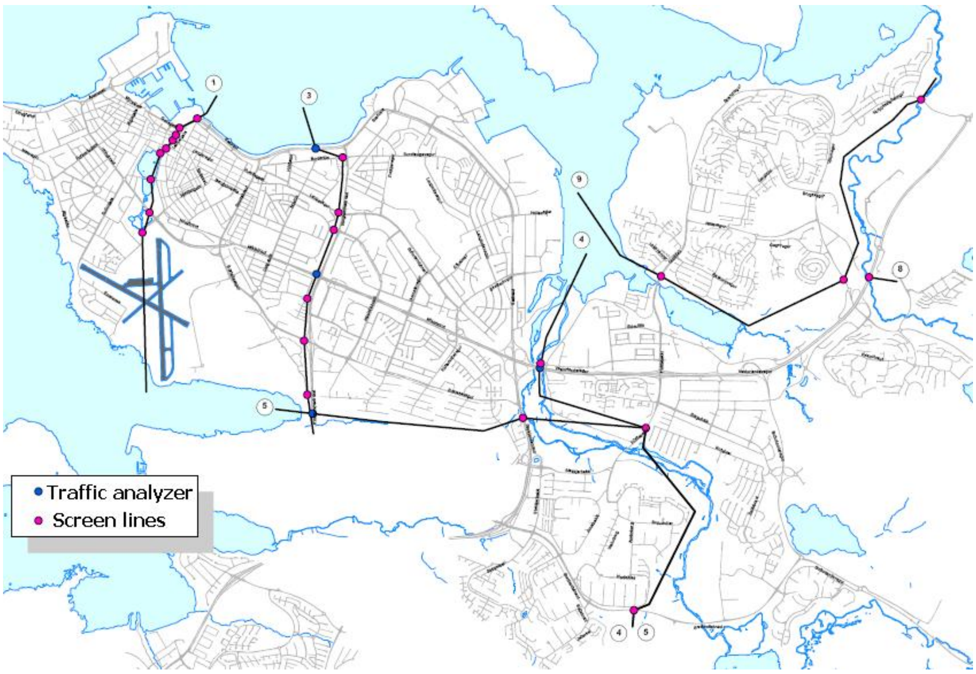

Figure 21)Map over screen line count done by Reykjavik municipality (Official homepage of Reykjavík, 2009)

At the first level of validation the screen lines were mainly used for validation. Best results found are listed in table 12. Based on the screen lines the car-occupancy was adjusted to balance the total amount traffic. The final car-occupancy factor used was 1.90 passengers per car. This is higher than observed car –occupancy of 1.72 passengers per car, since in this case all trips are considered to be travelled with car. At this level the travel length distribution coefficients (see chapter 6.4) were also adjusted and the best result found can be viewed in Figure 17.

						Largest deviation	
	Nr of streets	**Simulated traffic**	**Counted traffic**	**Average percentage deviation**	**Total deviation (in nr. of vehicles)**	**Street name**	**Deviation**
Section 1	8	79.300	87.941	15%	14867	Hafnarstræti:	36%
Section 3	8	149.934	166.474	21%	28448	Hamrahlíð:	-57%
Section 4	4	127.849	125.857	6%	5440	Höfðabakka - brú:	-11%
Section 5	4	180.664	163.701	10%	16963	Kringlumýrar -braut:	-16%
Section 8	1	24.580	25.185	2%	605	Vesturlands - vegur:	2%
Section 9	3	49.975	48.276	42%	9617	Korpúlfsstaða -vegur:	-94%
Total		612.302	617.434				
Total deviation				17,2%			

Table 12) Simulated traffic compared with screen-line counts (without mode choice)

At the second level where accuracy was reviewed by different road class categories it was found out that the multilane urban and minor collector classes had the worst performance while multilane highway had the best (see table 13). In the case of multilane urban, possible reasons could be that some of the roads should be classified under the multilane highway class and therefore have different volume/delay function. In the case of the minor urban the problem discussed in chapter 8.5 could be the reason. The problem was that the speeds provided by the road network data was inaccurate and possibly some streets have been assigned to wrong class.

Road class	**Nr of streets**	**Simulated traffic**	**Counted traffic**	**Average deviation**
Multilane highway	7	354.135	361.730	10%
Multilane urban	14	253.548	347.980	66%
Major collector	93	892.269	1.150.343	47%
Minor collector	70	407.272	440.800	53%
Housing street	20	62.565	58.433	33%
Total		1.969.789	2.359.286	-20%

Table 13) Simulated traffic compared with all counts by road class categories

The third level of validation is very time consuming process where every road link with large deviation is validated throughout the system. Due to limited time for this project minimum time was spent on this level. Although some coding errors where fixed such as number of lanes on highway ramps and turn bans.

Two scales are used to measure the accuracy or the performance of the model. The first one is percentage deviation. The percentage deviation is measured in each link then the average percentage deviation is taken over a whole screen line or all the screen lines. To do this the absolute value is taken of the percentage first to give the right outcome. Percentage deviation doesn't give the full image of the error since the smaller streets contribute as much to the error as the larger volume streets, therefore another scale is used or the root mean squared error (RMSE). RMSE is a frequently-used measure of the differences between values estimated by a model and the values actually observed, in this case traffic counts. Individual differences in each road link are aggregated into a single measure of accuracy. The results can be viewed in table 12, appendix C and D. The overall result gives 17% total percentage deviation of simulated traffic compared to screen line counts and the RMSE value is 0,973.

When individual sections are analysed section 1 and section 9 give the worst results regarding percentage deviation. Possible reasons are that section 1 crosses the Reykjavik downtown area which is very hard to simulate since large proportion of the traffic are recreation trips not related to land use data. Section 9 has three connections. One of them is relatively new so it could be that many road users simply haven't started to take advantage of the better accessibility this new road provides.

When the whole traffic flow is analysed the largest contributors to the RMS error value is section 5. This section counts the import/export of trips inside the Reykjavik city centre area from the south. The estimated volume is greatly overestimated in one of the road link with 10.000 cars over the observed traffic. The underlying cause is the fact discussed in chapter 2.2 and problem discussed in chapter 5.5 or that the trip patterns or trip chains are not realistic enough. The centre area has large surplus of attractions so there is a large import of trips into the centre area. The model overestimates these import trips because every trip a person does returns to home. For example a person living outside the centre does three trips a day to the centre, this means the person goes to the destination and returns back home three times. More realistic trip pattern would be going to the centre for work then doing some other related trip as well in the centre before returning home.

9.2 Validation with mode choice

The mode choice step splits road user into two modes, private transport and public transport. Validation is needed for both the modes to investigate the overall effect of the mode choice. Validation for the private transport is done by comparing car flows against screen line counts and validation of the public transportation is done by comparing calculated passenger entering or leaving the busses at the seven largest bus exchange stations with passenger counts from these stations.

For the private transport, best results were found with the car-occupancy factor of 1.66 passengers per car. When looking at the volumes raised by the model compare to the screen-line counts, it appears that the private transport can be simulated with little less accuracy when mode choice is applied (see table 14). Total percentage deviation for screen-line counts is 20% and the RMSE value is 0,967. (See appendix C).

						Largest deviation	
	Nr of streets	Simulated traffic	Counted traffic	Average percentage deviation	Total deviation in nr. of vehicles	Street name	Deviation
Section 1	8	75.602	87.941	19%	16855	Hafnarstræti:	45%
Section 3	8	144.229	166.474	22%	30265	Hamrahlíð:	-59%
Section 4	4	127.230	125.857	9%	9741	Höfðabakkabrú:	-15%
Section 5	4	186.197	163.701	14%	22496	Kringlumýrarbraut:	-18%
Section 8	1	23.778	25.185	6%	1407	Vesturlandsvegur:	6%
Section 9	3	48.900	48.276	47%	9326	Korpúlfsstaðavegur:	-111%
Total		605.936	617.434				
Total deviation				20,0%			

Table 14) Simulated traffic compared with screen line counts (with mode choice)

Best results found when calculated passenger flows are compared to passenger counts can be viewed in table 15.

Station	Simulated		Observed		
name	Arrival	Departure	Arrival	Departure	Average deviation
Hlemmur	4432	4514	3144	2805	34%
Ártún	1601	1462	667	607	58%
Lækjartorg	1037	1261	1013	460	36%
Spöng	754	533	385	302	47%
Mjódd	274	265	1918	1761	-583%
Hamraborg	2338	1922	1892	1858	12%
Háholt	1	1	156	190	-17200%
Ásgarður	149	154	501	389	-194%
Fjörður	469	436	1044	898	-115%
total	11055	10548	10720	9270	7%

Table 15) Passenger counts compared to simulated values in all major exchange stations

By studying the counted volumes and compare them with the calculated flows in a model without a mode choice it was noticed that too high modal shift to the public transport occurred on roads with high congestions. On the other hand were there was little or no congestion public transport volumes where to low. Possible reason is that the travel behaviour coefficients discussed in chapter 7.4.1 where to sensitive for travel time in car.

With other words, no acceptable results were found for the public transport within the given time frame of the project. To reach some acceptable results with this step all available information has to be included. As discussed in chapter 7.5 it is possible to further split the demand stratums to population segments having access to car or not and set different travel behaviour coefficients for each of those. This is large factor involving people’s choice in mode. This comes very clear when looking at the travel survey, 93% of the population has access to car while 4% of the population uses public transport. It is recommended that this will be implemented before continuing with this step.

9.3 Results compared to older models

The four step model used to day in Iceland is for the base year 2004. The main difference between this model and the older one is that this model uses demand stratums throughout the simulation process to better simulate travel done by different population segments. The older on does not have a mode choice step. The older model uses simplified road network with 2869 road links while this one has the entire road network with 7330 road links. When comparing the exact links in the screen lines between these two models this model has 17% total percentage deviation and 0,973 in RMS error while the older one has 32% total percentage deviation and 0,960 in RMS error.

10. Conclusion and discussions

The results presented in this study are based on four stage transport planning model. This is simplified simulation of traffic flows in the greater Reykjavik area. Each of the steps was evaluated separately then the overall simulation was validated. Now when the model has been built and input data, calculation methods and simulation performance have been evaluated the main conclusion is that the model has better accuracy than previous models that have been used in Iceland, when calculated volumes are compared to observed screen lines counts. This model has 17% average percentage deviation and 0,973 in RMSE from counts while the old one has 32% average percentage deviation and 0,960 in RMSE.

Included in this project is a test whether mode choice could be simulated with acceptable results in the study area. The main conclusions are that mode choice can be simulated but the results were not close enough to the reality. The main reason is that estimation of coefficients that simulate road user's preferences for mode choice was based on outdated data. To fully implement this step to the four step model new travel survey is highly recommended. It is also recommended to further split demand segment into population segment with access to car or not since that is the single most important factor influencing people's choice of mode.

During evaluation of each step some comments were made on how better accuracy can be achieved. Three most important of them are listed below:

- Attraction generation for jobs is estimation where the accuracy depends on how good match is between categories at two government agencies. By studying what is included in each of those categories, better match could be found and thereby better results. Spatial information on jobs where number of jobs with connection to address or geographical location like the population data used is though always the best data.
- One more purpose category could be included, that is shopping trips (which constitutes for around 8% of the trips). This could improve the accuracy of the model.
- More work is needed on assigning right volume/delay functions to road classes and roads need to be checked if they are in right category.

There is one major factor that affects these results that need to be kept in mind that this model is calibrated and validated against the same data. This limits the possibility to draw any conclusion on the models real reliability. This is tough common practise since the data availability limits the possibilities.

Though the mode choice step wasn't successful the author is certain that this model has reached the point where it can be used for guidance in city planning and decision making. Public transportation concludes only 4% of all trips and therefore is not a major error contributor however the results will always have to be looked at with this fact in mind.

VISUM was a good choice of modelling software, its user friendly interface, its well organized command structure and good user manual made it possible to finish this study in time. Of the total 22 weeks worked on this project it took only 12 weeks to learn and build a fully functional four stage transport planning model with the software. Only the manual was used to master the program and the author has no previous experience in this kind of work. The single most time consuming part of the modelling work was to manually build up the public bus system which took one and an half week.

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Appendix A

Calculation of productions and attractions

	Productions				Attractions			
					P	U	W	O
Zone	E	Pup	Stu	NE	Seats	Seats	Jobs	Trips
1	6571	1750	2980	1692	0	0	549,224	1979,04
2	3482	807	1659	846	0	0	401,918	1990,48
3	2755	582	1327	555	175,61	0	103,67	726,39
4	3708	930	1861	801	36,6452	0	521,747	1294,65
5	4491	674	1906	1193	27,5932	0	245,473	1903,27
6	5579	1144	2817	1024	433	0	354,134	2554,64
7	4864	1158	2316	969	259,95	0	299,266	2252,61
8	0	0	0	0	191,529	5924	168,68	1067,61
9	2145	323	1773	347	624,28	0	132,672	229,92
10	70	0	152	5	0	5924	1076,73	858,025
11	0	0	0	0	0	0	0	0
12	1520	432	631	360	18,229	0	57,4863	469,354
13	787	139	308	161	0	0	726,549	1862,75
14	2327	422	948	441	243,282	0	235,162	1379,11
15	1711	373	618	396	13,3596	0	107,331	726,525
16	1938	359	863	418	31,1516	0	114,387	928,844
17	524	42	204	95	0	0	395,045	1517,34
18	1677	202	817	312	47,0083	0	281,971	1677,08
19	3283	453	1093	1301	177,732	0	359,385	1985,22
20	7	0	2	1	0	0	646,706	2444,14
21	505	56	174	154	0	0	191,085	1288,22
22	593	49	241	165	55,3736	0	73,9798	428,124
23	0	0	0	0	0	0	14,7915	118,075
24	100	0	27	42	0	0	121,995	922,645
25	80	0	36	13	0	0	158,396	267,715
26	110	0	40	28	0	0	190,233	1201,17
27	23	0	9	5	20,6637	0	36,3586	299,775
28	168	10	82	27	0	0	1406,28	4012,45
29	237	14	123	33	0	0	627,551	1576,08
30	1588	181	650	345	74,0396	1415	510,763	1561,09
31	694	91	257	198	57,8083	0	159,139	716,378
32	1340	126	561	294	0	0	1060,56	3973,67
33	1529	70	614	472	30,6521	0	473,623	2766,18
34	1053	63	509	154	0	0	705,792	2643,3
35	2015	209	870	397	29,5284	0	353,037	1314,26
36	2722	356	1156	523	2,6844	0	164,872	1172,22
37	1379	300	557	350	0	0	70,9109	611,135
38	1146	133	482	228	0	0	2112,68	4360,82
39	1213	63	310	709	0	0	1000,6	1626,81
40	2442	195	1039	381	0	0	869,754	3645,17
41	2851	272	1079	727	452,603	0	519,965	2049,61
42	138	35	72	48	62,428	0	133,979	385,374
43	60	0	11	6	0	0	1570,29	3885,83
44	1693	52	627	388	0	0	406,65	2229,99
45	4111	481	1530	946	308,02	429	3203,81	6807,35
46	3068	335	1275	678	0	0	192,916	1364,71
47	4150	213	1141	1809	0	0	2853,99	10744,3
48	194	0	94	79	130,974	0	1208,35	2947,18
49	903	199	396	211	141,836	0	298,12	1191,14
50	3782	854	1485	1097	245,779	0	362,165	2337,77
51	4	0	1	0	43,0129	0	293,061	384,375
52	0	0	0	0	0	0	2,75813	24,465
53	4218	821	1768	664	43,4499	0	237,306	1784,08
54	0	0	0	0	0	0	341,287	1195,4
55	5390	1206	2310	1053	1213,41	1397	431,826	2336,03
56	7	0	0	5	0	0	8,70843	77,245
57	1313	276	524	387	469,333	0	343,072	759,713
58	0	0	0	0	3,87053	0	3142,8	12360
59	1466	63	380	674	0	5022	572,906	1584,32
60	2118	340	793	717	55,3112	0	444,98	2018,06

61	1326	67	244	682	564,224	0	298,274	532,266
62	1504	407	638	330	0	0	144,661	655,166
63	2643	411	809	906	0	0	162,383	1403,09
64	2232	545	821	660	10,8625	0	61,9408	379,504
65	3112	754	1175	800	384,057	0	167,779	525,081
66	1440	392	531	303	23,4105	0	95,1811	644,637
67	2536	631	931	686	21,6001	0	60,3904	511,91
68	2132	631	928	413	306,459	0	89,773	411,647
69	2994	661	1315	594	30,2151	0	207,527	925,609
70	1841	582	677	408	253,458	0	72,8206	367,115
71	1223	347	434	302	0	0	293,345	469,215
72	4	0	0	0	0	0	2481,81	8323,71
73	24	4	11	1	56,1227	2914	563,786	2364,46
74	2485	553	1018	834	501,047	0	631,569	2592,71
75	3297	956	1396	1040	0	0	358,849	1005,83
76	0	0	0	0	0	0	1125,55	4216
77	67	11	48	12	78,4095	0	2475,33	7628,24
78	0	0	0	0	93,3298	0	1438,86	4270,4
79	4	0	0	0	0	147	1279,83	4064,23
80	13	0	7	12	0	0	1751,95	3184,34
81	2979	846	1218	1030	467,336	0	327,597	2291,35
82	2154	653	790	805	0	0	918,065	2121,31
83	2803	903	1282	656	363,206	0	227,534	1429,93
84	28	4	4	8	0	0	319,867	1634,11
85	0	0	0	0	0	0	73,2542	649,775
86	1894	373	605	1100	0	0	1325,5	2943,86
87	954	282	387	318	94,2662	0	129,951	472,208
88	0	0	0	0	20,9134	0	57,2626	143,755
89	695	0	48	813	0	0	2053,19	2643,6
90	2311	475	818	1010	0	0	98,1896	679,965
91	2502	553	943	836	0	0	227,495	1395,97
92	2098	682	1023	546	24,4718	0	130,581	1059,38
93	5369	1324	2318	1888	542,062	0	590,032	4268,11
94	2865	785	1340	763	0	744	565,642	2258,65
95	0	0	0	0	0	0	2189,64	8281,41
96	1807	230	701	238	0	0	234,002	1458,17
97	0	0	0	0	0	0	558,365	1363,77
98	81	0	40	3	0	0	4146,09	6510,14
99	3588	953	1295	504	225,552	0	504,744	1506,86
100	111	11	43	6	0	2651	1968,41	2923,02
101	7	7	2	0	0	0	2177,75	4829,93
102	5365	1064	1263	772	33,0868	0	218,408	1349,39
103	33	0	11	2	0	0	2305,16	5301,46
104	3335	1019	1141	403	595,126	0	702,457	1722,94
105	4149	1241	1541	518	37,0822	0	42,6896	325,99
106	3629	1114	1514	324	400,288	0	175,352	968,815
107	1183	284	212	205	0	0	11,4542	89,11
108	312	16	30	81	0	0	518,726	2420,88
109	798	24	46	251	0	0	686,48	1184,48
110	4226	1052	899	699	447,172	0	226,349	1048,5
111	5247	1304	1225	752	564,286	0	206,549	1161,69
112	3339	958	791	482	30,1527	0	172,715	1498,84
113	6977	2083	1549	1127	60,9921	0	313,242	1860,46
114	2606	638	535	470	345,039	0	91,3318	269,55
115	5264	837	928	980	0	0	378,768	2390,85
116	3540	914	777	552	0	0	101,363	628,543
117	2510	268	448	450	624,28	0	110,813	231,785
118	6757	2303	1623	936	51,1909	0	262,236	1975,36
119	5168	1239	1167	784	525,956	2122	547,847	1571,45
120	2638	674	627	339	583,639	0	552,821	1424,54
121	4758	792	1062	721	55,7482	0	115,749	837,19
122	0	0	0	0	0	0	0	0
123	20	4	14	3	0	0	267,523	65,925

124	3411	1018	1356	569	329,745	0	88,6807	313,49
125	1736	845	717	187	400,101	0	155,97	836,075
126	1831	549	627	370	0	0	0	0
127	4119	870	1550	816	57,2464	0	75,6784	537,591
128	3779	1437	1116	578	661,05	1513	310,147	1807,53
129	6217	2227	2607	784	681,027	0	219,778	569,472
130	3031	895	1253	513	410,838	0	169,155	614,274
131	2646	1083	794	458	486,314	0	290,964	2045,93
132	4520	1368	1888	746	371,634	0	907,347	1838,06
133	28	7	12	4	0	0	0	0
134	122	58	44	16	101,383	0	539,822	1558,98
135	75	22	20	12	0	0	204,106	1810,45
136	11136	3036	3987	1783	418,08	0	1104,48	9336,67
137	4	0	1	0	0	0	0	0
138	10	0	6	2	0	0	117,455	1041,85
139	3973	1208	1432	382	3,62082	0	307,548	2724,02
140	0	0	0	0	0	0	0,04735	0,42
141	891	131	359	70	0	0	1328,17	2413,93
142	2907	590	744	379	0	0	81,8503	542,445
143	5192	1157	1231	891	319,569	0	1011,98	2119,21
144	3624	549	1010	521	51,3782	0	219,933	670,849
145	1489	97	244	326	0	0	365,338	1733,43
146	2180	377	596	305	0	0	146,785	348,265
147	1984	273	500	226	0	0	1471,48	3446,93
148	1297	273	331	161	287,855	1563	303,169	190,025
149	2788	526	639	511	20,1018	0	77,5633	409,125
150	4732	1056	1186	714	393,671	0	234,065	1631,71
151	3912	806	964	680	39,1423	0	106,936	486,568
152	3574	926	947	461	379,874	0	144,976	619,183
153	1493	276	325	209	0	0	34,2996	293,58
154	1934	478	492	242	397,042	0	125,119	643,51
155	3295	676	882	463	31,7134	0	97,0753	625,295
156	905	314	262	118	0	0	13,6486	121,065
157	0	0	0	0	0	0	2854,99	12513,9
158	36	0	4	3	0	0	311,501	2263,49
159	3934	933	1087	425	29,6533	0	67,4904	546,584
160	3520	720	936	432	50,7539	0	120,785	904,192
161	4385	974	1389	474	344,29	0	244,413	489,073
162	74	0	19	4	0	0	667,078	3238,38
163	217	4	40	25	0	0	1656,61	2318,96
164	0	0	0	0	0	0	1034,46	1232,57
165	4858	1732	1117	547	445,798	0	267,534	1879,97
166	2691	836	729	292	47,6325	0	568,007	3463,27
167	7000	1781	1397	1038	419,453	0	733,632	6046,01
168	6235	2034	1748	622	0	0	306,12	2393,39
169	115	17	28	24	0	0	0,16178	1,435
170	263	0	8	105	0	0	0,54058	4,795
171	0	0	0	0	0	0	0	0
172	7008	1618	1736	1307	168,431	0	1388,32	5789,56
173	781	153	237	99	0	0	8,25071	73,185
174	1579	359	439	313	0	0	48,9164	433,895
175	144	45	39	25	0	0	0	0
176	35	7	17	4	0	0	7,11203	28,215
177	931	230	227	170	0	0	39,2412	348,075
178	1313	335	322	242	0	0	19,3819	171,92
179	1126	146	251	302	78,8465	0	384,914	1662,49
180	24	10	11	2	0	0	936,506	3018,48
181	0	0	0	0	0	0	0	0
182	1442	392	414	115	315,324	0	391,483	3125,64
183	1534	457	537	201	260,762	923	63,5028	276,43
184	1849	387	549	311	0	0	32,7345	290,36
185	1147	303	292	220	0	0	18,7111	165,97
186	0	0	0	0	0	0	151,559	1344,35

187	2597	802	1032	340	0	0	9,95925	88,34
188	2331	544	642	444	0	0	460,709	722,689
189	1816	335	427	392	0	0	9,29636	82,46
190	366	59	135	80	0	0	10,3051	38,472
191	184	24	15	51	0	0	0	0
192	2548	914	806	549	311,328	0	123,315	751,345
193	2961	473	469	1372	0	0	144,124	1063,29
194	3723	1041	1032	849	54,4996	0	231,009	1673,45
195	1118	247	322	233	565,098	0	128,678	429,21
196	2068	497	624	472	68,4835	0	73,5117	474,23
197	213	21	30	88	0	0	0	0
198	1451	346	469	319	9,67633	0	582,444	2106,84
199	650	32	185	147	157,069	0	1729,72	4075,07
200	2297	388	496	747	0	593	429,401	1229,78
201	4360	1051	1402	908	17,6047	0	202,172	1521,29
202	2758	624	763	616	0	0	276,922	1346,59
203	301	7	87	40	0	0	2069,12	3179,26
204	2224	635	823	500	60,6176	0	21,8883	127,47
205	4597	1591	1589	753	492,494	0	144,283	706,176
206	4407	1140	1496	838	458,846	876	692,463	2212,62
207	2883	833	1004	611	42,451	0	41,8103	298,512
208	5666	2089	1653	906	131,661	0	640,633	5502,51
209	1851	250	467	502	0	0	1645,41	3237,95
210	2084	473	646	479	31,9007	0	34,1413	258,356
211	5019	1732	1548	736	0	0	565,117	5012,67
212	374	162	120	44	0	0	123,074	1091,69
213	4011	1334	1288	762	447,234	0	201,997	1091,63
214	2652	582	1031	447	0	0	760,977	5764,28
215	0	0	0	0	0	0	0	0
216	0	0	0	0	0	0	115,478	1024,31
217	5	0	0	3	0	0	23,6394	209,685
218	63	9	13	5	0	0	3,04223	26,985
219	5865	1726	1554	451	63,0522	0	462,891	3872,25
220	636	135	199	51	0	0	150,26	838,623
221	7264	1695	2000	638	961,765	0	676,58	2734,05
222	1148	255	337	92	0	0	45,4433	396,06
223	4275	1212	1272	311	41,7019	0	1231,12	5112,91
224	346	52	118	28	0	0	17,3637	122,64
226	0	0	0	0	0	0	1424,97	3360,74
227	11	0	1	0	0	0	1738,25	1976,29
228	6450	1609	1751	493	0	0	1138,83	10093,7
229	3561	881	948	287	0	0	979,102	8633,46
250	203	42	46	31	0	0	0	0
251	2272	575	608	262	0	0	0	0
252	51	0	11	7	0	0	0	0
253	244	30	55	50	0	0	0	0
254	212	105	76	16	0	0	60,1422	533,47
255	0	0	0	0	0	0	0	0
256	3611	1285	1475	429	0	0	0	0
257	499	159	195	83	0	0	161,2	914,691
258	1405	585	536	183	0	0	0	0
259	0	0	0	0	0	0	0	0
300	7429		1971	1155			2261,8	2261,8
400	6666		1769	1036			2029,48	2029,48
500	5226		1386	812			1590,93	1590,93
600	1260		334	196			383,667	383,667
	502104	**114896**	**163691**	**95925**	**26053**	**34157**	**122666**	**428044**

Appendix B

Calculation of external zone travel

Appendix B

Calulation of external zone travel

Through-trip distribution (Inputs)

Zone	Name	Classification	ADT	Percent trough	Trough trips	E-I and I-E trips	Vehicle occupancy	Person trips	Net import of work	Products	atrractions
300	Reykjanesbraut	Principal Arterial	11773	10	1177,3	10596	1,34	14198,238	70	9939	4259
400	Suðurlandsvegur	Principal Arterial	9604	10	960,4	8643,6	1,34	11582,424	70	8108	3475
500	Vesturlandsvegur	Principal Arterial	7355	10	735,5	6619,5	1,34	8870,13	70	6209	2661
600	Nesjavallaleið	Minor Arterial	1025	1	10,25	1014,8	1,34	1359,765	50	680	680
			29757		2883,5	26874					

Through-trip distribution (Raw percentages)

	Origin station			
Destinaton station	300	400	500	600
300		16,1	16,1	16,1
400	12,8		12,8	12,8
500	9,4	9,4		9,4
600	2,4	2,4	2,4	
Total	24,6	27,9	31,3	38,3
Norm factor	4,1	3,6	3,2	2,6

Through-trip distribution (Normalized percentages)

	Origin station			
Destinaton station	300	400	500	600
300	0,0	57,9	51,5	42,1
400	52,2	0,0	40,9	33,4
500	38,2	33,6	0,0	24,4
600	9,6	8,4	7,5	0,0
Total	100	100	100	100

Principal Arterial:

$$Y_{ij} = -7.40 + 0.55 \times PTTDES_j + 24.68 \times RTECON_{ij} + 45.62 \times \frac{ADT_j}{\sum_{j=1}^{n} ADT_j} \quad (5\text{-}3)$$

Minor Arterial:

$$Y_{ij} = -0.63 + 86.68 \times \frac{ADT_j}{\sum_{j=1}^{n} ADT_j} + 30.04 \times RTECON_{ij} \quad (5\text{-}4)$$

where

Y_{ij} = percentage distribution of through-trip ends from origin station i to destination station j,

$PTTDES_j$ = percentage through-trip ends at destination station j,

$RTECON_{ij}$ = route continuity between stations i and j: 1 = Yes, 0 = No, and

ADT_j = average daily traffic at the destination station j.

Appendix B

Calulation of external zone travel

Through-trip table (asymmetrical)

	Origin station				
Destinaton station	**300**	**400**	**500**	**600**	Total
300	0,0	556,3	379,1	4,3	939,7
400	614,8	0,0	301,1	3,4	919,3
500	449,5	323,0	0,0	2,5	775,0
600	112,9	81,1	55,3	0,0	249,4
Total	1177	960	736	10	

Through-trip table (symmetrical)

	Origin station						
Destinaton station	**300**	**400**	**500**	**600**	Calculat	Given	Growth factor
300	0	586	414	59	1059	1177,3	1,11
400	586	0	312	42	940	960,4	1,02
500	414	312	0	29	755	735,5	0,97
600	59	42	29	0	130	10,25	0,08
Calculated	1059	940	755	130			
Given	1177,3	960,4	735,5	10,25			
Growth factor	1,11	1,02	0,97	0,08			

Through-trip table (Fratar adjustment)

	Origin station			
Destinaton station	**300**	**400**	**500**	**600**
300	0	653	433	5
400	700	0	300	3
500	472	304	0	2
600	5	3	2	0

$$T_{ij} = (t_i G_i) \frac{t_{ij} G_j}{\sum_x t_{ix} G_x}$$

where

T_{ij} = number of trips estimated from zone i to zone j
t_i = present trip generation in zone i
G_x = growth factor of zone x
$T_i = t_i G_i$ = future trip generation in zone i
t_{ix} = number of trips between zone i and other zones x
t_{ij} = present trips between zone i and zone j
G_j = growth factor of zone j

Appendix B

Calulation of external zone travel

Through-trip table (Fratar adjustment-average)

	Origin station						
Destinaton station	300	400	500	600	Calculat	Given	Growth factor
300	0	676	453	5	1134	1177,3	0,96
400	676	0	302	3	982	960,4	1,02
500	453	302	0	2	757	735,5	1,03
600	5	3	2	0	11	10,25	1,03
Calculated	1134	982	757	11			
Given	1177,3	960,4	735,5	10,25			
Growth factor	1,04	0,98	0,97	0,97			

Through-trip table (Fratar adjustment-iteration1)

	Origin station			
Destinaton station	300	400	500	600
300	0	648	429	5
400	700	0	304	3
500	472	309	0	2
600	5	3	2	0

Through-trip table (Fratar adjustment-average)

	Origin station						
Destinaton station	300	400	500	600	Calculat	Given	Growth factor
300	0	674	451	5	1130	1177,3	0,96
400	674	0	307	3	984	960,4	1,02
500	451	307	0	2	759	735,5	1,03
600	5	3	2	0	11	10,25	1,03
Calculated	1130	984	759	11	2883		
Given	1177,3	960,4	735,5	10,25			
Growth factor	1,04	0,98	0,97	0,97			

Appendix C

Results of simulated traffic compared to observed traffic.

Simulated traffic compared to observed traffic, screen-line counts (without mode choice)

Section 1				
	Simulated traffic	Observed traffic	Percentage deviation	deviation
Geirsgata:	21381	19168	-12%	-2213
Hafnarstræti:	3133	5717	45%	2584
Austurstræti:	1967	1637	-20%	-330
Skólabrú:	2827	2921	3%	94
Vonarstræti:	3923	4488	13%	565
Skothúsvegur:	6631	5416	-22%	-1215
Hringbraut:	27515	36399	24%	8884
Njarðargata:	8225	9195	11%	970
Total:	75602	87941	14%	16855

Section 3				
	Simulated traffic	Observed traffic	Percentage deviation	deviation
Sæbraut:	18465	23413	21%	4948
Borgartún:	13266	18213	27%	4947
Laugavegur:	17524	20003	12%	2479
Háaleitisbraut:	15517	16640	7%	1123
Miklabraut:	42760	45884	7%	3124
Hamrahlíð:	10654	6688	-59%	-3966
Bústaðavegur:	25703	35337	27%	9634
Suðurhlíð:	340	296	-15%	-44
Total:	144229	166474	13%	30265

Section 4				
Street name	Simulated traffic	Observed traffic	Percentage deviation	deviation
Vesturlandsvegur:	79444	83628	5%	4184
Bíldshöfði:	4069	4031	-1%	-38
Höfðabakkabrú:	27507	23833	-15%	-3674
Breiðholtsbraut:	16210	14365	-13%	-1845
Total:	127230	125857	-1%	9741
				0

Section 5				
	Simulated traffic	Observed traffic	Percentage deviation	deviation
Kringlumýrarbraut:	73981	62770	-18%	-11211
Reykjanesbraut:	68499	62733	-9%	-5766
Höfðabakkabrú:	27507	23833	-15%	-3674
Breiðholtsbraut:	16210	14365	-13%	-1845
Total:	186197	163701	-14%	22496

Section 8				
	Simulated traffic	Observed traffic	Percentage deviation	deviation
Vesturl.vegur við Úlfarsá:	23778	25185	6%	1407
Total:	23778	25185	6%	605

Section 9				
	Simulated traffic	Observed traffic	Percentage deviation	deviation
Gullinbrú:	28741	28379	-1%	-362
Víkurvegur:	11383	15734	28%	4351
Korpúlfsstaðavegur:	8776	4163	-111%	-4613
Total:	48900	48276	-1%	9326

Simulated traffic compared to observed traffic, screen-line counts (without mode choice)

Section 1				
	Simulated traffic	Observed traffic	Percentage deviation	deviation
Geirsgata:	21838	19168	-14%	-2670
Hafnarstræti:	3637	5717	36%	2080
Austurstræti:	1744	1637	-7%	-107
Skólabrú:	2854	2921	2%	67
Vonarstræti:	4171	4488	7%	317
Skothúsvegur:	7140	5416	-32%	-1724
Hringbraut:	28609	36399	21%	7790
Njarðargata:	9307	9195	-1%	-112
Total:	79300	87941	10%	14867

Section 3				
	Simulated traffic	Observed traffic	Percentage deviation	deviation
Sæbraut:	19318	23413	17%	4095
Borgartún:	13613	18213	25%	4600
Laugavegur:	17448	20003	13%	2555
Háaleitisbraut:	18731	16640	-13%	-2091
Miklabraut:	43876	45884	4%	2008
Hamrahlíð:	10508	6688	-57%	-3820
Bústaðavegur:	26101	35337	26%	9236
Suðurhlíð:	339	296	-15%	-43
Total:	149934	166474	10%	28448

Section 4				
Street name	Simulated traffic	Observed traffic	Percentage deviation	deviation
Vesturlandsvegur:	81988	83628	2%	1640
Bíldshöfði:	3947	4031	2%	84
Höfðabakkabrú:	26441	23833	-11%	-2608
Breiðholtsbraut:	15473	14365	-8%	-1108
Total:	127849	125857	-2%	5440
				0

Section 5				
	Simulated traffic	Observed traffic	Percentage deviation	deviation
Kringlumýrarbraut:	72895	62770	-16%	-10125
Reykjanesbraut:	65855	62733	-5%	-3122
Höfðabakkabrú:	26441	23833	-11%	-2608
Breiðholtsbraut:	15473	14365	-8%	-1108
Total:	180664	163701	-10%	16963

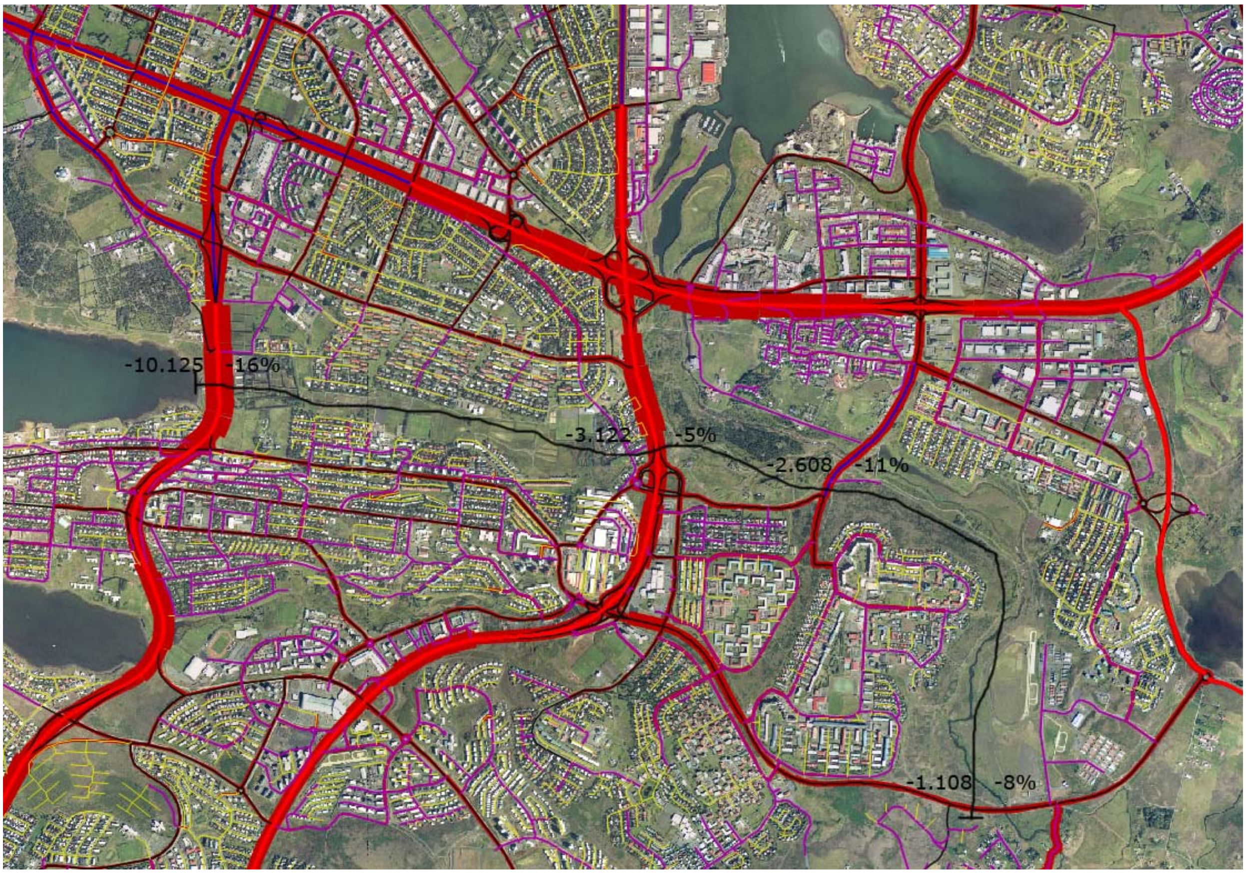
Section 8				
	Simulated traffic	Observed traffic	Percentage deviation	deviation
Vesturl.vegur við Úlfarsá:	24580	25185	2%	605
Total:	24580	25185	2%	605
				0

Section 9				
	Simulated traffic	Observed traffic	Percentage deviation	deviation
Gullinbrú:	30105	28379	-6%	-1726
Víkurvegur:	11775	15734	25%	3959
Korpúlfsstaðavegur:	8095	4163	-94%	-3932
Total:	49975	48276	-4%	9617

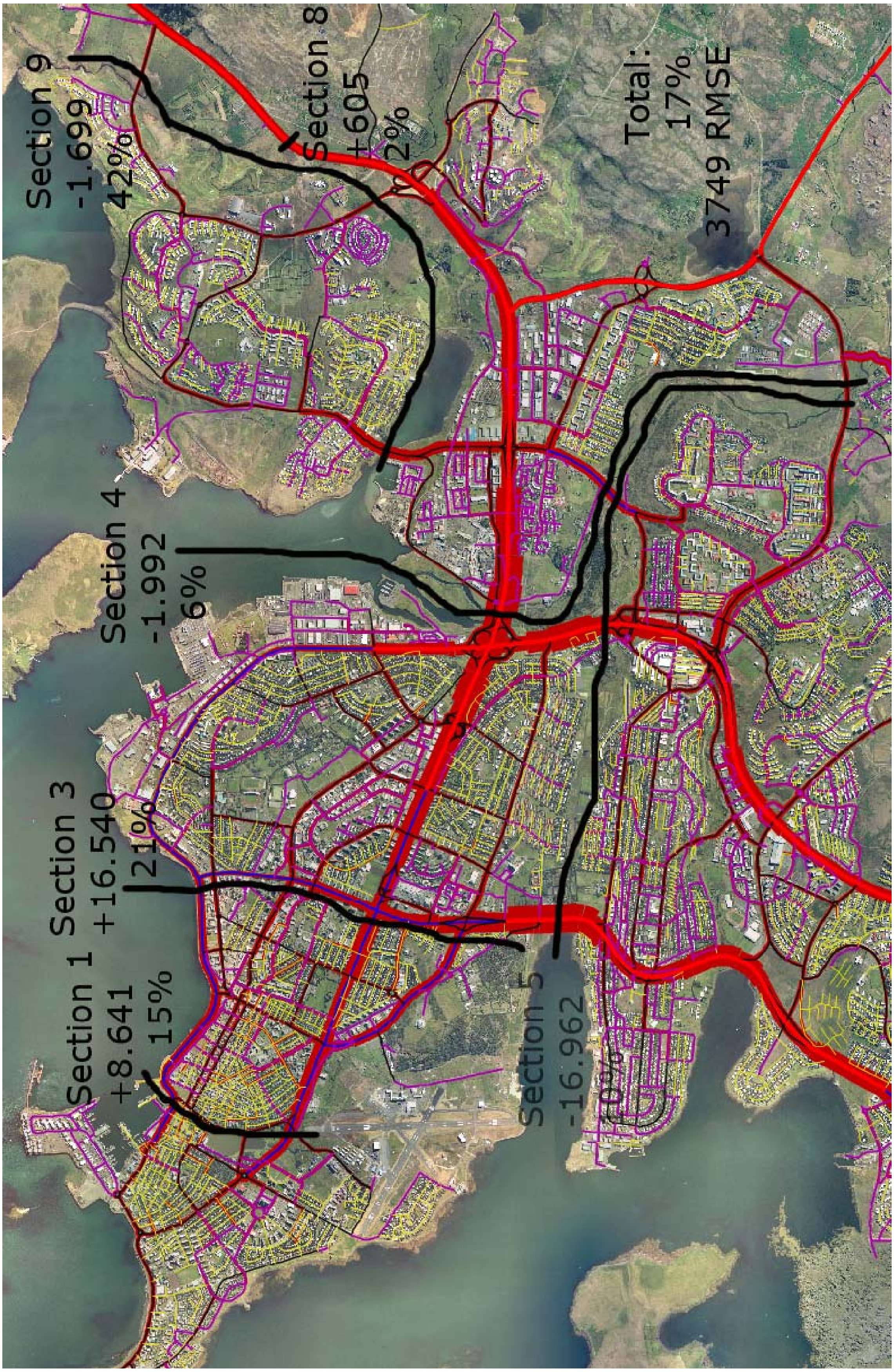
Appendix D

Results of simulated traffic compared to observed traffic (figures)

Overview of screen-line 5. Numbers indicate the total observed traffic in each link subtracted by the estimated traffic. Minus is overestimated traffic while plus is underestimated.



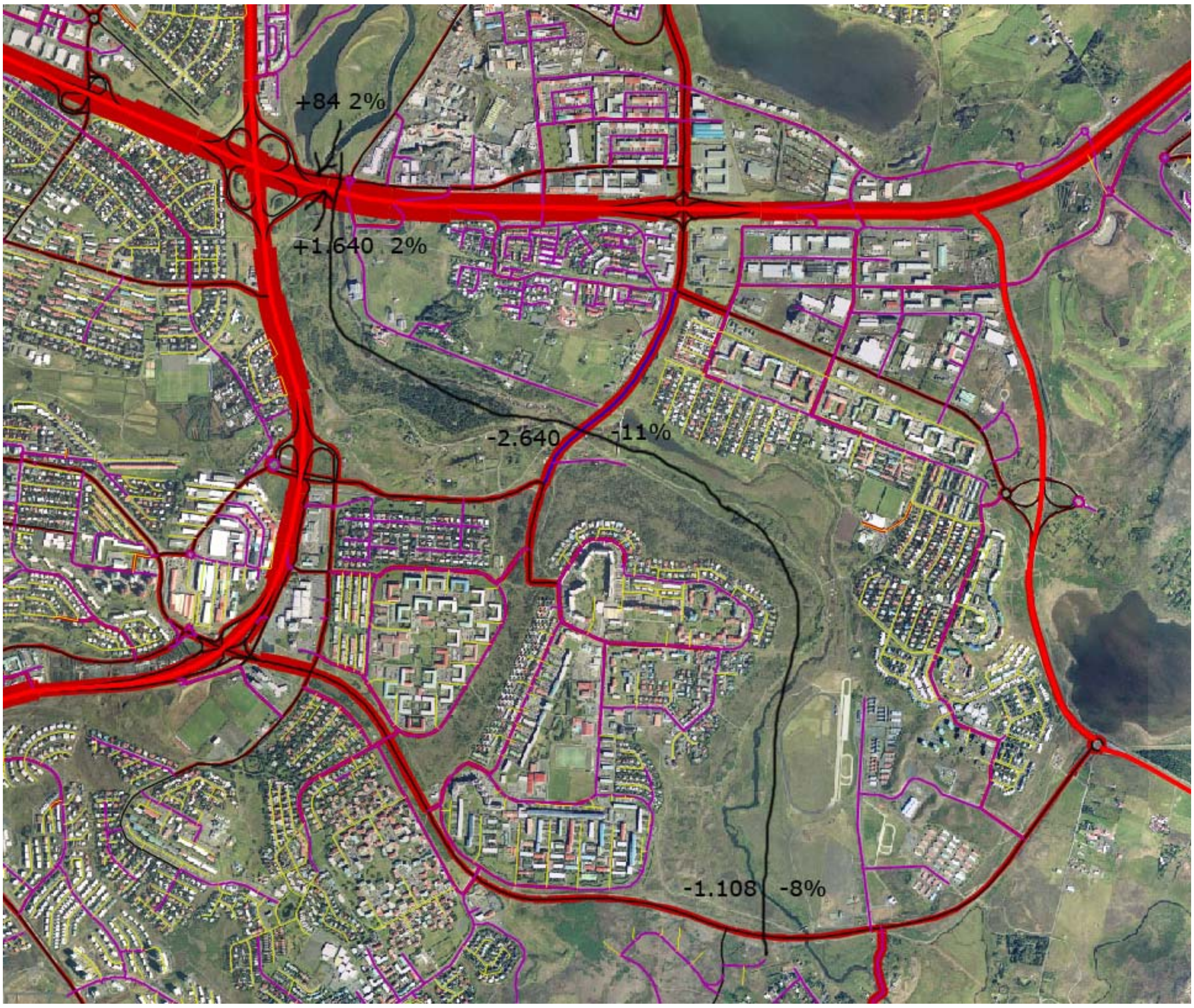
Overview of the screen-lines. Numbers indicate the total observed traffic over the screen-line subtracted by the estimated traffic. Minus is overestimated traffic while plus is underestimated. The percentage value under each section is the average percentage deviation. In the lower right hand corner is the total average percentage deviation and the root mean squared error (RMSE).



Overview of screen-line 1. Numbers indicate the total observed traffic in each link subtracted by the estimated traffic. Minus is overestimated traffic while plus is underestimated.

Overview of screen-line 3. Numbers indicate the total observed traffic in each link subtracted by the estimated traffic. Minus is overestimated traffic while plus is underestimated.

Overview of screen-line 4. Numbers indicate the total observed traffic in each link subtracted by the estimated traffic. Minus is overestimated traffic while plus is underestimated.



Overview of screen-line 8. Numbers indicate the total observed traffic in each link subtracted by the estimated traffic. Minus is overestimated traffic while plus is underestimated.

Overview of screen-line 9. Numbers indicate the total observed traffic in each link subtracted by the estimated traffic. Minus is overestimated traffic while plus is underestimated.