Evaluation of the situation at Korsvägen during the construction period of Västlänken

A case study of a layout proposal

Master's Thesis within the Sustainable Energy Systems programme

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MASTER’S THESIS

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ABSTRACT

The construction of Västlänken will have a large impact on the city of Gothenburg in many aspects. As a consequence of Västlänken, Korsvägen will be transformed into a construction site during several years. The focus of this master thesis is based on three main topics regarding Korsvägen; pedestrian density, vehicle transit time and air pollution.

The strategy by Trafikverket is to divide the structure of Korsvägen into two different construction stages, Stage 1 and 2. This investigation is performed in contrast with the current state of Korsvägen. Necessary and relevant data associated to this project is collected and utilized in a simulation program, PTV Vissim. Results regarding the topics are recorded and stored. A comparable analysis is made for each result separately in contrast with the different stages of Korsvägen and the time of the day.

Passengers using the public transport stops are affected by increased pedestrian density on the waiting areas in Stage 2. This is a result of smaller waiting areas in association with the temporary public transport stops. The difference in transit time for mass transportation trucks during a typical work day was surprisingly small. The appearances of traffic jams do not occur in the simulation model and explains the insignificant variation. The air pollution surrounding Korsvägen will decrease due to reduced traffic intensity as a result of the new limited traffic diversion. Västlänken is today in its planning phase which means that the available data for this assignment is limited.

Key Words: Västlänken, Pedestrian Density, Vehicle Transit Time, Air Pollution, Korsvägen, Stage 1, Stage 2, Mass Transportation Trucks, PTV Vissim.

Contents

Preface

This master thesis was written between January and June in 2014 as a last part of our master education, Sustainable Energy Systems. The project was carried out at the department of Technology Management and Economics at the Division of Logistics and Transport at Chalmers University of Technology in Gothenburg, Sweden. This project was conducted on behalf of ÅF Infrastructure AB with Trafikverket as a client. ÅF generously offered us an office, which we used frequently throughout the entire project and a special gratitude is dedicated to ÅF to show our appreciation. We have experienced an openness and willingness from the employees to provide us with their expertise. Special thanks are dedicated to our supervisor at ÅF, Dr. Carlos Morán, who provided us with material necessary to complete this task.

We would like to send our thanks to the PTV Group, which is the developer of the simulation software used throughout this project, PTV Vissim. Without a license and their engagement in supporting us with vital information regarding the features in the program, this master thesis would have been difficult to accomplish. We also appreciate the enthusiasm shown by Anders Sjöholm and Oskar Kryh at Ramböll AB, who provided us with helpful advice regarding the simulation program.

Finally, special thanks are dedicated to our examiner, Dr. Magnus Blinge. His support regarding strategy and planning of this master thesis has helped us write this report in the way we desired.

Gothenburg May 2014

Erik Solli Hansson

Carl Stenberg

Notations

DICTIONARY

Trafikverket	An authority for long term planning of the Swedish transport system and the client of Västlänken.
Trafikkontoret	The instance responsible for the roads in Gothenburg.
Liseberg	An amusement park in Gothenburg with 2,9 million visitors yearly.
Universeum	A Center of Science next to Korsvägen with 535 000 visitors yearly.
Svenska Mässan	A center for meetings, conferences and exhibitions.
Scandinavium	An indoor sports arena used mainly for hockey games but also for music concerts.
ÅF AB	A consultant agency responsible for the construction of the Korsvägen station. The company has 6’800 employees.
Ramböll AB	Ramböll is a Norwegian technical consultant agency with 9’000 employees in 23 different countries.
WSP AB	One of the largest technical consultant agency in the world with almost 15’000 employees.
Världskulturmuséet	Museum of culture located south of Korsvägen.
Västtrafik	The company running the public transport system in the region of Västra Götaland.
Waiting area	Pedestrian area associated to public transport stops.
E6	A national highway passing through Gothenburg in Sweden.
Mass transports	Trucks used for mass transportation.

ABREVIATIONS

STC	Service Tunnel Chalmers
STL	Service Tunnel Liseberg
PT	Public Transport
LOS	Level of Service
HGV	Heavy Goods Vehicle
Södra Vägen S	The road of Södra Vägen connected to Korsvägen from the south
Södra Vägen N	The road of Södra Vägen connected to Korsvägen from the north
CO	Carbon monoxide
NO_x	Nitrogen oxides
VOC	Volatile organic compound
Ped	Pedestrian

1 Introduction

This chapter introduces the project of Västlänken. A theoretical background regarding the difficulties of the construction work related to Korsvägen in association with mass handling is discussed. The aim of this master thesis is stated with its corresponding research questions. The limitations associated to this project are also clarified. The last part of this chapter considers the outline of structure of this report.

1.1 Background

The population of Gothenburg is continuously increasing. In combination with a limited space for urban transport, a new effective public transport system is necessary. Västlänken will be an eight km long railway through Gothenburg. Six km will be located underground with commuter stations at Korsvägen, Haga and the Central Station. The project is conducted by Trafikverket with a strict budget of 20 billion Swedish crowns. Västlänken is currently in its planning phase and the construction work will start in 2017. (Trafikverket, 2014c)

During the construction period of Västlänken, 3 million m^3 of masses will be generated (Trafikverket, 2014b). It will be a challenge to transport the masses from the service tunnels to the deposition places with low urban environment affections. Depending on varying traffic intensity during the day, there will be possibilities for Trafikverket and the contractors to save money by driving residual masses when the transit time is low. The question related to when these time intervals occur and if they are worth considering, depends on how large the savings are. This master thesis is conducted to the consultant company ÅF AB, which is responsible for the construction of the commuter station at Korsvägen.

Figure 1 Map of Korsvägen including associated roads, walkways, PT stops and tourist activities.

Korsvägen is a crossroads located in the center of Gothenburg. It is built as a big traffic roundabout in order to connect five main roads and to handle the traffic of more than 30’000 vehicles per day, see Appendix B. Södra Vägen, Eklandagatan, Örgrytevägen and Skånegatan are the names of the roads connected to Korsvägen. Södra Vägen passes through Korsvägen from the southeast to the northwest. A visualization of the current state of Korsvägen is presented in Figure 1. Korsvägen contains eight PT sites, named from A to H. More than 2’000 PT vehicles pass through every day, as seen in Appendix H. Together with people that work, live and visit activities in the bounded area, Korsvägen is situated in a highly populated location. Within 10 minutes by foot, there live 14’000 people and work 20’700 people working. The area is visited by more than 6 million attraction visitors, yearly. See Appendix C for further information. In the surroundings of Korsvägen, there are also several tourist attractions, i.e. Liseberg, Universeum, Världskulturmuséet, Hotel Gothia Towers, Scandinavium and Svenska Mässan. Some of these attractions are illustrated in Figure 1 and the complete list can be found in Appendix C. The popular location of Korsvägen results in a high demand for public transport and a new train station will be an important part of the future infrastructure solution. (Trafikverket, 2014d)

According to a proposal from Jonatan Lövkvist at ÅF, the layout of Korsvägen during the construction period of Västlänken will be divided into two different stages during the construction period, Stage 1 and 2. These proposal stages are illustrated in Figure 2. In this report, the current state of Korsvägen will further on be called Stage 0.

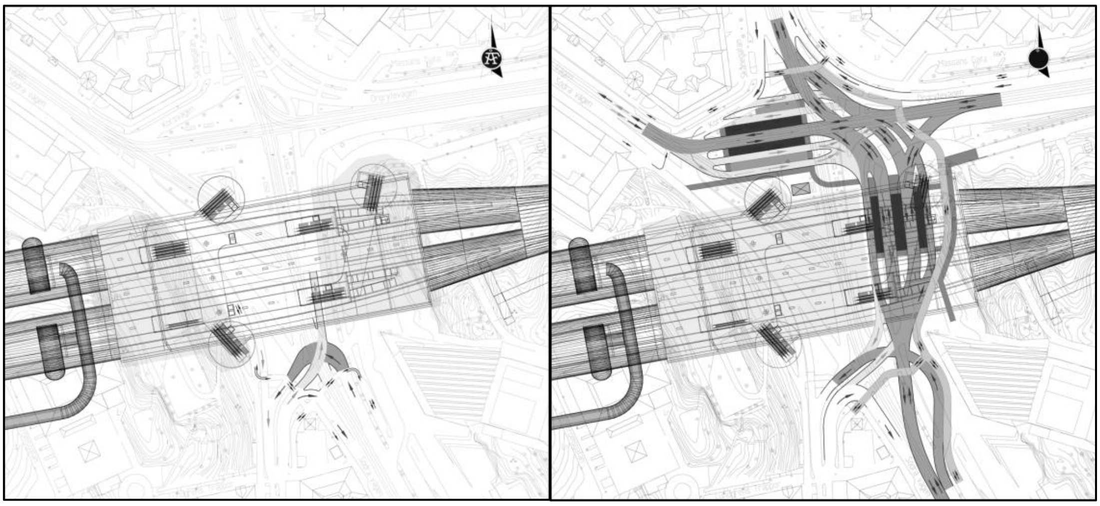

Figure 2 Two layout proposals of Korsvägen during the construction period of Västlänken by Jonatan Lövkvist. Stage 1 is presented to the left and Stage 2 to the right. The traffic changes are colorized and the horizontal lines illustrate the tunnel of Västlänken.

During Stage 1, no vital changes are made in the general structure of Korsvägen but no vehicle traffic will be permitted to pass through Korsvägen between the north and the south part. From Örgrytevägen, it will be allowed to drive to either Skånegatan or Södra Vägen N. Vehicles from Skånegatan will only have one option, which is Södra

Vägen N. Vehicles driving on Södra Vägen S to Korsvägen are only permitted to continue the journey on Eklandagatan and vice versa[1]. Today, there are no plans of changing the PT system of Korsvägen during Stage 1[2]. Figure 2 shows Korsvägen in Stage 1 and 2 compared with its current state. Changes in vehicle roads, bus lanes and tram lanes are visualized in Figure 2. The new PT stops for Stage 2 are colored black for tram stops and grey for bus stops. The reconstruction of walkways and cycle-tracks is presented as light gray. The horizontal line areas represent the open shaft construction in both stages and the reason for the changing layout is based on the methodology explained further in Chapter 3.

The minor difference of Stage 1 and 2 is that the road connecting Örgrytevägen and Södra Vägen N is only used for PT and is thus not available for private vehicles. However, the PT structure will look completely different in Stage 2. The reason for the different structure is based on the performed shaft work. A consequence from the temporary format change during Stage 2 is that the waiting areas will have a completely new look. This will lead to different levels of pedestrian density. That is a reason for the level of service investigation in this report.

1.2 Purpose

The main purpose of this master thesis is to reflect the area between the service tunnels and highway E6 via Korsvägen during the construction period of Västlänken by using the simulation tool PTV Vissim. Evaluate the situation regarding pedestrians at Korsvägen and the client of Västlänken. The main purpose is divided into three sub-purposes with a corresponding research question.

The first sub-purpose is to give a recommendation to the contractor regarding the time when the mass transports from the service tunnels to E6 should be performed. This lead to the first research question: *At what time during the day should the mass transports be performed with respect to transit time?*

The second sub-purpose is related the pedestrian density changes at the waiting areas of Korsvägen. The second research question reads: *How will the pedestrian densities change during the day and are the changes acceptable?*

The third sub-purpose relates to the daily traffic emission at Korsvägen during the construction of Västlänken. The last research question is defined as follows: *How much will the emissions related to vehicle traffic change during the construction period?* All results are generated using the simulation program PTV Vissim, developed by the PTV Group.

1.3 Aim and Limitations

The modeled geographical area includes the route from the entrance of the two service tunnels to the entrance of E6 through Korsvägen. The reasons for several of the limitations throughout this project are associated with restrictions regarding the

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[1] Jonatan Lövkvist (Project Manager, ÅF Infrastructure AB), interviewed by Carl Stenberg and Erik Solli Hansson the 17th of February, 2014.

[2] Magnus Lorentzon (Project Manager, Västtrafik AB), interviewed by Erik Solli Hansson the 27th of February, 2014.

simulation tool used for traffic analysis. Due to the size of the network and the time frame studied, the simulations are time consuming, which restricts the outcomes. A finite amount of available input data also affects the accuracy of the results.

According to the permitted working hours, the time frame simulated is between 7:00 a.m. and 10:00 p.m. a common work day. The car traffic statistics was collected during week 38 in September 2013. Input data regarding the vehicle routing decisions at Korsvägen are missing due to unavailable information. The same goes for the lengths of the cycle phases used in the signal heads along the roads of the network. Vital assumptions where made for the input data regarding pedestrian input numbers and the amount of pedestrians alighting PT vehicles due to lack of accuracy in statistics in this matter. In real life, mass transports will also drive directly between the shafts and the deposition sites, but this is not considered in this project[3].

The stated limitations are acceptable with regards to the purpose of this project. Their absences may have an effect the outcomes but the proportions are concerned as small compared to the context. However, one should keep the restrictions in mind in order to successfully complete this task.

1.4 Outline

Chapter 1 includes background information about the project, which gives the reader a broader perspective in the area of this matter. The purpose of the study and the limitations is also stated.

Chapter 2 contains a brief description regarding the methodology behind this master thesis.

Chapter 3 explains with explaining the principles regarding traffic analyses using simulation software tools. A deeper comment on the simulation program used is also included in this chapter. Some general information about mass handling is included together with the definition of LOS a short review on air quality.

Chapter 4 presents the results obtained from the simulation program using the input data described in Chapter 2. The subchapters relate to the three main results of this project, i.e. vehicle transit time, pedestrian density and emission.

Chapter 5 includes analyses of the results, which are linked to the above mentioned chapters in order to enhance the explanations. A sensibility analysis is performed.

Chapter 6 discusses the critical examination of the results that eventually lead to a recommendation, found in Chapter 8.

Chapter 7 contains the conclusion of this master thesis. This chapter will answer the research questions stated in Chapter 1. A statement of further research of this area is also included in this chapter.

Chapter 8 presents the ultimate recommendation to Trafikverket.

Chapter 9 states the source of all references stated in the report.

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[3] Christer Brevell (Project Manager, ÅF Infrastructure AB), interviewed by Erik Solli Hansson and Carl Stenberg the 28th of April, 2014.

2 Methodology

This chapter treats the methodology behind the investigation for using a simulation program for traffic analysis. Applicable data is first collected from different sources in association to PTV Vissim. Data regarding vehicle traffic, pedestrian activities and PT in connection to Korsvägen are gathered. Desired results are generated from the software and cost regarding mass transport is calculated on based of the empirical findings.

2.1 Data collection

Trafikkontoret measures the intensity of vehicle traffic on several roads in Gothenburg. Statistic data regarding the amount of vehicles trafficing the roads of Södra Vägen, Örgrytevägen and Eklandagatan are available every 15 minutes. This material was provided by e-mail from Karin Björklind after an interview[4]. Data regarding the traffic flow on Skånegatan was unavailable from Trafikkontoret and instead collected from a survey conducted by WSP (Refsnes, 2012, p. 8). Corresponding vehicle route choices were estimated in PTV Vissim based on the traffic flow to and from Korsvägen. The predicted traffic flow in the year 2020 was collected using numerical data established from a survey by Ramböll (Trafikverket, 2014a). In contrast with today's statistics, new values were calculated based on these estimations. Data concerning bicyclists were provided by Trafikkontoret which every day measures the flow on the cycle path next to Södra Vägen every day. This was also learned from an interview with Karin Björklind at Trafikkontoret[4].

Pedestrian data are based on statistics from a case study produced by WSP where figures on people who live, work and visit surround areas of Korsvägen are stated in the report (Refsnes, 2012, pp. 29, 35). A mean value is calculated in order to apply this information in the simulation program PTV Vissim. This report also includes data about pedestrians who start, end and change their PT travel connected to Korsvägen. In order to utilize these numbers, it was necessary to develop different load levels. The levels are based on a PT travel survey conducted by Västtrafik (Västtrafik AB , 2007, p. 11). The levels represent 100%, 60% and 30% of the pedestrian activity related to the peak load. These levels depend on the time during the day as seen in Appendix C for more information about this matter. Västtrafik also provided the time table related to the PT system of Korsvägen, which was applied directly into PTV Vissim.

2.2 Simulation

The material necessary to develop the simulation models in PTV Vissim relates to background material of Korsvägen with corresponding data. Three separate models were designed to reflect different construction stages of Korsvägen. Stage 0 represents today's structure. Stage 1 and 2 reflect the proposal drafts developed by Jonatan Lövkvist, which are thoroughly described in Chapter 1. All collected numerical data was applied in the three models. The main difference between the

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[4] Karin Björklind (Traffic analyst, Trafikkontoret Gothenburg), interviewed by Erik Solli Hansson the 27th of February, 2014.

models relates to the layout design and to data regarding vehicle traffic flows. After completion of the models, results were generated from the simulation program. Vehicle transit times and pedestrian densities at the PT areas during the day are presented in tables and graphs, see Chapter 5. The real road network of Korsvägen is implemented directly into PTV Vissim. By utilizing a map it is possible to include a view of the surrounding areas. Figure 3 illustrates the simulation models created in PTV Vissim.

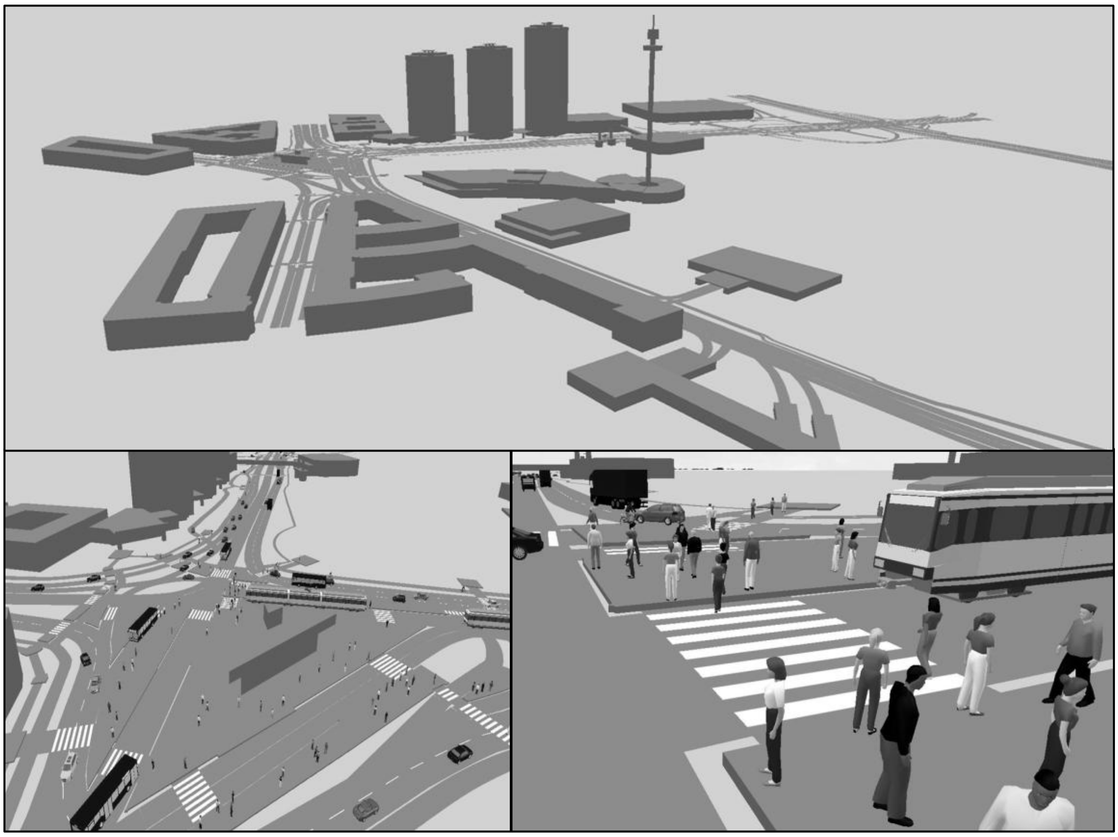

Figure 3 Screen shots from the simulation models.

2.3 Cost calculation

The expenses on behalf of Trafikkontoret regarding mass transport are based on the transit time for trucks driving through Korsvägen. The travel time is generated from the three models in PTV Vissim. The cost for a moving truck is assumed to be 1392 SEK per traveled hour[5]. This investigation is performed during six different time intervals during the day as found in Figure 20 (Västtrafik AB , 2007, p. 11). The costs regarding mass transports during the entire construction period are calculated for each time interval. The outcome of results is presented in a bar chart as seen in Figures 9 and 10.

[5] Christer Brevell (Project Manager, ÅF Infrastructure AB), interviewed by Erik Solli Hansson and Carl Stenberg the 28th of April, 2014.

3 Frame of reference

This chapter consist of the theoretical background related to this project. The theory behind traffic analysis and its application area is first stated. The way different simulation techniques are utilized in computers is introduced briefly. The main focus of this chapter is within the description of the simulation, PTV Vissim, and its corresponding technical structure. Some general information related to mass handling is also included in this chapter. The last part consists of explanations behind pedestrian density, LOS and air pollution.

3.1 Traffic simulation techniques

Using computers for traffic analyses requires advanced software tools with well-integrated simulation models. In order to run these types of programs, the demand for computer performance is relatively high and this is one of the reasons why this technique hasn't been commercialized that long. Today, there are many different kinds of traffic analysis programs available and most of them are possible to run on an ordinary computer. The need for enough computer capacity is still necessary to decrease the simulation time. Depending on the type of traffic situation that are under investigation, different simulation techniques can be used for different purposes. With regards to network size, level of accuracy, type of input data and results, different models should be utilized for a specific scenario. The three main models utilized by traffic simulation programs are categorized as macroscopic, mesoscopic and microscopic. These models are developed according to the different aspects and purposes of different studies. There exists a number of simulation softwares based on these three models. (Refsnes, 2012, p. 39)

In the macroscopic model, the traffic flow is defined as a continuous flow. It makes this type of simulation tool more efficient to use if the network size is big enough with many crossroads. The input data for such a model are rough compared to the other models. Macroscopic models are often used to determine effects from major changes in traffic route choice. Calculating the consequences on the current traffic flow if a toll station is added to one or a number of roads within the network are one application area. The major output result of such a study is traffic volume changes on the roads but noise data is also an optional result. The simulation program PTV Visum is used to simulate macroscopic models for Trafikkontoret in Gothenburg. (Refsnes, 2012, pp. 39-40)

This software tool is mostly used for traffic planning in order to forecast traffic situations but also for GIS-based data management. Experts in this area use PTV Visum to develop an efficient and enhanced public transport system due to its advantage in an analysis of expected traffic flows. Figure 4 shows an example of the resulting appearances from this software. Every road is given a number, which represents the calculated traffic volume (PTV Group, 2013c). Another simulation tool, used by Trafikverket, is the SamPers-model. Compared to PTV Visum, SamPers is used as a national model system for traffic analyzes to determine route choice decisions and travel time for personal transport according to the model Emme. Trafikverket utilizes this tool to design and develop models for socioeconomic analyzes. It is also used to forecast the traffic flows in order to calculate the expected growth with respect to quantity for different scenarios (Saxton, 2011, pp. 17-18).

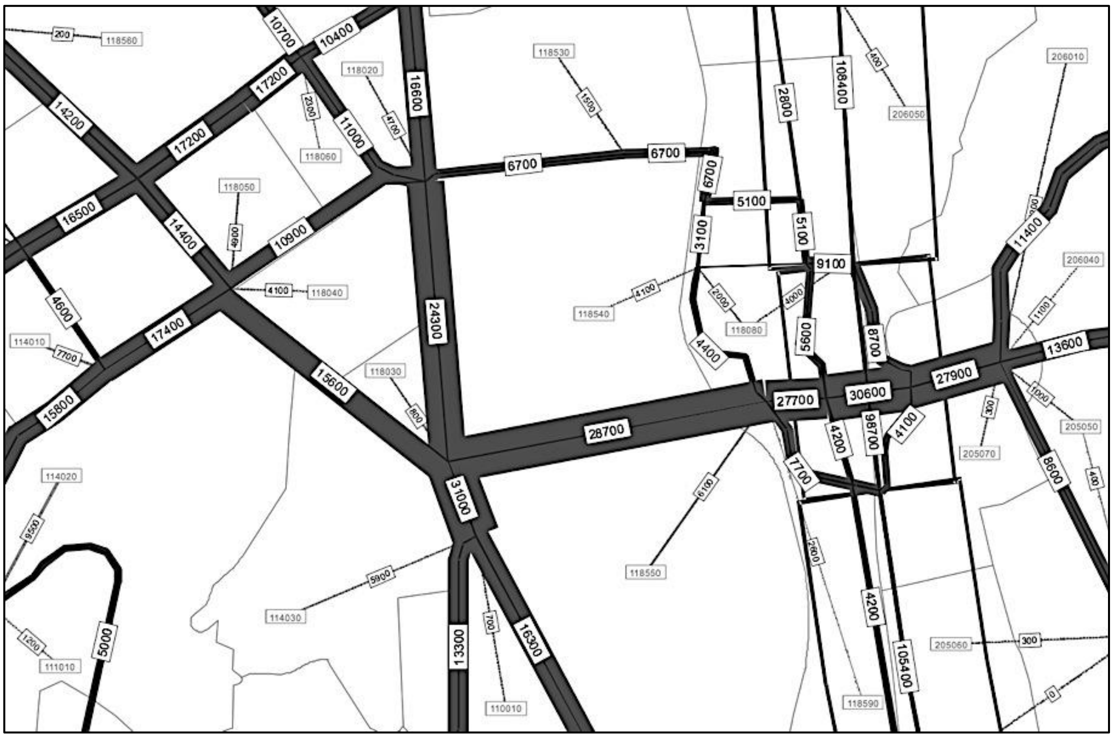

Figure 4 Illustration of a macroscopic simulation from the software PTV Visum regarding Korsvägen. The numbers reflect the traffic volume on corresponding roads.

Another way of simulating traffic is according to the mesoscopic model. This model divides the traffic flow into smaller pieces and tracks the vehicles with regards to location, velocity, acceleration and size (Refsnes, 2012, p. 39). Compared to the microscopic model, the mesoscopic model has a wider perspective with lesser details but is mostly used as a tool for analyzing queue appearances. It is also possible to visualize the traffic situation. Trafikkontoret uses PTV Visum also for this kind of simulation model (Almroth & Jerling, 2011).

The microscopic model utilizes the highest level of accuracy compared to the other two models. The simulation tools based on this model takes into account the differences in individual driving behaviors with regards to acceleration and retardation. This model makes it possible to analyze detailed interactions of vehicles with regards to several parameters, i.e. travel time, queue length, emissions and congestion. Microscopic models are used for simulating smaller networks where singular crossroads are usually investigated. The simulation tool contains an integrated stochastic function in order to reflect the real world as close as possible. This means that it is necessary to run the simulation a couple of times in order to receive enough data to calculate an average value of the result concerned. This is the main difference compared to the other two models where the input data is most likely taken from statistics. The input data collection for microscopic simulations is time-consuming but the results can easily be generated after the network is defined. This master thesis is conducted using a microscopic simulation tool called PTV Vissim, which is deeply described in the following section. (Refsnes, 2012, p. 39)

3.2 PTV Vissim

PTV Vissim and PTV Visum are both developed by the German software provider, PTV Group. Their expertise in urban mobility and traffic engineering has resulted in a leading company in traffic analyzes for many years (PTV Group, 2013b). PTV Vissim, as a leading software tool for simulating microscopic models, includes many objects that help creating an accurate view on reality. The user of this software can design and create a unique network in 2D/3D, either based from an existing road network or as a concept for an upcoming future network. Roads, sidewalks, bus stops, obstacles and signal heads are just a few objects that are possible to implement and visualize in the program. After the static network is created, all moving objects can be implemented. The dynamic inputs include private transport, HGV, buses, trams, cyclists and pedestrians. The data for every static and dynamic object within the network are specified by the user, which makes each network unique. By configuring the evaluation function, results are recorded and stored as a text file or to a database. PTV Vissim also has a function for visualization. This makes it possible to record the simulation at one specific time and place. It is easier to find errors and conflict zones in the model if one studies the traffic flow from the visualization rather than from comparing results. Hence, it is hence important to keep in mind that the traffic flow in the network needs to be analyzed before actual results are generated.

PTV Vissim provides the user with an opportunity to include a number of add-on modules into the interface to enhance the software. Examples of the most common add-on modules that are comparative with PTV Vissim are enViVer, VAP controller and PTV Viswalk. enViVer is used for calculations of emissions, which is based on almost 3’000 vehicles, measured under different driving conditions. By using this tool, it is possible to generate many different emissions within a specific area. Vissim generates output data from the simulation and exports it into external files. It is then possible to use enViVer for further calculations on emissions based on the data provided by the software. Another common add-on is the VAP controller, which enables Vissim to simulate signal controls, both phase and stage based. It is possible to implement detectors on the roads for optimizing the signal controllers and create a more realistic control signal systems compared to the ones created without VAP controller. A more detailed description of the add-on module, PTV Viswalk, which is used frequently throughout this project, will be presented more thoroughly later in this chapter. (PTV Group, 2013e, pp. 1-2)

PTV Vissim utilizes well-integrated advanced models to create realistic simulations with high accuracy on results. The results are therefore highly depending on these models. The PTV Vissim design is based on two models, Wiedemann and Helbing. The application area of these models, together with the methodology behind its designs, is described in the following subchapters. (PTV Group, 2013d)

3.2.1 The Wiedemann model

Unlike other simulation tools, where the driving behavior is based on constant speed, PTV Vissim utilizes a model developed by Rainer Wiedemann in 1974. The basic idea of the model is that a faster moving vehicle, which is approaching another slower moving vehicle, will reach a specific distance to the upcoming vehicle when the driver starts to decelerate. The driver of this vehicle will decelerate his speed below the speed of the vehicle ahead. The distance between the two vehicles will increase and the driver will start to accelerate the vehicle again until he reaches a specific distance between the vehicles. As the driver approaches the vehicle, he will decelerate again and so on. The driver will follow this type of driving behavior until he reaches an equilibrium distance to the vehicle upfront. This is illustrated in Figure 5, where the iteration process of the car following model is described. (PTV Group, 2013d, pp. 20-21)

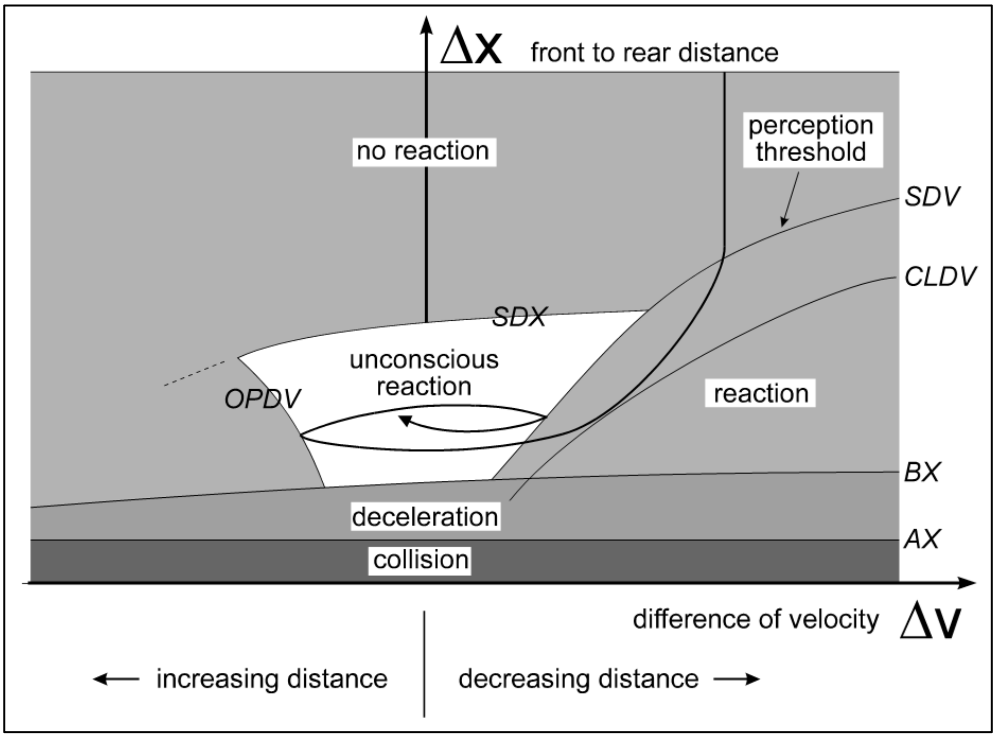

Figure 5 The Wiedemann model illustrating the car following logic used for calculating the driving behavior in PTV Vissim. (PTV Group, 2013d, p. 21)

Each driver within the network is connected to a specific vehicle. This means that a specific driving behavior is assigned a vehicle with its own technical data parameters, which can be modified. It is also possible to change and specify attributes regarding driving behavior and interferences with other objects (PTV Group, 2013d, pp. 20-21). PTV group states a warning sign about changing parameters of the driving behavior in their official manual. Due to the complexity of this function, together with preknowledge of this matter, changing this type of parameter is negligible in this project (PTV Group, 2013d, p. 158).

The Wiedemann model includes four different driving states that essentially describe the driving behavior under different traffic situations. The driver switches between the states as he reaches a certain threshold. 'Free Driving', 'Approaching', 'Following' and 'Braking' are the names of the four driving states used in PTV Vissim. 'The Free Driving state' does not reflect to other vehicles, which means that the driver only needs to maintain the desired speed, which due to an unbalanced accelerator control will vary around its preferred speed. 'Approaching' is another state, which refers to a driver that decelerates his current speed while he approaches an upcoming vehicle. This will proceed until he reaches the safety distance to the vehicle in front. The aim of the driving behavior in the 'Following state' is to keep a constant safety distance to the preceding vehicle. Due to the stochastic occurrences in PTV Vissim, a variety distance between the two vehicles will occur. The driver in the 'Braking state' will adjust his deceleration rate depending on the driving behavior of the vehicle upfront. As the distance between the two vehicles will decrease, the deceleration rate will increase depending on the safety distance. These four states are depending on the driving attributes of the preceding vehicle, i.e. acceleration, speed and distance that also include the characteristics of the driver himself and the corresponding vehicle. (PTV Group, 2013d, p. 160)

3.2.2 The Helbing model

The Helbing model is used for pedestrian simulation in PTV Vissim. In order to utilize this model, a specific add-on module is required, which is mentioned in Chapter 3.2. PTV Viswalk is a common add-on module to PTV Vissim, which provides the user with the possibility to implement a more advanced and realistic pedestrian simulation. Professor Dirk Helbing developed the model in 1995 and works today as a scientific advisor for PTV Group. The model is based on the social force model, which allows pedestrians to walk freely in a 2-dimensional plan. Due to this effect, pedestrians will find their way to the destination area by themselves (PTV Group, 2013e, p. 2).

The basic idea behind the social force model is to add the social, psychological and physical forces, which result in a total force. This force is then converted into one physical parameter, acceleration, which sets the actual motion of pedestrians. This methodology takes into account the interaction of other pedestrians and obstacle along the route of reaching its destination. The user only needs to define an origin area and a destination area in order to create a route. The program will calculate the entire route, along with the interactions of other obstacles and pedestrians. (PTV Group, 2013d, p. 473)

The motions of pedestrians simulated by PTV Viswalk can be divided into three separate levels. Each level represents a time interval for which the time of performing the action can be stated:

- <u>Strategic level</u> (minutes to hours): The pedestrian calculates the route by generating a number of destinations. This level is defined by the user.
- <u>Tactical level</u> (seconds to minutes): PTV Viswalk also includes the network in the calculations and chooses a route for the pedestrian. A part of this level is controlled by the user.
- <u>Operational level</u> (milliseconds to seconds): The pedestrian computes the motion according to the calculations, thus avoiding other pedestrians and obstacles making it possible to move through a crowd of pedestrians. This level is totally controlled and performed by PTV Viswalk. (PTV Group, 2013d, p. 474)

This realistic pedestrian behavior is visualized in Figure 6. It illustrates an actual simulation in PTV Vissim and the movements of the pedestrians are shown.

Figure 6 An illustration of a pedestrian simulation in PTV Vissim using the Helbing model. (PTV Group, 2013a)

Unlike the Helbing model, pedestrians are also possible to be simulated according to the Wiedermann model. In this case, pedestrians follow a specific link between the origin area and the destination area. This way of simulation technique is comparable with vehicles because the Wiedemann model is designed and developed based on different driving behaviors. PTV Viswalk will not, unlike the Helbing model, calculate the pedestrian route decisions. The user will instead define the route in advance. This way of simulating pedestrians will not reflect the realistic parameter as much as the Helbing model. Instead of moving freely, the motions of pedestrians will be restricted to a 1-dimensional way of moving. This type of pedestrian simulation is already included in PTV Vissim and does not require any add-on modules. Even though the Wiedemann model follows a simplified model, there are situations where it is useful and the need for the Helbing model can be neglected. Examples of this matter are situations for simulating pedestrian crossings where the interactions with vehicles are studied. The need for a more advanced model may thus be insignificant. (PTV Group, 2013d, pp. 476-477)

3.2.3 Node Evaluation

The function of the Node Evaluation in PTV Vissim is used for recording emission data from motorized vehicles. The data is collected within a specific area, a so called Node, which is defined by the user. The theory behind the function is complicated compared to the other evaluation functions used throughout this project. The emission data is completely based on the total amount of fuel consumed within the node. PTV Vissim uses simplified factors to convert fuel consumption into emissions, see Appendix F. CO, NO_x and VOC are the three emissions that can be generated directly from the output data.

The converting factors have been developed by Oak Ridge National Laboratory of the U.S. Department of Energy. Fuel consumption is based on a program called TRANSYT 7-F, which refers to mean values of the North American vehicle fleet during the last 10 years[6]. The fuel itself cannot be referred to one specific kind; instead it contains a mixture of many different kinds of fuel. The converting factors have been developed based on the mean value of fuels. This means also that it doesn't take into account the fuel consumed and emissions released from different vehicle types and instead handle every vehicle type in the same way. The equations from TRANSYT 7-F used for calculating fuel consumption are presented and described further in Appendix F.

3.3 Mass handling

Huge amounts of masses will be generated during the construction work of Västlänken. The complexity of mass handling requires a plan by Trafikverket regarding mass handling. Five contractors are responsible for this assignment, which can be divided into three categories: extraction, transport and deposition. (Trafikverket, 2014b, p. 7)

3.3.1 Extraction

The Gothenburg soil contains both rock and clay but also some contaminated masses. Depending on the geographical location, different types of masses occur (Trafikverket, 2014b, p. 8). Various construction techniques are utilized depending on the properties of the soil. The construction method used in rock soil is a mixture of drilling and blasting and it can be divided into different stages.

1. Injection of cement outside the edges of the tunnel structure in order to strengthen the construction and seal it from water.
2. Drilling long vertical holes and using explosives to blast inside these holes.
3. The produced masses are extracted and transported away from the site. Finally, the tunnel is treated with shotcrete in order to reinforce the structure.

This cycle is normally applicable once a day for each tunnel (Trafikverket, 2014a, pp. 3-5). The possibility to sell the rock on the market is relatively good. It can easily be used as a building or filling material. This is possible under the condition that the rocks can be crushed in the tunnel[7].

The material properties of clay make it impossible to utilize blasting or drilling techniques due to its solute condition. The methodology used for clay soil is called "cut & cover". Simply explained, a huge hole is created by digging it in the ground and building the actual tunnel construction separately in concrete (Trafikverket, 2014a, pp. 6-7). A fifth of the total masses generated from the digging are used as filling material outside the structure (Trafikverket, 2014b, p. 4). Clay is estimated to be more difficult to sell on the market. The disadvantage with clay is that it is difficult to compress and sags easily appear. Requirements for it as a building material are consequently not fulfilled. However, it can be used as a filler material and also as a construction material at sites with low requirements on precision requirements[7].

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[6] Dörthe Müller (PTV Group Support), interviewed by Carl Stenberg the 30th of April, 2014.
[7] Christer Brevell (Project Manager, ÅF Infrastructure AB), interviewed by Erik Solli Hansson and Carl Stenberg the 3rd of April, 2014.

3.3.2 Transport

The transport part of mass handling includes mass transport from the extraction sites to the deposition site. There are 10 service tunnels associated to Västlänken and the main function of these is to enhance the connection between the ground and the underground levels. In this case, the extraction sites refer to the two service tunnels, located south of Korsvägen, service tunnel Chalmers and service tunnel Liseberg. The locations of the tunnels with its corresponding routes to E6 are illustrated in Figure 7.

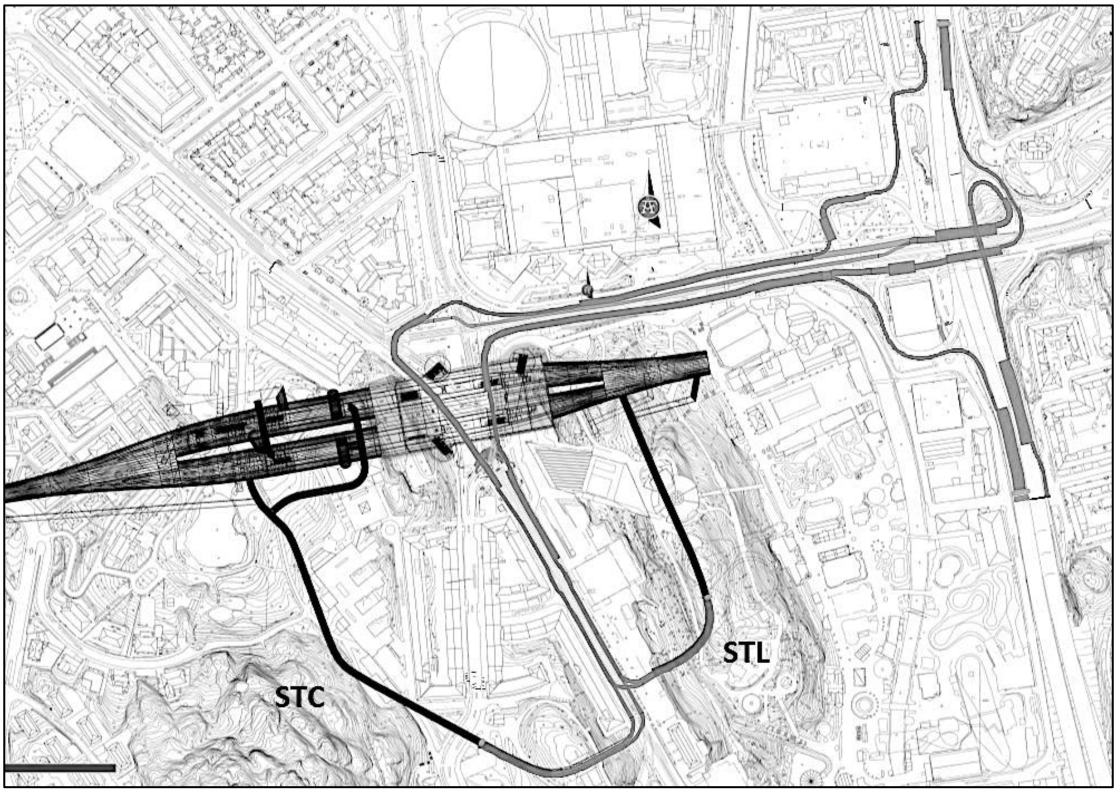

Figure 7 Korsvägen at Stage 1 with its associated service tunnels, STC and STL. The grey lines are possible mass transport routes between the service tunnels and E6. At Stage 2, the routes will look similar with only small changes in the intersection Korsvägen.

The mass transport routes from STC and STL will most likely go by E6 due to its suitable traffic condition and flexible infrastructure. Depending on the location of the deposition sites, the route from Korsvägen will vary. If the transport route includes E6, there are two route choice alternatives. One alternative is to go through Korsvägen and one option is to go via Mölndalsvägen.

Depending on varying traffic intensity, the transit time from the service tunnels to E6 through Korsvägen for the mass transport trucks will vary during the day. The transit times are measured from the mouths of STC and STL up to the access ramps of E6 and back. The routes are illustrated in Figure 7.

Regarding STL, it is estimated to drive 70 vehicles per day during three and a half years. This includes trucks driving residual masses and other vehicles containing materials related to the construction work in both directions. The number of vehicles driving to and from STC is estimated to 312 during four years. In total, 382 vehicles will traffic the road through Korsvägen every day.[8]

3.3.3 Deposition

The demand for residual masses in Gothenburg is limited and the need for potential buyers outside the region is necessary. Although, the port of Gothenburg is in need of almost 2 billion m^3 in case of an expansion of the harbor. If this turns out to be the case, most of the masses generated from Västlänken could be used for this project. The transport route from STC and STL to the port of Gothenburg is possible via E6 in a northbound direction. This makes Korsvägen the shortest transport route compared to Mölndalsvägen. Other applicable projects in the region of Gothenburg concern flood protection from a possible sea level rise. Dikes connected to road and rail infrastructure are also worth considering. One example of an old deposition site in the Västra Götaland region is Brudaremossen's landfill site. This covers 20 hectares of field, where clay masses could be used as filling material. Transport of masses abroad is also seen as an option. Langøya in Norway and different salt mines in Germany are possible permanent deposition sites. (Trafikverket, 2014b, pp. 16-17)

3.4 Level of Service

Level of Service, LOS, is a measurement of pedestrian density. Depending on the pedestrian environment to be measured, there are several definitions of LOS. Walkways, stairways and queuing areas are examples of environments with different definitions. In this study, LOS is investigated for waiting areas associated to PT stops. These are categorized as queuing areas and the definitions of LOS are presented in Table 1. The value of LOS for queuing areas is defined as the number of pedestrian per area. The different criteria vary from A to F, where A represents the lowest value of pedestrian density and F the highest. The definitions are based on photographic studies of crowds with different levels of pedestrian density. The effect on people is considered and criteria for the six different LOS criteria are consequently defined. LOS A to C are considered as acceptable levels according to the study. Pedestrian densities above LOS C are categorized as harmful and should be avoided. (Brian L. Bowman, 1989, pp. 21-23)

Table 1 Six LOS criteria for queuing environments with corresponding descriptions. Acceptable LOS are defined as A to C.

LOS	[Ped/m^2]	Description
A	<0,8	Circulation possible without disturbing other pedestrians.
B	0,8-1,1	Standing still and small circulations is possible without disturbing other pedestrians.

[8] Maria Fransson (Geologist, ÅF Infrastructure AB), interviewed by Carl Stenberg the 7th of May, 2014.

C	1,1-1,5	Standing still and making small circulations is possible but affects other pedestrians.
D	1,5-3,6	Standing still without affecting other pedestrians is possible. Movements must be as a group. Acceptable during short periods but not in long-term ones.
E	3,6-5,6	All pedestrians are in physical contact with each other. Very discomforting in long-term.
F	>5,6	All pedestrians are in close physical contact to each other. Very discomforting also during short periods. There is a risk for panic.

3.5 Air pollution

Three different types of emissions associated to air pollution are investigated in this project. The emissions of carbon monoxide, nitrogen oxides and volatile organic compound are recorded around Korsvägen by using the simulation program. A brief description of their individual properties and associated effects on humans is stated below.

CO is a toxic gas, which is both smell- and colorless. Due to the fact that it is not detectable by humans makes it a dangerous gas. Symptoms associated with this gas are headache, nausea and dizziness. These symptoms are facts already at low doses, especially indoors (EPA United States Environmental Protection Agency, 2013). In the case of Korsvägen, CO is produced in internal combustion engines from the vehicles trafficing the roads. If the oxygen level is too low to produce carbon dioxide during combustion, CO is formed (Tikuisis, et al., 1992).

The chemical designation and the most common name of nitrogen oxide is NO_x. Different combinations of the two substances, nitrogen and oxygen, together form this compound. There exist many mixtures but especially two compounds are associated with air pollution, nitrogen oxide and nitrogen dioxide, NO and NO_2, respectively. In this study, the emissions of NO_x are formed and produced from the combustion engines at high temperature within the enclosed area of Korsvägen. In the presence of sunlight, reactive NO_x-particles have the ability to react and form smog near the source, also called ground-level ozone. People in the presence of such smog expose themselves to danger by causing damages to their lungs. Children and persons with asthma are extra vulnerable for such environment. (United States Environmental Protection Agency, 2007)

VOC is a generic term of numerous amounts of substances in gaseous form. Because it contains different chemical compounds, it is produced from many different sources but one of these is from motorized vehicles. The same smog formed by NO_x-particles can also be created from VOC-particles. VOC have the ability to form ground-level ozone by reacting with nearby oxygen molecules. Both NO_x and CO contribute with oxygen for this type of reaction but it only occurs in the absence of sunlight. This makes these three compounds interesting to investigate further. (EPA United States Environmental Protection Agency, u.d.)

4 Results

The chapter is divided into several parts where different results are presented in graphs, charts and tables. Results related to vehicle transit time and LOS are partly presented in this chapter; the rest is presented in Appendix A and D.

4.1 Vehicle transit time

The transit times were recorded in PTV Vissim by using the function Vehicle Travel Time. Totally there are eight potential routes for the mass transports and the travel time during the day is recorded for all of them in the three models. Figure 8 visualizes the transit time for one of the eight route choices, i.e. from STL to E6 N. The transit times for the other seven route choices are presented in Appendix A.

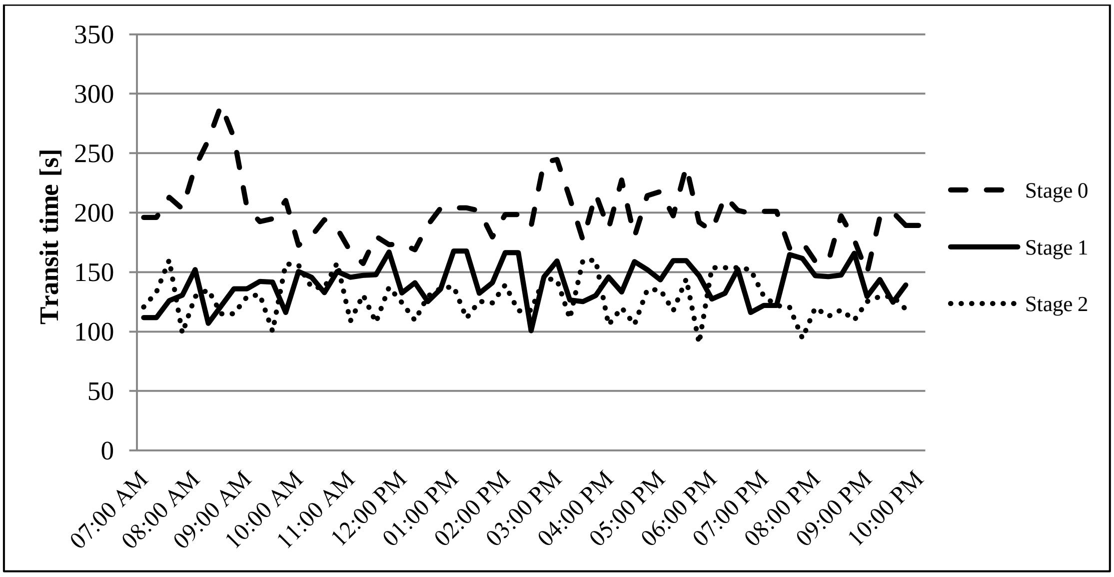

Figure 8 Transit times during the day for mass transports from STL to E6 N.

Figure 9 and Figure 10 visualizes how the transit cost per truck from the service tunnels to E6 varies during the day for Stage 1 and Stage 2, respectively. The values are based on the average transit time for the eight different routes during the day and considers an hourly cost of of 1392 swedish chrones per hour for renting the mass transportation trucks. The fact that the values are mean values from all the routes makes it important to consider that deviations between the different routes might occur.

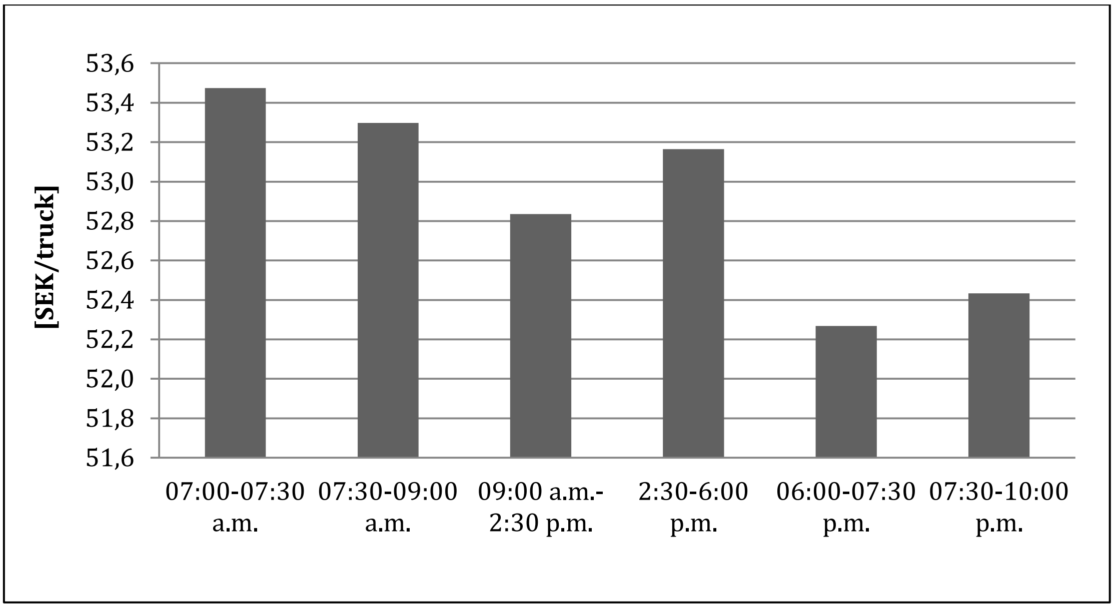

Figure 9 Average transit cost, one way, for the eight route alternatives during the day at Stage 1.

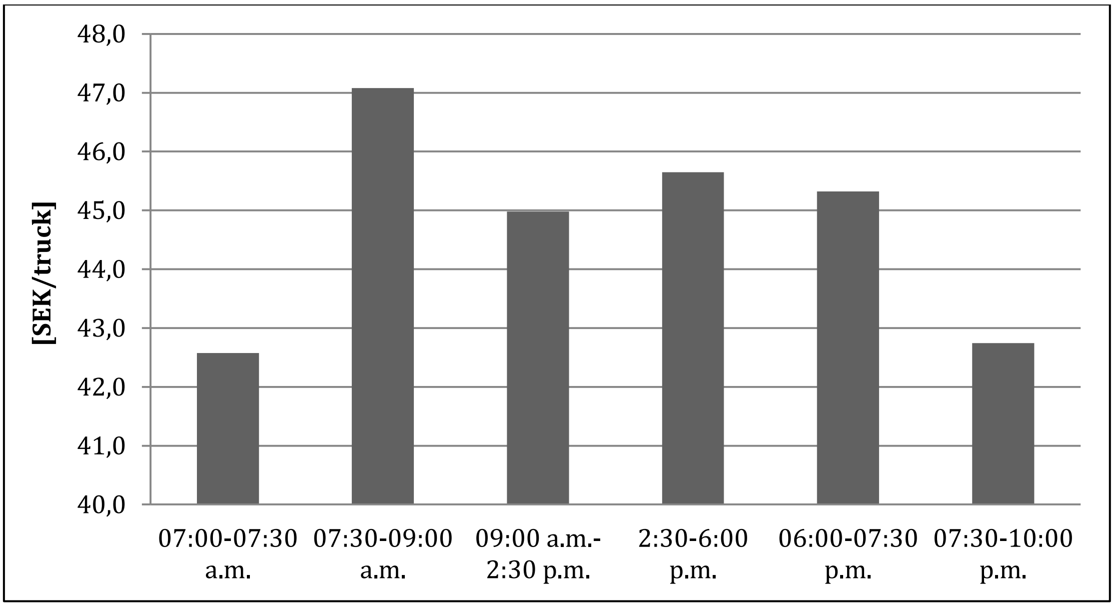

Figure 10 Average transit cost, one way, for the eight route alternatives during the day at Stage 2.

Table 2 visualizes possible savings if choosing the shortest transit time and avoiding the longest one. In Stage 1 chosen driving time is between 06:00-07:30 p.m. and avoided driving time 07:00-07:30 a.m. In Stage 2 chosen driving time is between 07:00-07:30 a.m. and avoided driving time 07:30-09:00 p.m. Stage 0 represents Korsvägen today and is presented only in comparative purpose.

Table 2 Yearly possible savings by driving the mass transports at the right time periods during the day.

	Stage 1	Stage 2
Highest transit cost [SEK/truck]	53,5	47,1
Lowest transit cost [SEK/truck]	52,3	42,6
Difference [SEK/truck]	1,2	4,5
Vehicles [1/year]	49 436	49 436
Total possible gain [SEK/year]	59 323	222 462

4.2 Pedestrian density

The number of pedestrians in the model varies during the day and the data is based on statistics, but the waiting time on the platforms is not. No statistics for Korsvägen regarding average waiting times for buses and trams are available and therefore a sensitivity analysis for this variable is performed. Due to lack of time there was no possibility to make a sensitivity analysis for all the stages and one stage consequently had to be chosen. The results show that the pedestrian density is, in general, at its highest during Stage 2. As a consequence of this, the sensitivity analysis is performed for this stage. The results of this are presented in Figure 11.

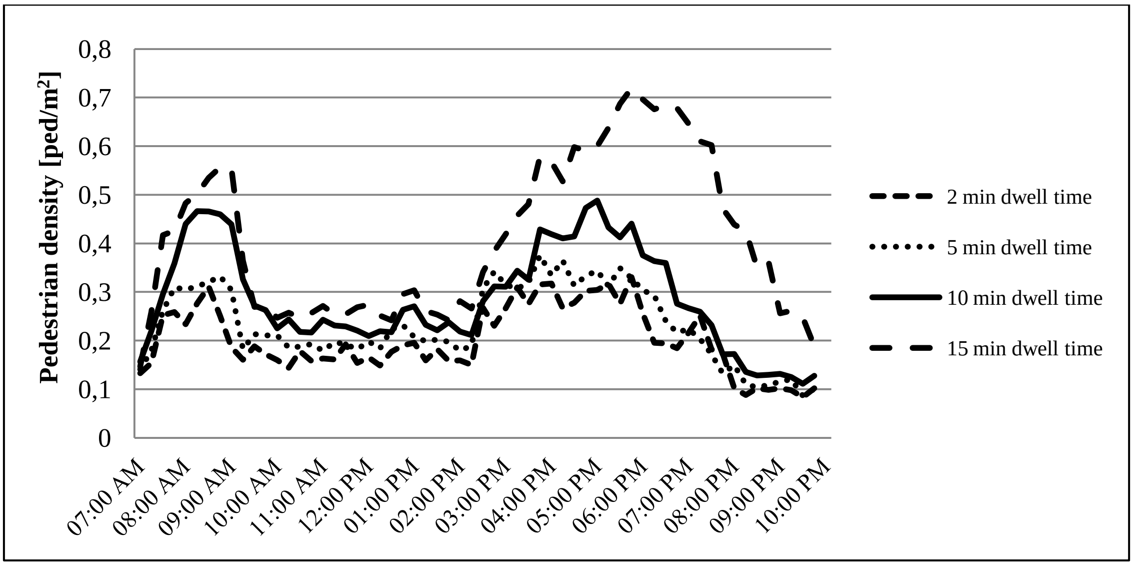

Figure 11 Sensitivity analysis at Stage 2 of the pedestrian density with dwell time at waiting areas as the varying parameter.

In Figure 12 and 13, the line 'Stage 2, average', is the average pedestrian density value for all waiting areas in Korsvägen Stage 2. Figures 12 and 13 presents results from two different PT stops existing in the current state of Korsvägen. The names of the sites are presented in Figure 1.

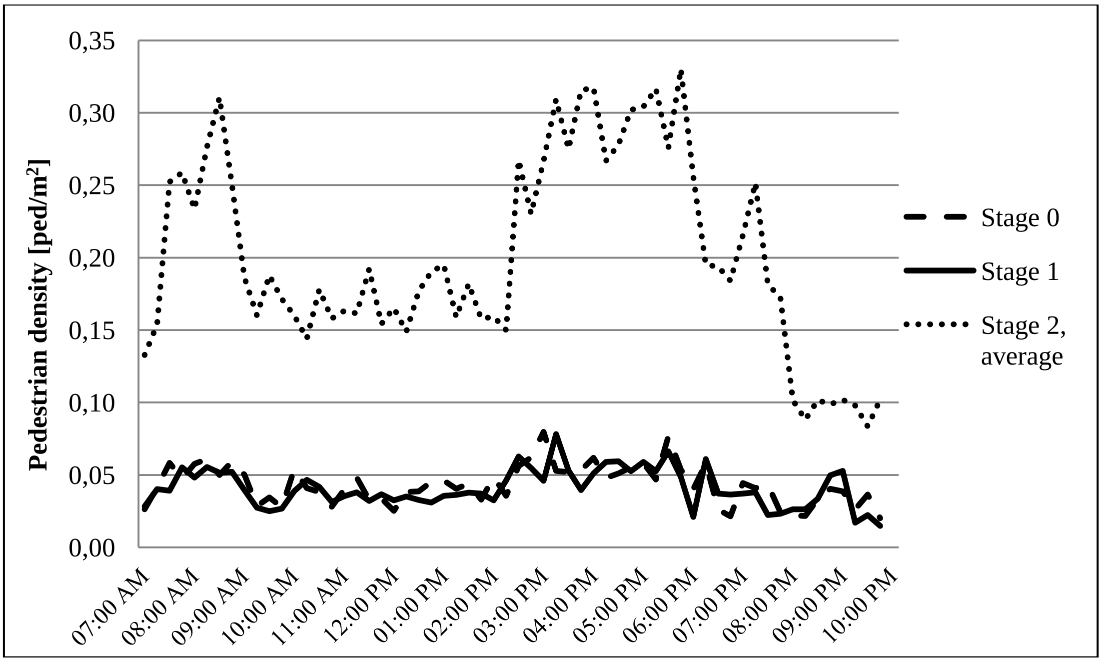

Figure 12 The pedestrian density at Site A during Stage 0 and Stage 1 compared to the average pedestrian density at all platforms during Stage 2.

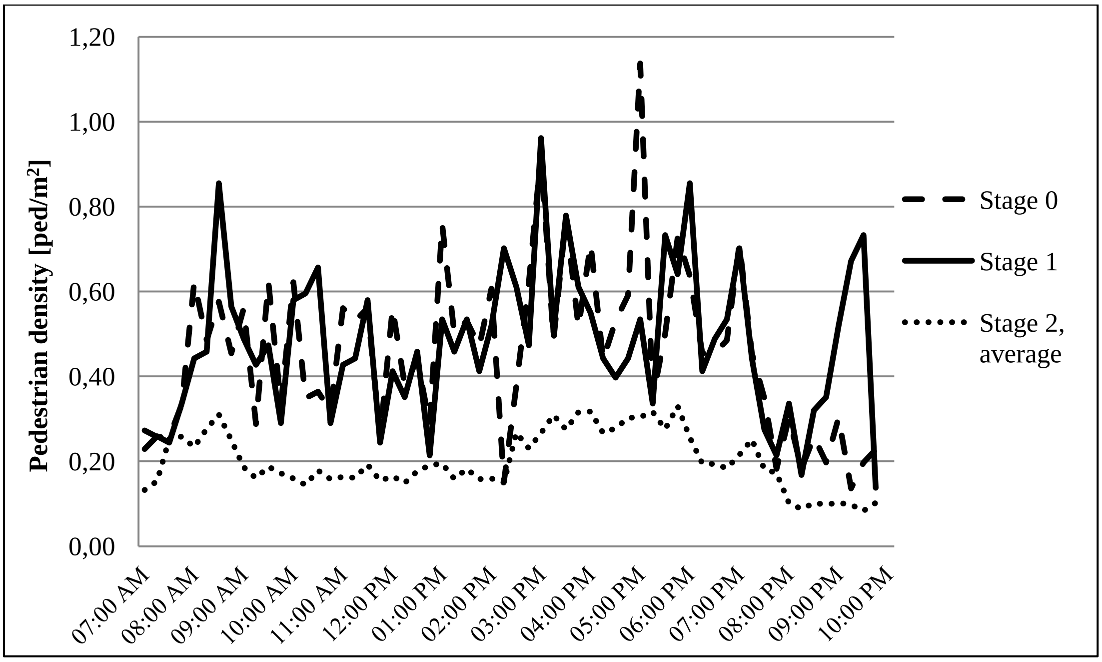

Figure 13 The pedestrian density at Site H, the boarding platform, during Stage 0 and Stage 1 compared to the average pedestrian density at all platforms during Stage 2.

4.3 Emission

The result data of emission was recorded using the Node Evaluation function for all three stages. The studied area in all stages is of the same characteristic function, i.e. identical size and position. In this way, a fair comparison between the stages is possible. The emission data is generated in PTV Vissim by a calculation using simplified converting factors multiplied by the fuel consumption. The result of fuel consumption together with the emissions for all stages is shown in Table 3. The values represent the total amount in kg for emissions and liters for fuel consumption from 7 a.m. to 10 p.m.

Table 3 Total fuel consumed and emissions released by the vehicle fleet trafficking Korsvägen.

	Emissions [kg]			Fuel consumption [liters]
	CO	NOX	VOC	
Stage 0	35,1	6,8	8,2	1905
Stage 1	8,6	1,7	2,0	467
Stage 2	5,8	1,1	1,4	317

The actual amount of these values and the differences between the stages are of importance to this study. This study was conducted in order to show and analyze the change in air pollution from surrounding traffic of Korsvägen by comparing current situation and a proposed future scenario. The change in fuel consumption between the stages is visualized in Figure 14.

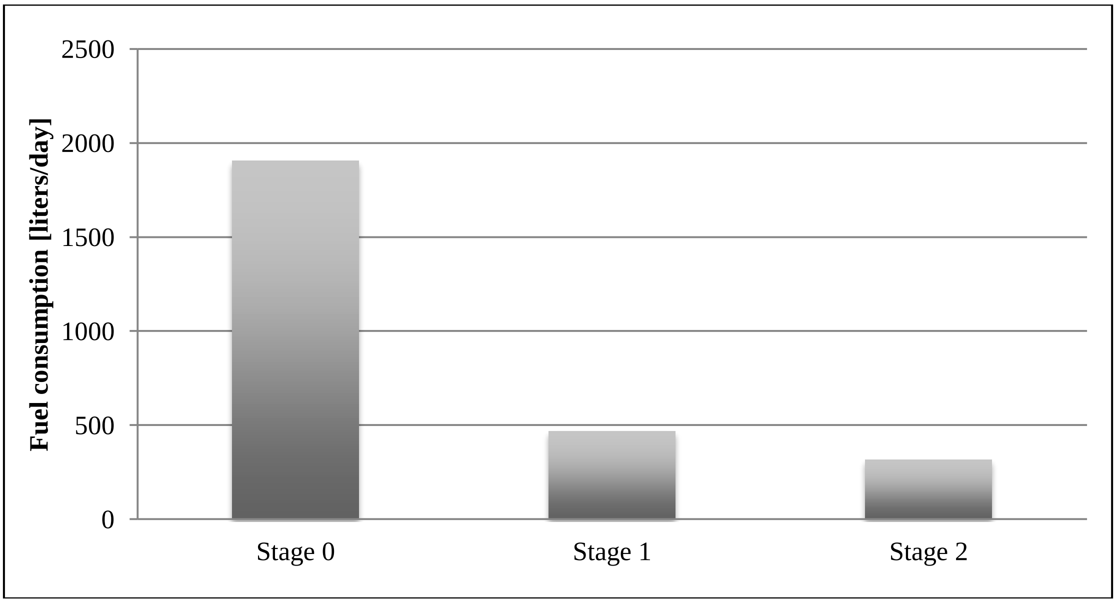

Figure 14 Total amount of fuel consumed during a working day within the node for all three Vissim-models.

By plotting the fuel consumption values from Table 3, one can clearly see the difference between the stages. As explained in Appendix F, the emissions are calculated directly in PTV Vissim based on the fuel consumption. The results are visualized in Figure 15.

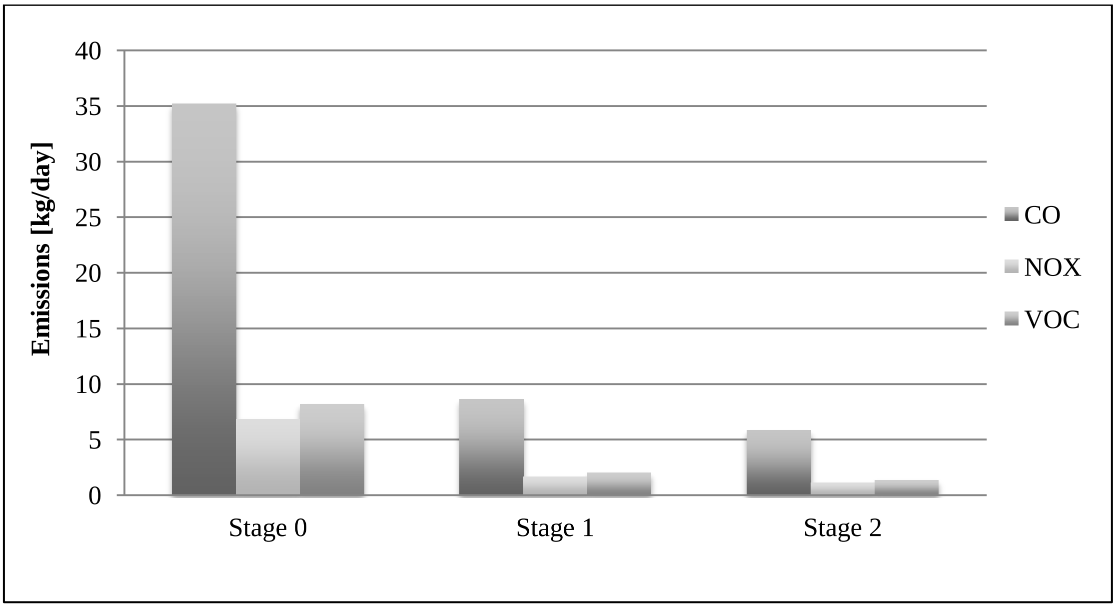

Figure 15 Emissions generated during a working day inside the node at Korsvägen.

5 Analysis

This chapter consists of the analytic part of this master thesis. All results presented in Chapter 4 are analysed and the outcomes are deeply explained using the theoretical background as a reference.

5.1 Reliability analysis

The results utilized from PTV Vissim are stochastic. Five simulation runs with five different random seeds were performed, see Figure 16-17. Due to a time requirement of 2-3 hours per simulation run, this was not possible to perform for all results. The average deviation from the average value for each random seed is 5% for transit time and 1% for pedestrian density. This makes the vehicle transit time results at Stage 2 reliable, but not for Stage 1 due to its small result variations.

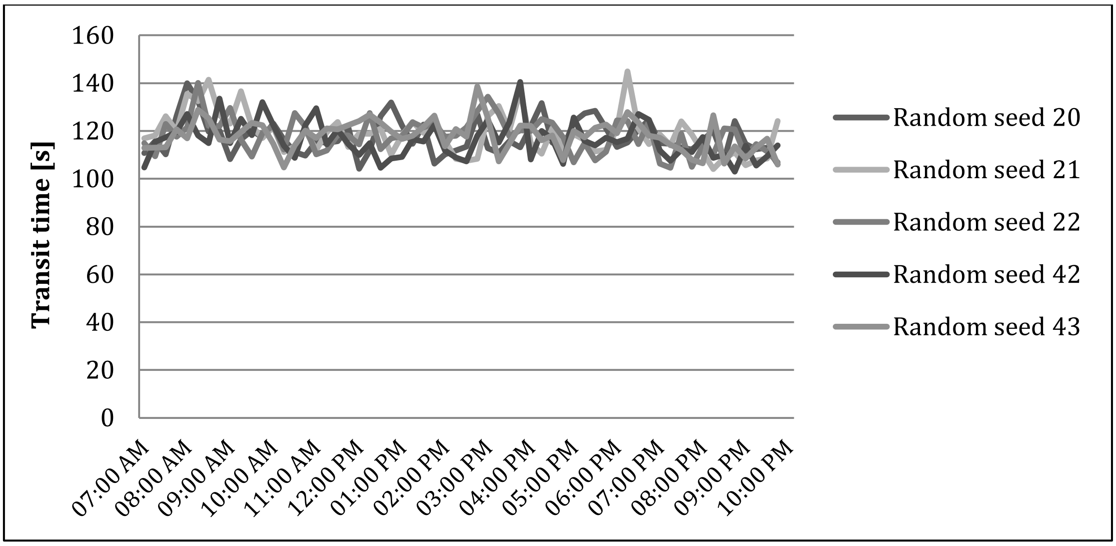

Figure 16 Reliability analysis of the vehicle transit time results at Stage 2.

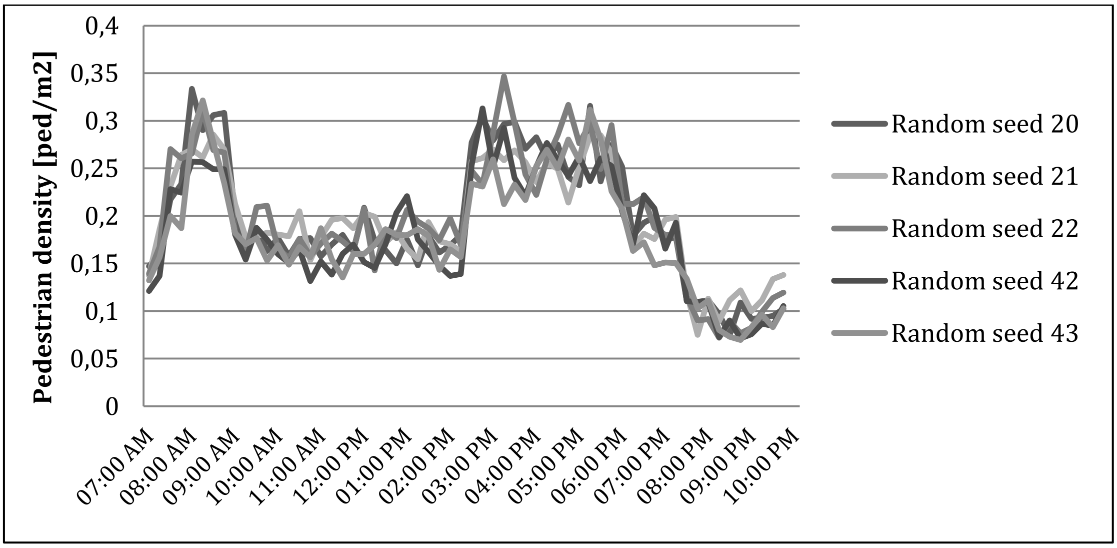

Figure 17 Reliability analysis of the pedestrian density results at Stage 2.

5.2 Vehicle transit time and transit cost

The vehicle inputs in the models aim to reflect the vehicle flow from the real Korsvägen. This is important due to the vehicles impact on the transit time through Korsvägen for mass transporting trucks.

There are six tram and 15 bus lines passing Korsvägen daily (Västtrafik AB , 2014a). The PT time schedule between 07:00 a.m. and 10:00 p.m. is implemented in PTV Vissim with high accuracy. There are two PT stations within the area covered by the simulation model, Korsvägen and Liseberg. PT vehicles stopping at Liseberg also stop at Korsvägen. The Liseberg station is thus not considered in this thesis. The PT vehicles partly drive along with the mass transport trucks and consequently affect their transit time. To affect other pedestrians and vehicles as realistically as possible, all PT vehicles follow their real path through the model and have a speed of 40 kilometers per hour.

No data regarding the daily vehicle traffic flow on Skånegatan was available. However, the amounts of cars during peak hours are found in Refsnes (2012, p.8). To implement a realistic amount of vehicles, the ratio between the number of vehicles during peak load on Skånegatan and Örgrytevägen and the available data during the day at Örgrytevägen contributes to the implementation data on Skånegatan. This makes the relation between Örgrytevägen and Skånegatan linear during the day.

Figure 18 presents the average number of cars on all roads leading to Korsvägen during week 38, year 2013. Örgrytevägen is the heaviest loaded road and Eklandagatan the second heaviest. In general, between 07:30 a.m. and 09:00 a.m. the roads have the largest amount of traffic. From 09:00 a.m. the traffic intensity is the same during the day until the afternoon rush when people go home from work between 03:00 p.m. and 06:00 p.m. There is a tendency at Örgrytevägen that the afternoon rush is delayed compared to the other roads.

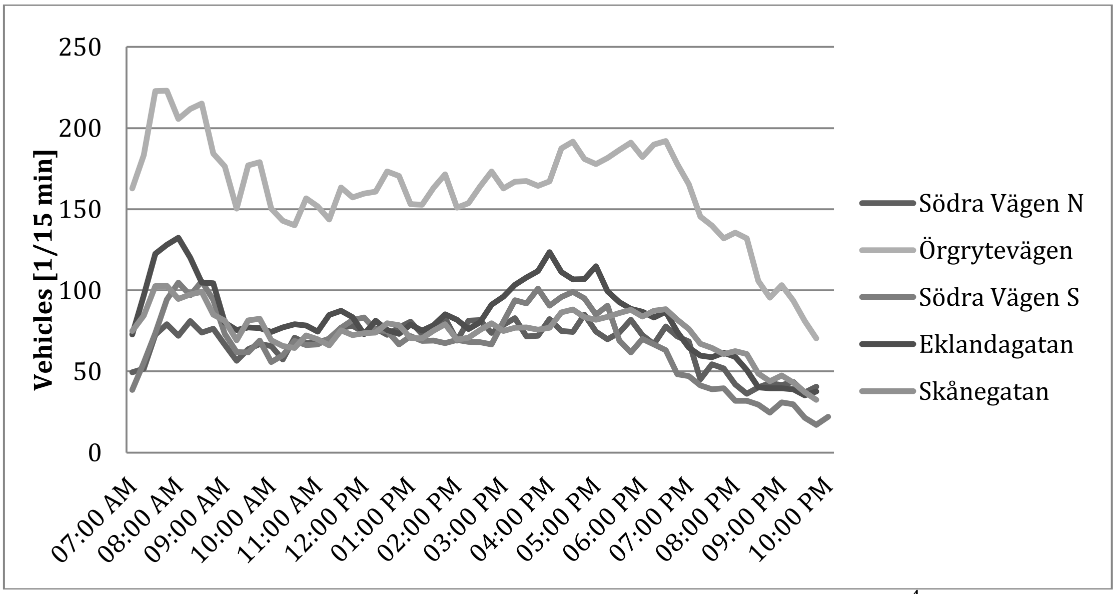

Figure 18 The traffic flow in direction towards Korsvägen in 2013[4].

Due to the changes regarding the traffic situation related to Korsvägen at Stage 1 and 2, a macroscopic model was designed by Ramböll in order to show these effects. The study presents the quantity changes for all major roads in Gothenburg between today and the construction period, i.e. 2014 and 2020, respectively (Trafikverket, 2014a). Thus, it is assumed a linear relation between the traffic intensity on each road in 2014 and 2020. From the study, the ratio between today's traffic flow and the traffic flow in 2020 can be calculated and applied in the models of Stage 1 and 2. Södra Vägen N is an exception because it will be completely closed for car traffic towards Korsvägen during the construction period of Västlänken[1]. Figure 19 visualizes the traffic intensity for all roads leading to Korsvägen year 2020. The size of the traffic flow is important due to its impact on other vehicles and consequently on their transit time.

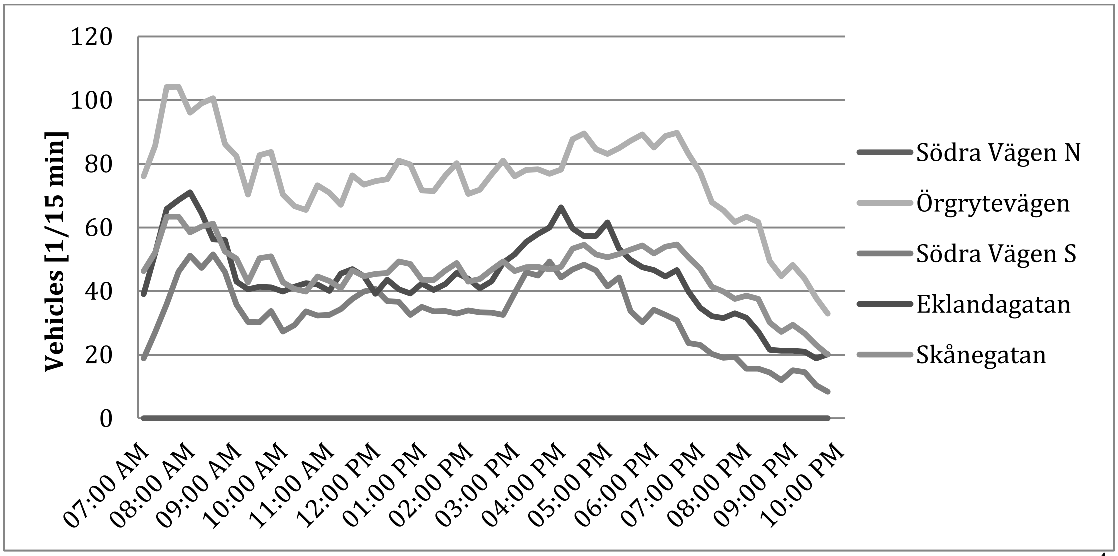

Figure 19 The estimated traffic flow in direction towards Korsvägen in 2020[4] (Trafikverket, 2014a).

The vehicle route choice ratios inside Korsvägen are obtained from an iteration procedure in PTV Vissim. A deviation of less than 10% between the traffic flow in the model and real statistics on roads in direction away from Korsvägen at 07:15 a.m. was accepted. This is a procedure aiming to reflect a realistic vehicle flow.

Seven roads contribute with input vehicles to Örgrytevägen, but their traffic flow statistics are unavailable. The contribution from each of these roads was consequently estimated by logic reasoning but their total vehicle input to Örgrytevägen is correct due to statistics. The exact contribution from each road is therefore assumed to be negligible for the results in this thesis.

Table 4 visualizes the differences in transit time between before and after the start of the construction of Västlänken. In average, the amount of cars entering Korsvägen during the construction period (equal at Stage 1 and 2) of Korsvägen will be reduced by 48 %, while the transit time at Stage 1 and 2 will be reduced with 28% and 39%, respectively (Trafikverket, 2014a, p. 41). This shows that the connection between traffic intensity and transit time is not linear. This is a probable reason for the limited connection between the transit time and the traffic intensity in Stage 1 and 2. As a consequence of this argumentation, there is a minimum transit time which is reached before the number of cars in the model is set to 0.

Table 4 Transit time reductions for mass transports and estimated traffic flow reduction.

Route	Reduction transit time Stage 1 [%]	Reduction transit time Stage 2 [%]	Reduction no of vehicles driving to Korsvägen
Average	28%	39%	48%

Time is money, which makes it relevant to transform the varying transit times during the day to potential economic savings. A cost analysis is performed during six time intervals per day. The time intervals are presented in Table 6 in Appendix C. The different transit times are transformed into costs for the client. For the mass transports, an hourly cost of 1392 SEK is estimated for Trafikverket[9].

During a year there are estimated to be 225 work days and 382 vehicles related to the service tunnels south of Korsvägen, including both directions. This results in 85’950 vehicles per year. A yearly potential saving is calculated with by multiplying the number of vehicles and the costs for operating during the whole time. The costs for the six load levels are compared to each other and differences between the highest and the lowest costs are performed, see Table 2.

Figure 8 visualizes a prolonged transit time between 07:30-09:00 a.m. for Stage 0. According to Figure 18, this is when the traffic flow peaks. On the other hand, Figure 9 shows that the transit time cost for Stage 1, which is based on the average transit time, decreases between 07:00-07:30 a.m. and 07:30-09:00 a.m., despite the traffic intensity increase. Table 2 is based on average values from all route choices and not only from one. In total Figure 9 shows that the transit costs during Stage 1 are similar during the day, only differing with 1,2 SEK/truck between the longest and shortest transit times.

Figure 10 presents the transit costs during the day for Stage 2. The cheapest time to perform the mass transports between 07:00 a.m.-07:30 a.m. and between 07:30 p.m. and 10:00 p.m. Possible savings during Stage 2 are presented in Table 2.

5.3 Pedestrian density

The pedestrian density on a waiting area depends on several parameters; dwell time, size of the waiting area and the number of vehicles arriving to a specific site.

5.3.1 Sensitivity analysis

In Figure 11, a clear connection between pedestrian density and dwell time can be noticed. The longer dwell time, the more congestion situations appear. Figure 11 also visualizes that the pedestrian density peak is more and more delayed, the longer dwell

[9] Christer Brevell (Project Manager, ÅF Infrastructure AB), interviewed by Erik Solli Hansson and Carl Stenberg the 28th of April, 2014.

time is. Pedestrians with a long waiting time wait for a longer time before they leave the platform, which provides a delay in the graph before the peak is achieved. Not even with a dwell time of 15 minutes, serious congestion appears. During the day, LOS A is maintained. This confirms that the platforms at Stage 2, according to the LOS definitions, have a capacity large enough.

5.3.2 Level of Service

The behavior types and amounts of pedestrians in the models impact on the pedestrian densities at platforms. It is therefore important to reflect the pedestrian movements as realistically as possible. The pedestrian area surrounding Korsvägen is split into eight different areas in the simulation models. These areas have their own individual amounts of pedestrian input, as seen Appendix C, which are based on a Refsnes (2012). The amounts of habitants, employees and attraction site visitors are stated in Appendix C. Refsnes (2012) also states the numbers of pedestrians who start, end and change their PT travels at Korsvägen during peak hours. The amount of pedestrians is in reality dynamic during the day but this is too complicated to apply in the simulation models. Three different load levels are performed as an approximation. These are based on the total number of started travels every 30 minutes during the day with Västtrafik. The load levels implemented are 100%, 60% and 30% of peak load. These load levels are estimated to occur frequently in a survey by Västtrafik (Västtrafik AB , 2007). The load levels during the day are illustrated in Figure 20.

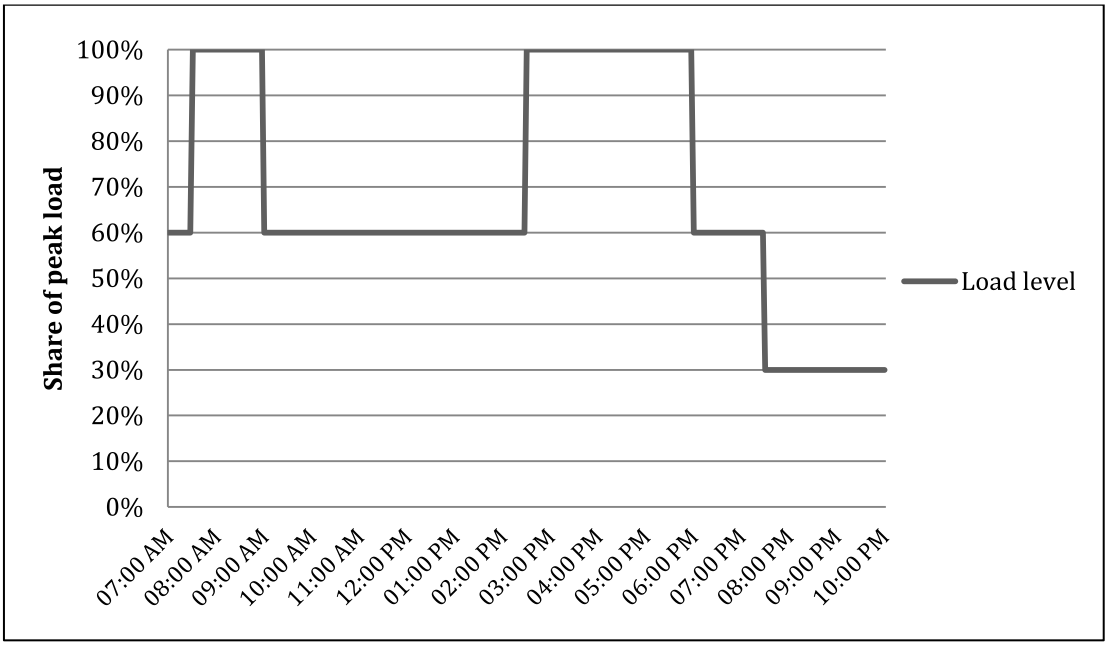

Figure 20 Pedestrian input during the day, ratio of peak load. (Västtrafik AB , 2007, p. 11)

The pedestrian density rate is, according to Figures 12-13, depending on the current load level. The transit time from the input areas to the platforms makes the congestion some minutes delayed. At 07:00 a.m., there are no pedestrians in the model, because this is the time when the simulation starts. As a consequence of this, it takes a couple of minutes before the pedestrian density is realistic. Based on the time it takes to reach a platform, wait for a PT vehicle, walk to another platform and to walk back to an input area, it takes around 11 minutes before the simulation model is reliable, i.e. at 07:11 a.m. According to Figures 12-13, the pedestrian density at the waiting areas is continually increasing also after 07:11 a.m. Primarily, it is important to consider that all measuring values are visualizing the maximum value during a quarter. For instance, 7:00 a.m. in the graphs gives the maximum value between 7:00 a.m. and 7:15 a.m. At 7:30 a.m. the congestion should therefore be higher due to a higher input number. Figures 12-13 represent one site each existing during Korsvägen Stage 0 and Stage 1, respectively. For each figure, the pedestrian density for this site during Stage 0 and Stage 1 is compared to the average pedestrian density at Stage 2. This is a consequence of completely different bus and tram stops at Stage 2. The results in Figures 12-13 and Appendix D show that, with exception for the boarding site, during Korsvägen Stage 2, there will be a higher pedestrian density compared to Korsvägen today. The high congestion number at the boarding site is explained by its small area. LOS B and in rare occasions C is here obtained. These are acceptable levels. Regarding the alighting site, people only alight and do not board arriving PT vehicles. This results in low pedestrian density which is found in Appendix D.

In general, it can be seen that the pedestrian density increases when the load level is increased. In Figure 12, around 07:30 a.m. the congestion is increased which is an effect of the increase from semi-load to peak-load. At 09:00 a.m., semi-load is again implemented into the model, which is reflected in Figure 12. The relation between the pedestrian density and the load level can be considered during the day.

5.4 Emission

A clear reduction in fuel consumption and emissions between the construction stages is visualized in Figure 14-15, especially between Stage 0 and Stage 1. The percentage reduction from Stage 0 to Stage 1 and 2 is 75,5% and 83,4% respectively. Based on the theory behind the Node Evaluation function in PTV Vissim, it is obvious that reduced vehicle traffic will affect the total fuel consumption. According to Table 4, the total vehicle traffic surrounding Korsvägen will decrease by 48% between today's volume and the amount present in the year 2020. Equation 13 states four factors that influence the total fuel consumption. These factors are speed, distance, delay time and number of stops. A reduction in car traffic results in less delay time and fewer numbers of stops as the congestion on the roads will decrease. The total distance traveled will also decrease due to fewer vehicles frequenting the roads. The average speed within the node will increase because reduced car traffic will result in less congestion. Based on Equation 13, all four terms will, due to fewer vehicles using the roads, decrease the fuel consumption within the node. This explains the drastic reduction in total fuel consumption between the stages visualized in Figure 14.

The quantity in vehicle traffic during Stage 1 and 2 are identical and do not explain the difference in fuel consumption. The difference between the stages is shown by the road linking Örgrytevägen and Södra Vägen N. This connection is removed in Stage 2 due to the reconstruction of the public transport stops, which is shown in Figure 2. It means that the vehicles entering the node on Örgrytevägen are only allowed to drive to Skånegatan instead of having the possibility to drive to Södra Vägen N. The travel distance from Örgrytevägen to Södra Vägen N are 185 m compared to 115 m, which is the distance to Skånegatan. With the same amount of vehicles on the roads, the total travel distance between Stage 1 and 2 will therefore decrease by 70 m per vehicle driving to Södra Vägen N from Örgrytevägen due to this effect. This explains the small but significant reduction in fuel consumption between Stage 1 and 2.

6 Discussion

This chapter starts with discussions related to simulation techniques and corresponding concerns. Also included in this section are consequences related to input data that have a significant influence on results. Some general thoughts regarding the project of Västlänken are also stated.

The reliability of results by utilizing software tools for traffic analysis is depending on the structure of the program. The outcome will differ from reality but the question is how much. In order to create this kind of software, many assumptions are applied, which limits its application area. Exact reflection of reality is too complex and advanced to simulate. It will always lack some factors but it may be insignificant regarding the influences on results. The simulation software used in this project is highly advanced for this type of traffic analysis. PTV Vissim contains a user interface that is easy to learn and apply, even for users that lack experience. Another advantage regarding this software is that it is possible to run simulations on ordinary laptop computers. By applying some tricks in the creation of the networks, it is possible to increase the simulation speed and save time without compromising the results. PTV Vissim is based on stochastic occurrences. In order to generate reliable results, the mean values of several simulation runs are necessary. Due to the size of the networks created in the software, this is only applied once because it would be too time-consuming to apply this for each result. The findings of such simulation resulted in a 5% average deviation that is valid for every result generated throughout this project.

There are some traffic situations that need to be stated to clarify the reliability of results. Differences in driving conditions and unexpected traffic situations are not taken under consideration in the program. These types of constraints may have small influences on the results but are still worth mentioning. One parameter that is considered as crucial regarding limitations in PTV Vissim is that each driver obeys the traffic rules. In reality this may differ due to illegal driving and human mistakes. Also the acceleration and deceleration follow a complex car-following-theory in the program but in reality there are larger variations in driving behavior. This clarification should be considered for the results associated with this project. The results regarding emissions are somewhat misleading and critical assumptions in PTV Vissim are listed below.

- It is based on mean values of the North American vehicle fleet.
- It does not take into account the influence from individual vehicle types.
- It does not take into account the influence from PT.

The equation used for calculating fuel consumption is developed based on values of the North American vehicle fleet and may differ from Swedish values. Differences in fuel taxes between the regions might have an effect on the fuel consumption due to changes in driving behavior and choice of vehicles. The average gasoline price in the United States was 6.44 SEK/liter which compared to the Swedish price which was 14.27 SEK/liter in late 2013. This will most likely lead to less environmental friendly cars trafficing the roads in the United States. The resulting fuel consumption and emissions will at Korsvägen be lower due to this effect (Bloomberg.com, 2013). By utilizing mean values of an entire vehicle fleet, the results from individual vehicle types are thus not included. The vehicle types using the roads through Korsvägen are different types of cars and HGVs. This means that either if it is an environmentally friendly car or a huge truck for goods transport driving on the roads, both vehicles are treated the same way. A higher level of accuracy in results should include separate impact figures for different types of vehicles. Influences from mass transports are thus not separately treated and will have the same effects as an ordinary vehicle. This means that the vehicles associated to the construction work around Korsvägen are not included. The numbers of vehicles of this matter are 382 per day, which compared to the total number of vehicles trafficking the roads, which is almost 30000, are relatively small. It is therefore reasonable to neglect such impact.

Another assumption related to emission results is that the fuel consumed by PT vehicles is not included. There are more than 2000 PT vehicles passing through Korsvägen every day. It is still relevant to use the results for a comparable study between the stages due to the fact that the same number of PT vehicles will pass through Korsvägen in all three stages. Many vehicles used by Västtrafik for public transport are today using renewable fuels. 13% of the total bus fleet is running on renewable fuels (Västtrafik AB, 2010, p. 4). Together with trams that are running on green electricity, vehicles used by Västtrafik stand for 1% of the total CO_2 emissions in the region of Gothenburg (Västtrafik AB , 2014b). The missing fuel consumption from public transport could therefore be negligible without compromising the result.

The amounts of cars, pedestrians and PT vehicles are parameters affecting the travel time for mass transports. In reality, the PT timetables during Stage 1 and 2 are not yet decided but in the models they are kept the same, which might result in deviations between the simulation results and the future reality. During Stage 0 and Stage 1, pedestrians that are queuing on the waiting areas in the simulation models are spread out. Site A, site D and site F have one third each of the available area in the “island” of the commuter station of Korsvägen. This area is available in reality, but people are normally standing closer to the boarding platforms. This contributes to a lower value in pedestrian density in the models. However, people spread out also in reality if the density is too high. This is also current regarding site B, site C and site E, which have larger areas measured than used in the real world. However, at site B, the pedestrian density is higher compared to site C and site E although the number of PT lines is the same. The areas have different sizes and the number of PT vehicles arriving to the platforms differs. Results regarding pedestrian densities are thus somewhat misleading, due to the assumptions made that each PT site attracts the same amount of people, even though it differs in reality. Statistics related to this matter is unavailable and not included in this project.

It is assumed that the number of visitors is the same every day and peak values are converted into average values. For instance, Liseberg has most of their visitors during the summer months and no visitors during closed up period. The capacity demand for pedestrian density at waiting areas during opening hours is thus not reflected in this investigation. Other attraction sites around Korsvägen might also have their visitors during concentrated hours.

Finally, the construction work of Västlänken is estimated to start at 2018 but the accomplishment of the project is not fully decided. Several parameters used in this thesis are only estimations and many assumptions regarding input data are used.

7 Conclusion and further research

In this chapter, drawn conclusions related to the purpose of this master thesis are stated. A recommendation for further research regarding this thesis is also included in this chapter.

The transit time for mass transports and its associated costs are varying depending on construction stage and time of the day. At Stage 1, the layout of Korsvägen is almost identical compared to today but corresponding vehicle traffic flow is reduced by 48 %. This results in lower traffic intensity and thus a lower influence on the transit time for mass transports. The variation in transit time is relatively low during the day in Stage 1 and associated costs for such operation is negligible. At Stage 2, it is possible to save up to 400’000 SEK per year by performing the mass transports between 07:00-07:30 a.m. and 07:30-10:00 p.m. These variations are a result of the differences in transit time for mass transports during the day.

Pedestrian densities on waiting areas in the different stages are compared to each other. The waiting areas in Stage 1 are identical compared to current state. Even though the vehicle traffic on the surrounding roads is decreased by half compared to today, the pedestrian density on waiting areas is insignificant. This indicates an acceptable value according to the definition of LOS. Thus, the vehicle traffic has a small impact on pedestrian density. The average pedestrian density at waiting areas during Stage 2 is doubled compared to today. The values will still be acceptable according to LOS. There is a clear connection between pedestrian load levels and pedestrian congestion.

The differences regarding air quality of Korsvägen between the stages turned out to be remarkably high. Due to the radical reduction in vehicle traffic intensity during the construction periods, the emissions are also reduced. The fuel consumption and emissions have a linear relation due to the converting factors. A total reduction by 75% and 83% during Stage 1 and 2 occurred during a day. This indicates that the relation between emissions and vehicle traffic intensity is nonlinear and follow Equation 13. The differences in emissions between Stage 1 and 2 are explained by a small change related to vehicle traffic. The road connecting Örgrytevägen and Södra Vägen N are not included in Stage 2 and the total travel distance within node is somewhat smaller.

In order to improve and enhance the simulation models developed in this master thesis, modifications that are related to further research are written below. Most of the following suggestions are related to limitations and others are speculations arising during the work.

- Implement a vehicle lane that is only allowed for mass transports, covering parts or the entire route.
- Investigate the possibility to modify the network to permit private vehicles to cross Korsvägen from south to north and vice versa.
- Include more emission particles in the calculations of air quality surrounding Korsvägen. This should also include the influences from the construction work.
- Expand the geographical region and investigate alternative route choices regarding mass transports. Interesting route choices from the service tunnels to E6 are via Mölndalsvägen and Nellickevägen.

8 Recommendation

This chapter consists of recommendation to Trafikverket to consider in the planning of Korsvägen.

The recommendations are based on the findings in this master thesis. In order to improve the surroundings of Korsvägen during the construction period, some parameters are highly relevant to optimize. The following recommendations are listed in order of essentially.

- Involve Västtrafik in the planning progress of the PT stop of Korsvägen. Their expertise and experience are important to include in the design of the two layout proposals.
- Increase the size of the waiting areas associated to the PT stop during Stage 2. Findings prove that the pedestrian density increases by a factor of two compared to today.
- No large savings are occurring for the mass transport in the adaption to time during the day in Stage 1. Remarkable cost savings are possible during Stage 2 if the mass transport is performed during 07:00-07:30 a.m. and 07:30-10:00 p.m.

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Appendix A - Vehicle transit time

Figures 21-27 illustrate the variations in transit time for mass transports during the day. The transit time in Stage 0, Stage 1 and Stage 2 are compared to each other for all possible routes between the service tunnels and E6.

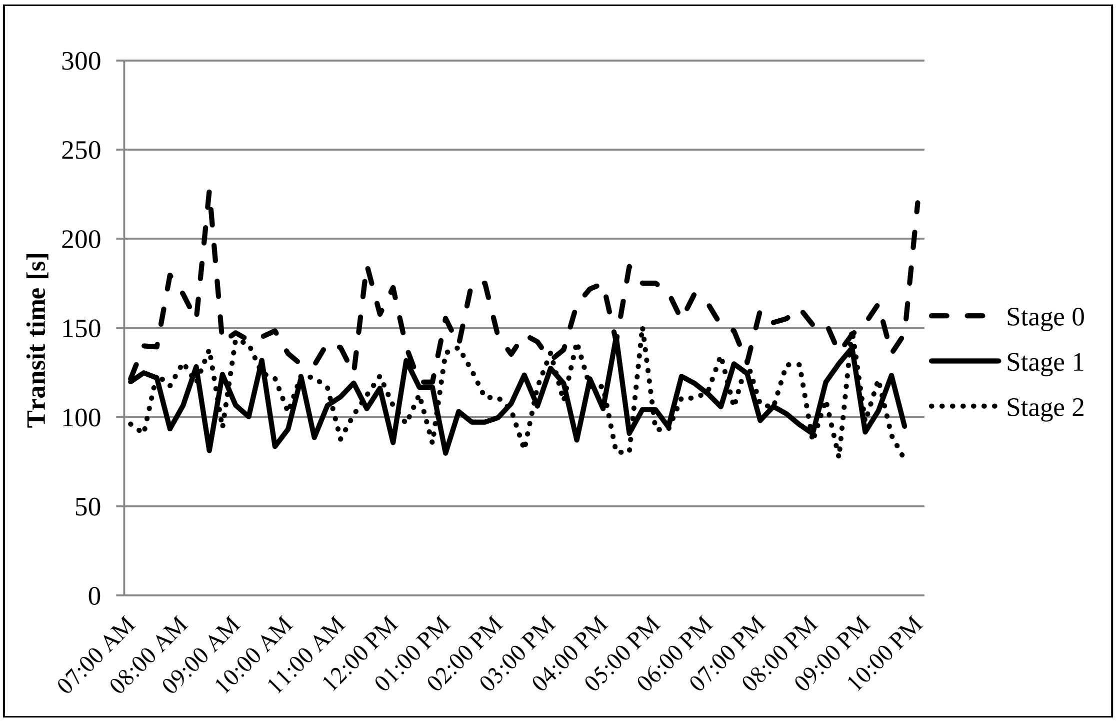

Figure 21 Transit times for mass transports from STL to E6 S.

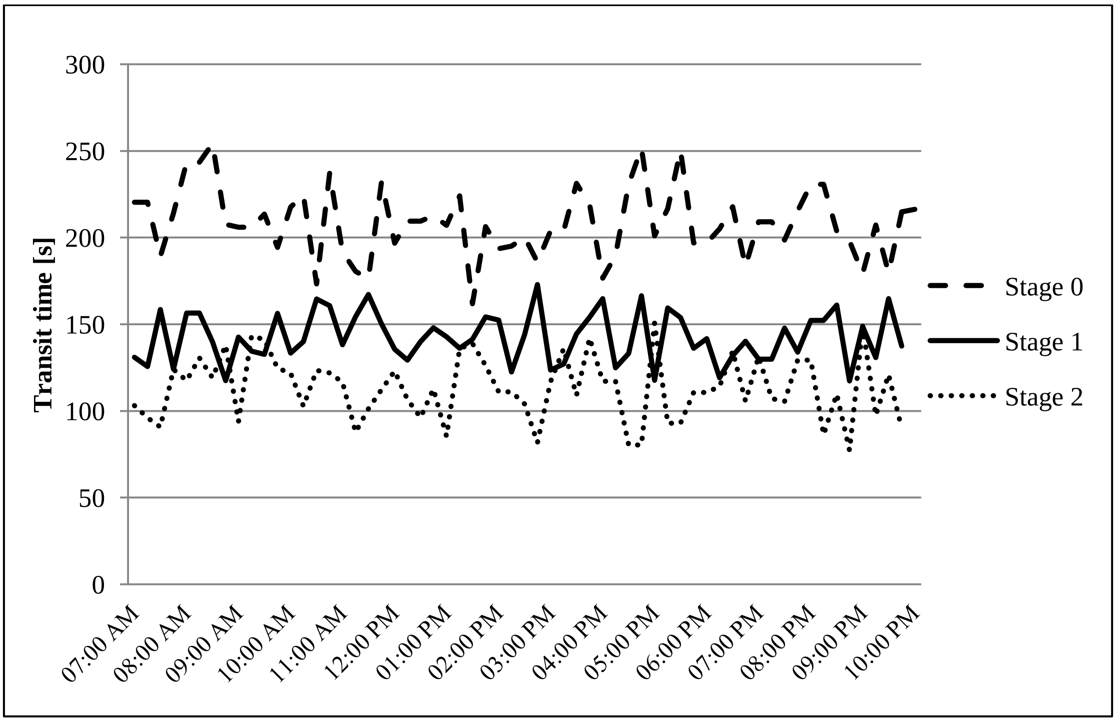

Figure 22 Transit times for mass transports from STC to E6 N.

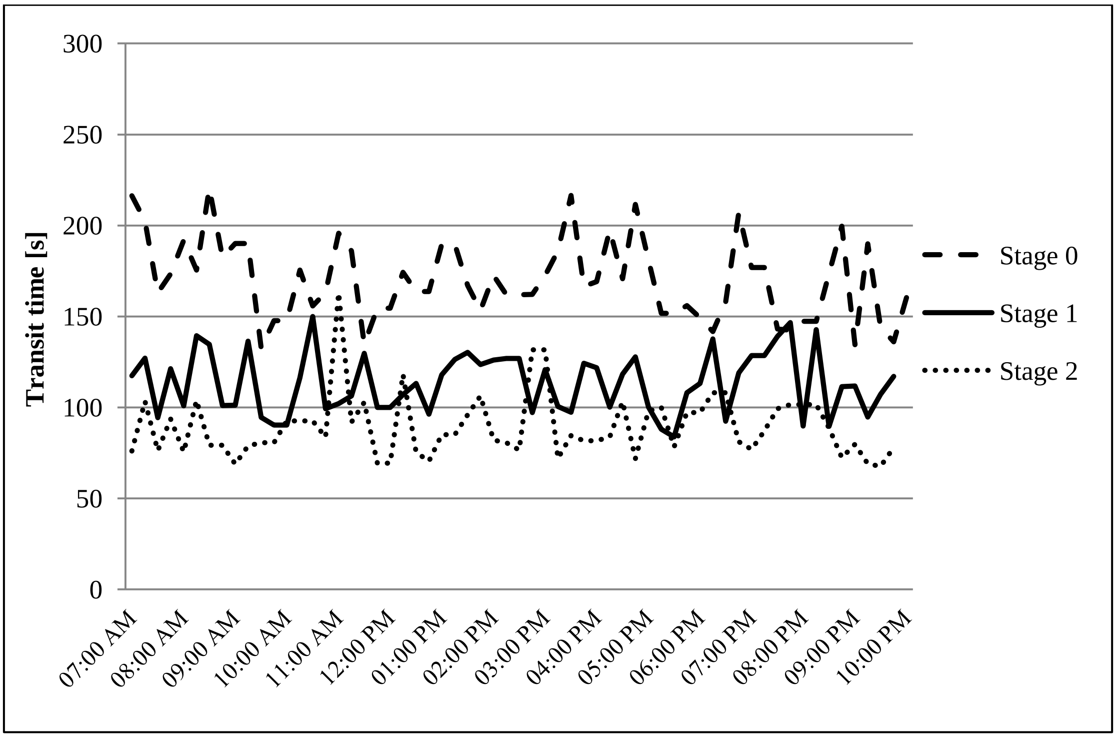

Figure 23 Transit times for mass transports from STC to E6 S.

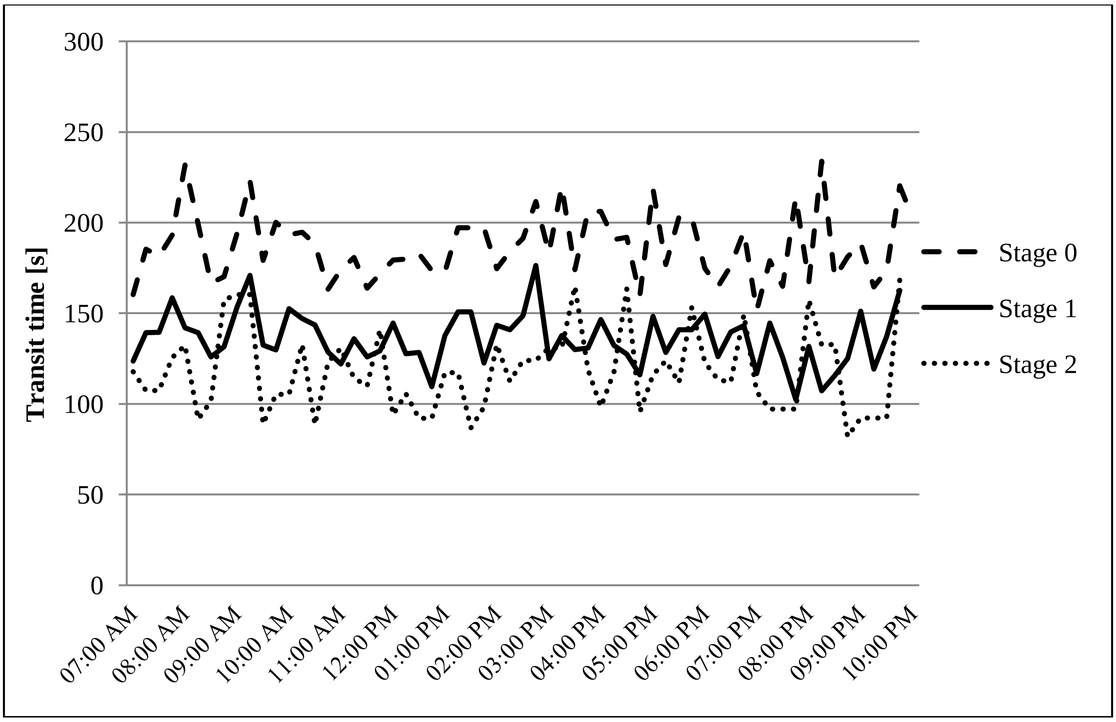

Figure 24 Transit times for mass transports from E6 N to STL.

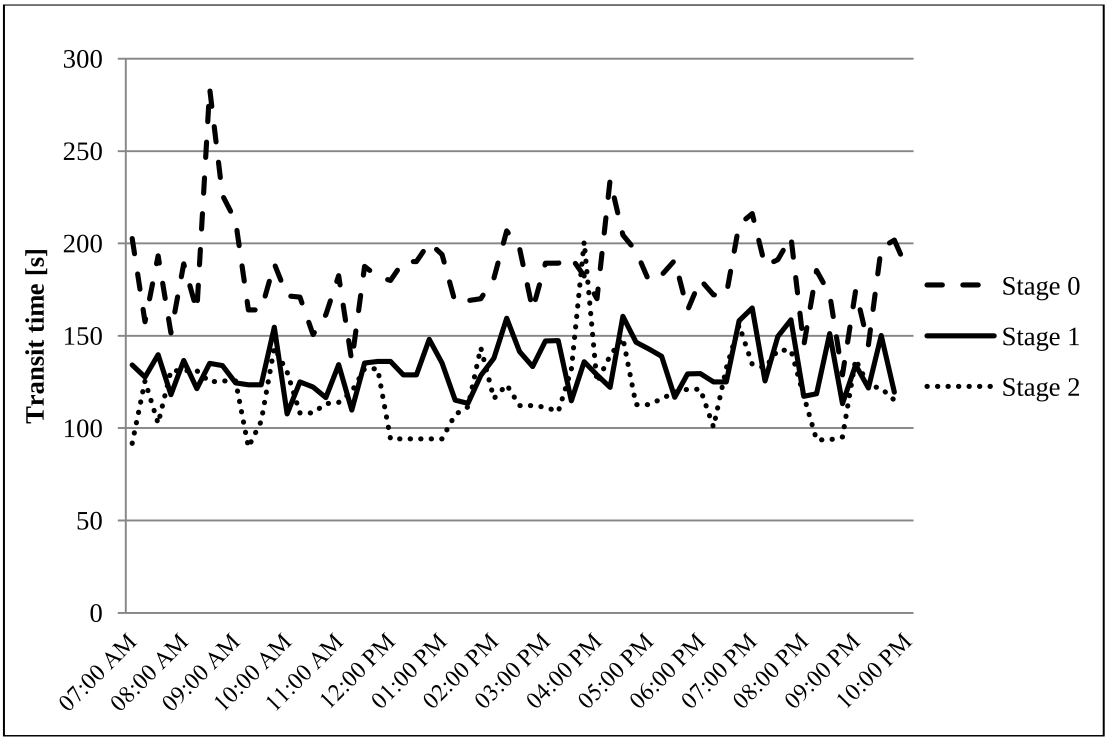

Figure 25 Transit times for mass transports from E6 N to STC.

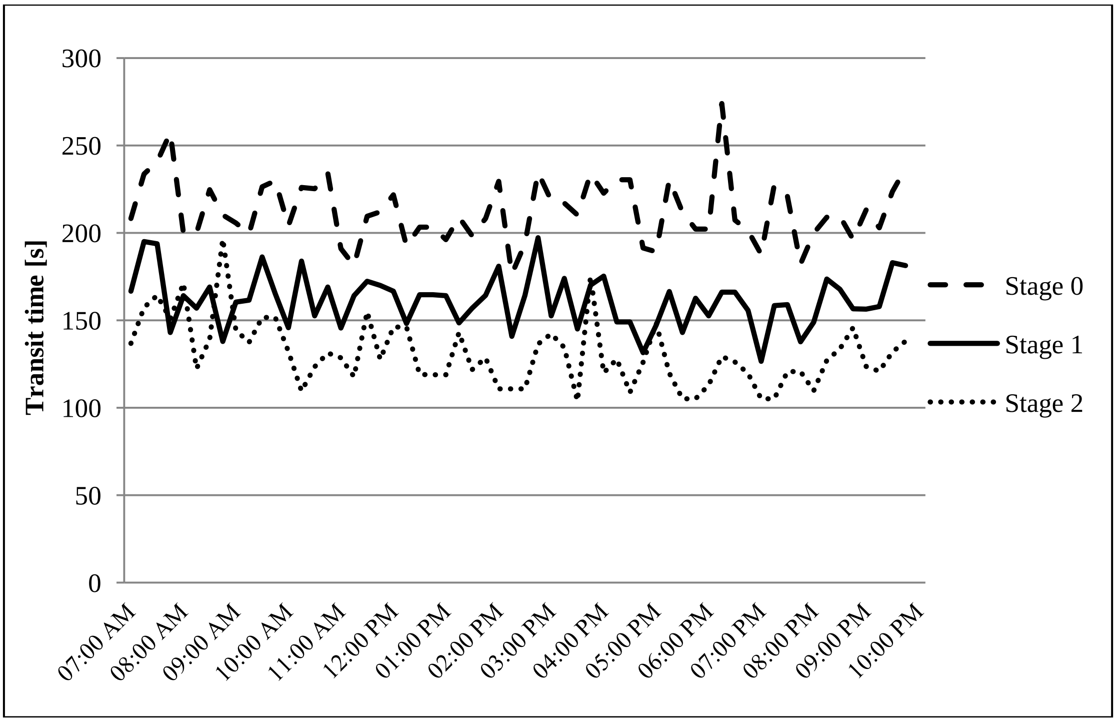

Figure 26 Transit times for mass transports from E6 S to STC.

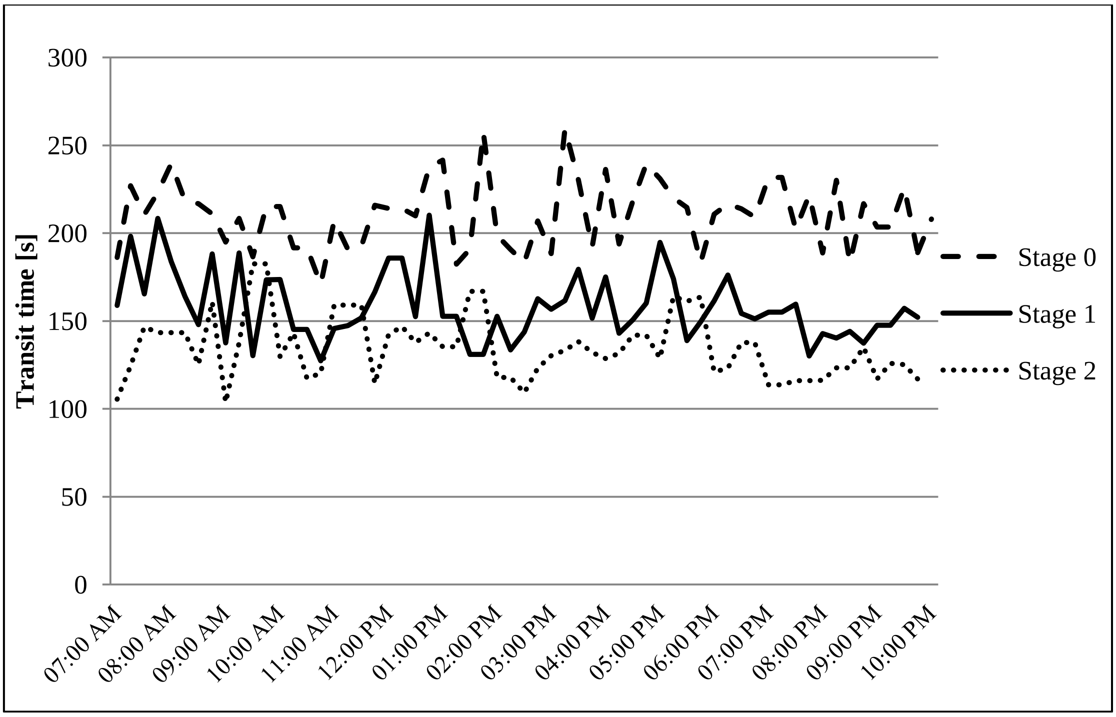

Figure 27 Transit times for mass transports from E6 S to STL.

Appendix B – Vehicle traffic

The input data used in the simulation models regarding vehicle traffic flow and bicycle data is presented in Figures 28-29. The measuring stations record the vehicle flow every 15 minutes.

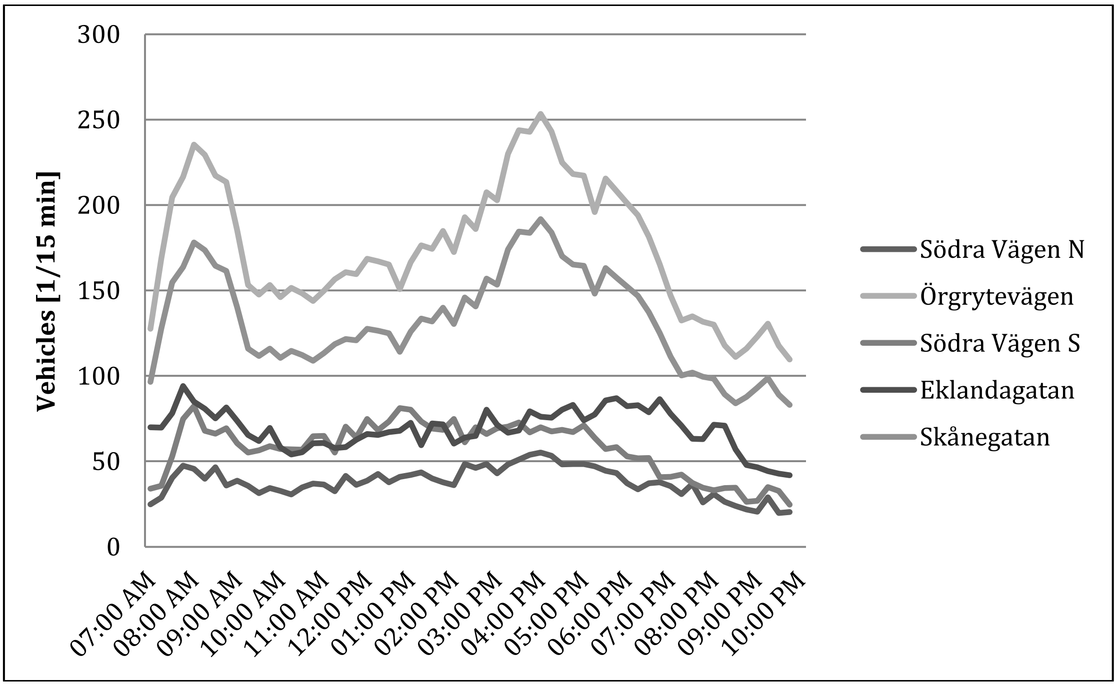

Figure 28 The traffic flow in direction away from Korsvägen in 2013.

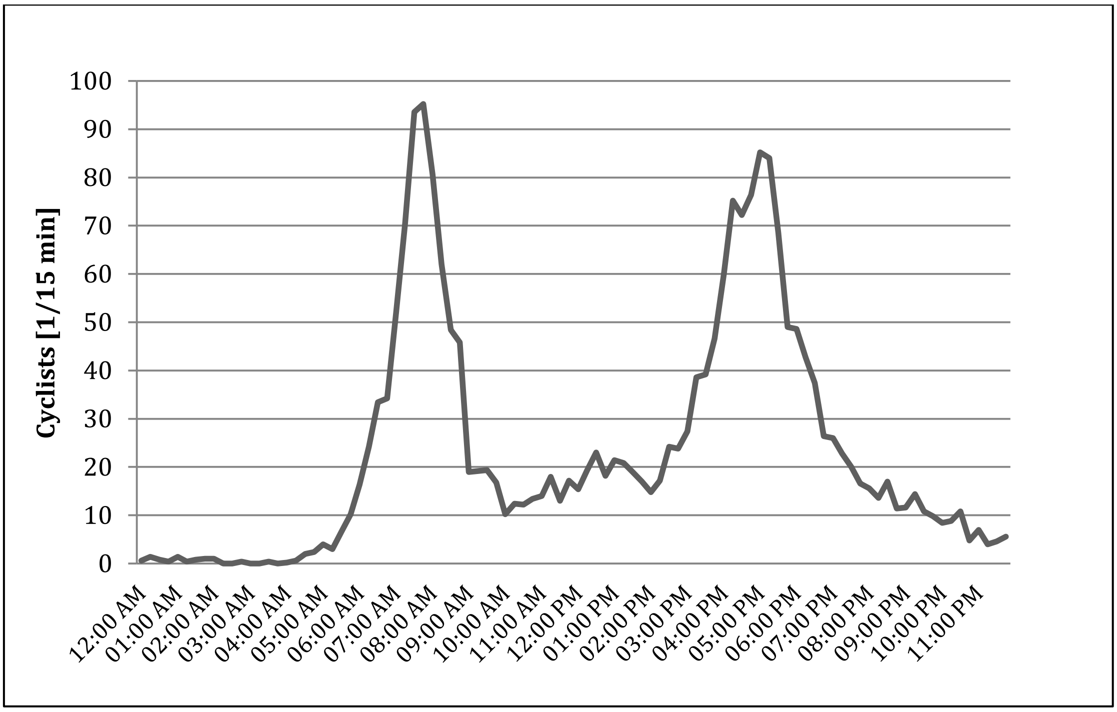

Figure 29 Bike traffic including both directions during the day at Södra Vägen S.

Table 5 The vehicle traffic flow reduction, including both directions, between 2014 and 2020 on roads connected to Korsvägen.

Road	Traffic flow: 2014 [Vehicles/Day]	Traffic flow: 2020 [Vehicles/Day]	Reduction [%]
Södra Vägen N	7134	3635	49
Eklandagatan	10158	5450	46
Södra Vägen S	8051	3932	51
Örgrytevägen	22816	10665	53
Skånegatan	14013	8954	36

Appendix C – Pedestrian input and ratios

The number of pedestrians who start, end and change their PT travels at Korsvägen per hour during the different load levels is performed in Equation 1.

$$(Travel\ starts\ alt.finished\ travels\ alt.travel\ changes) * (1\ alt.0{,}6\ alt.0{,}3) \qquad (1)$$

The number of travels from Korsvägen during an hour is the same as the sum of all pedestrian inputs in the model during the same hour. This means, all pedestrians from input areas are walking to a waiting area, no pedestrians will walk between two different pedestrian input areas. The number of habitants, employment places and visitors at attractions in the different areas only decide the numbers of pedestrian inputs at different pedestrian input areas and the ratio for the different route choices from the platforms to the pedestrian input areas. The sum of pedestrian inputs from the different input areas during a specific hour is decided by the number of pedestrian travel starts from Korsvägen during the same hour.

Regarding the attraction sites, a very rough approximation is used. It is assumed in the model that the number of visitors per year divided by 365 is the number of pedestrians visiting the attractions every day between 7:00 a.m. and 10 p.m. In reality, this number is very fluctuating over the year and during the day. Thereafter, the aim was to calculate how large ratio of the people that is present in the eight different areas. Equal formula is used for work places and attraction sites, respectively, see Equation 2.

$$\frac{No.of\ habitants\ in\ the\ unique\ area}{(Total\ no.of\ habitants + Total\ no.of\ work\ places + Total\ no.of\ attraction\ site\ visitors)} \qquad (2)$$

The ratios for the numbers of habitants, work places and attraction site visitors are summed together and a total ratio for a specific area is performed. This is the base for the pedestrian input numbers and the route choice ratios from the platforms. When calculating the input number for the eight input areas, Equation 3 is used.

$$No.of\ pedestrians\ starting\ their\ journey * Ratio\ for\ the\ area * Load\ Level \qquad (3)$$

The route choice ratios from the platforms to the input areas are depending on the rate of pedestrians changing from one public transport mode into another. Therefore, Equation 4 is used as a first step.

$$\frac{No.of\ finished\ journeys}{No.of\ finished\ journeys + No.of\ pedestrians\ changing\ transport\ mode} \qquad (4)$$

From Equation 3, the ratio of travelers changing transport mode is easily calculated. The ratio of the pedestrians walking from the platforms to the different areas is then performed with Equation 5.

$$Ratio\ for\ the\ area * Ratio\ of\ finished\ journeys \tag{5}$$

It is assumed that all platforms have the same number of onboard going pedestrians all the day. With this in mind, the share of the pedestrians leaving a bus, going to one single platform is calculated with equation 6.

$$\frac{No.of\ pedestrians\ changing\ transport\ mode}{No.of\ finished\ journeys + No.of\ pedestrians\ changing\ transport\ mode} * \frac{1}{8} \tag{6}$$

Regarding Stage 2, the term $1/8$ in Equation 6 is changed into $1/9$ depending on the increased number of platforms. The bus and tram traffic is exactly implemented into the model according to the current time table at Korsvägen. For all pedestrian time intervals, the total number of buses and trams is calculated, see Table 6.

Table 6 PT vehicles and their corresponding pedestrian alighting ratio.

Time interval	PT vehicles [1/h]	Ratio [%]
7.00-7.30	90	60
7.30-9.00	315	100
9.00-14.30	792	60
14.30-18.00	688	100
18.00-19.30	218	60
19.30-22.00	228	30

Now, the aim is to calculate how many pedestrians are leaving the PT vehicles during the different time intervals. It is assumed that the same number of pedestrians leaving all the vehicles during the same time intervals is the same. This means, it makes no sense which PT line is coming to a platform, the same amount of pedestrian will leave the vehicle during the same time interval. The total amount of pedestrians leaving a PT vehicle during peak hour is the sum of people changing transport mode and people finishing their journey, 1406 pedestrians. During semi-load this will be $0{,}6 * 1406 = 844$ and during low-load periods $0{,}3 * 1406 = 422$ pedestrians. (Funktionsanalys)

The total number of pedestrians changing transport mode or finishing their journey at Korsvägen between 07:00 a.m. and 10.00 p.m. is calculated, see Equation 7.

$$844 * 0{,}5 + 1406 * 1{,}5 + 844 * 5{,}5 + 1406 * 3{,}5 + 844 * 1{,}5 + 422 * 1{,}5 = 14419 \tag{7}$$

With x as the number of alighting passengers from PT vehicles during peak load, Equation 8 can be written. Number of vehicles used in Equation 8 is collected from Table 6.

$$0{,}6 * x * 90 + 1 * x * 315 + 0{,}6 * x * 792 + 1 * x * 688 + 0{,}6 * x * 218 + 0{,}3 * x * 228 = 14419 \tag{8}$$

This gives $x = 8{,}32$, which means that number of pedestrians leaving all public transport vehicles during peak load is 8. During semi-load, 5 pedestrians will leave the PT vehicles and during low-load periods only 2 pedestrians will leave the PT vehicles.

There are eight areas in (Refsnes, 2012) and also eight input areas in the model. Two areas from (Refsnes, 2012) do have the same input area in the model. These are Liseberg and Sofierogatan/Nellickevägen. Input numbers and route choice ratios from and to waiting areas are therefore summed together for these two areas. Also, as noticed above, Liseberg and Universeum/Världskulturmuséet are splitted into two different areas. Input and route choice ratios for these are based on their yearly visitor number. Liseberg receives 78% of the total amount of pedestrians and Universeum/Världskulturmuséet 22%.

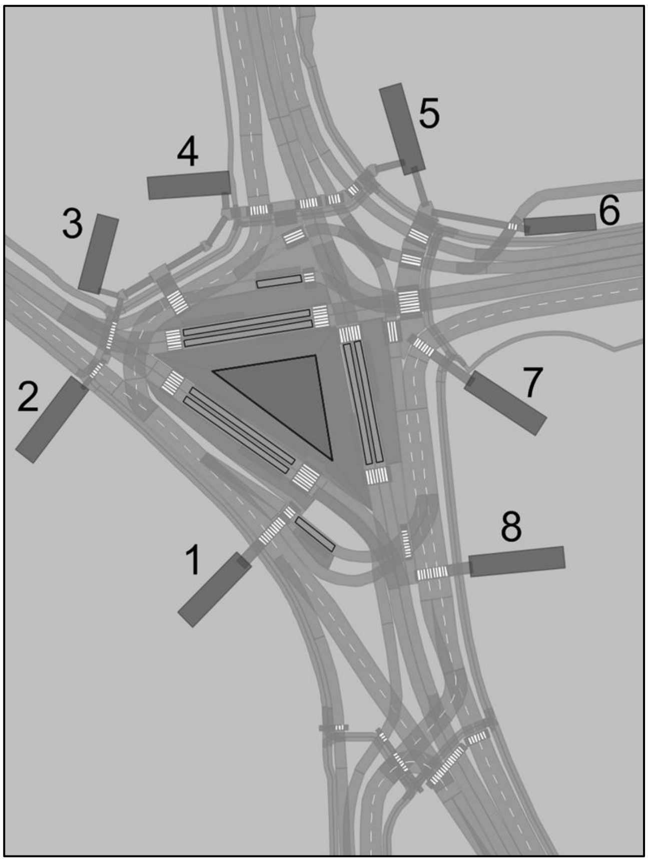

Figure 30 Input areas at Korsvägen in the simulation model.

Table 7 The table presents how large ratio of the total pedestrian input each area around Korsvägen contributes with.

Surrounding area	Area in Vissim	Habitants [%]	Work [%]	Activities [%]	Sum = Input ratio [%]
Eklandagatan/Carlanderska sjukhuset	1	4,7	1,2	0,0	5,9
Renströmsgatan/Göteborgs Universitet	2	1,0	2,4	0,0	3,5
Burgårdsgatan/Tegnérsgatan	3	3,9	1,2	0,0	5,2
Korsvägen/Burgårdsgatan	4	1,4	0,1	0,0	1,6
SvenskaMässan/Scandinavium/Vallhalla	5	0,0	5,8	25,8	31,6
Åvägen/Fabriksgatan/Focus	6	2,2	2,0	0,0	4,2
Liseberg/Sofierogatan/Nellickevägen	7	0,2	5,5	31,9	37,6
Universeum/Värlskulturmuséet	8	0,0	1,6	9,0	10,6
Sum	1-8	13,5	19,8	66,7	100,0

Table 8 The table shows the number of pedestrians changing, starting and finishing a travel during the different load-levels. The ratio between changed travels and finished travels and the opposite at Korsvägen is also presented.

Pedestrian PT travels [pedestrians/h]	Peak-load (100%)	Semi-load (60%)	Low-load (30%)
Changes	752,2	451,3	225,7
Started (total input from all input areas)	683,2	409,9	205,0
Finished	654,6	392,8	196,4

$$Q = \frac{Finished\ travels}{Finished\ travels + Changing\ travels} = 46{,}5\% \tag{9}$$

$$X = \frac{Changing\ travels}{Finished\ travels + Changing\ travels} = 53{,}5\% \tag{10}$$

Table 9 Route choice ratios and number of pedestrians alighting PT vehicles during the day.

Surrounding area	From platforms to input areas = area ratio*$Q_{Equation\ 9}$ [%]
Eklandagatan/Carlanderska sjukhuset	2,8
Renströmsgatan/Göteborgs Universitet	1,6
Korsvägen/Burgårdsgatan	0,7
Burgårdsgatan/Tegnérsgatan	2,4
Åvägen/Fabriksgatan/Focus	2,0
Svenska Mässan/Scandinavium/Vallhalla	14,7
Liseberg/Sofierogatan/Nellickevägen	17,5
Universeum/Värlskulturmuséet	4,9
Sum	46,5

Table 10 Number of alighting passengers from PT vehicles during the different load levels.

	Peak-load	Semi-load	Low-load
Alighting passengers per PT vehicle	8	5	2

Ratio from input areas to platforms in Stage 0 and Stage 1 is calculated in Equation 11.

$$(Input\ areas \rightarrow platforms)_{Stage\ 0,1} = \frac{1}{8} \times X_{Equation\ 10} = 6{,}68\ \% \tag{11}$$

Ratio from input areas to platforms in Stage 2 is calculated in Equation 12.

$$(Input\ areas \rightarrow platforms)_{Stage\ 2} = \frac{1}{9} \times X_{Equation\ 10} = 5{,}9\ \% \tag{12}$$

Appendix D – Pedestrian Density

Figures 31-36 represent the results related to pedestrian density. The average value of all PT sites in Stage 2 (green) is compared to PT sites in Stage 0 and Stage 1. The graphs illustrate the variations in pedestrian density during the day.

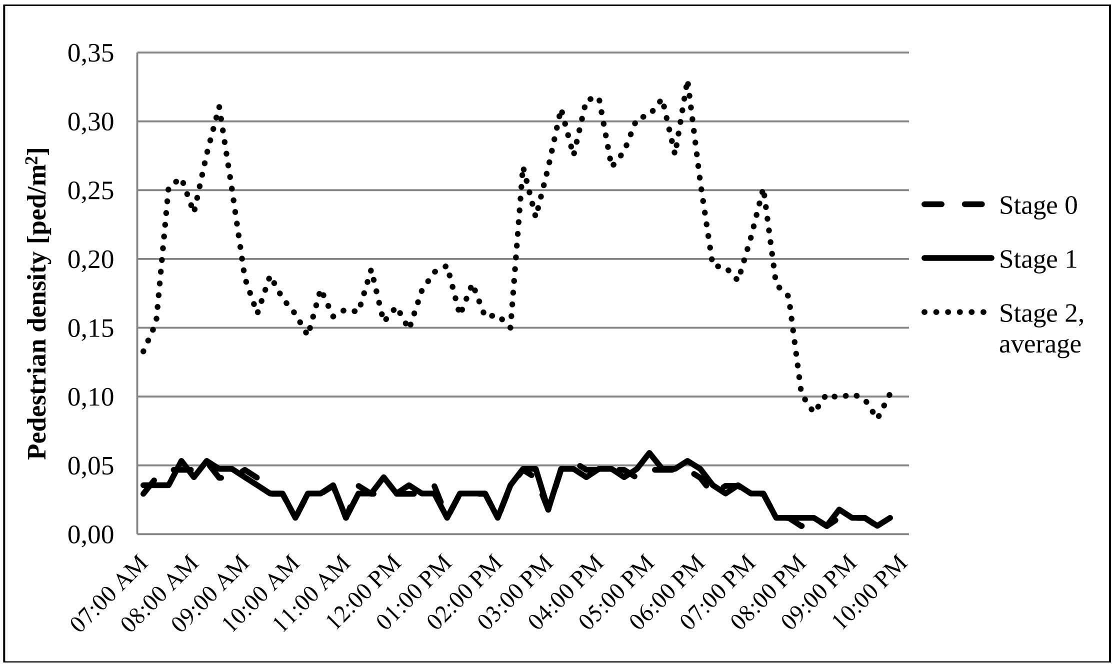

Figure 31 Pedestrian density at the alighting site, Site H, and the average pedestrian density at all platforms at Stage 2.

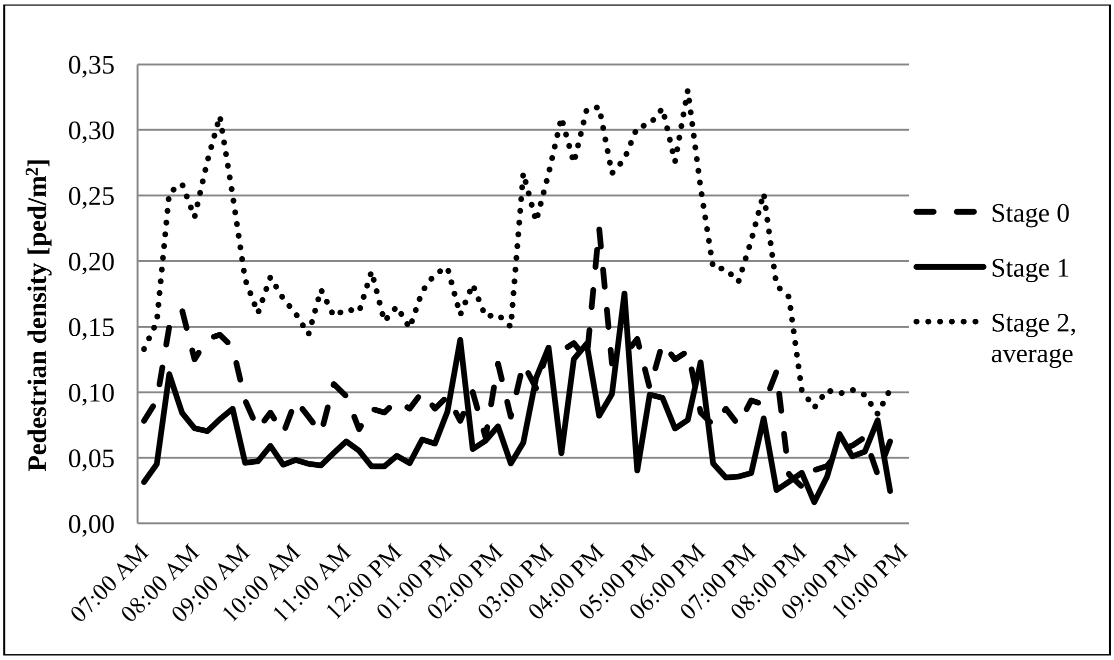

Figure 32 Pedestrian density at Site B and the average pedestrian density at all platforms at Stage 2.

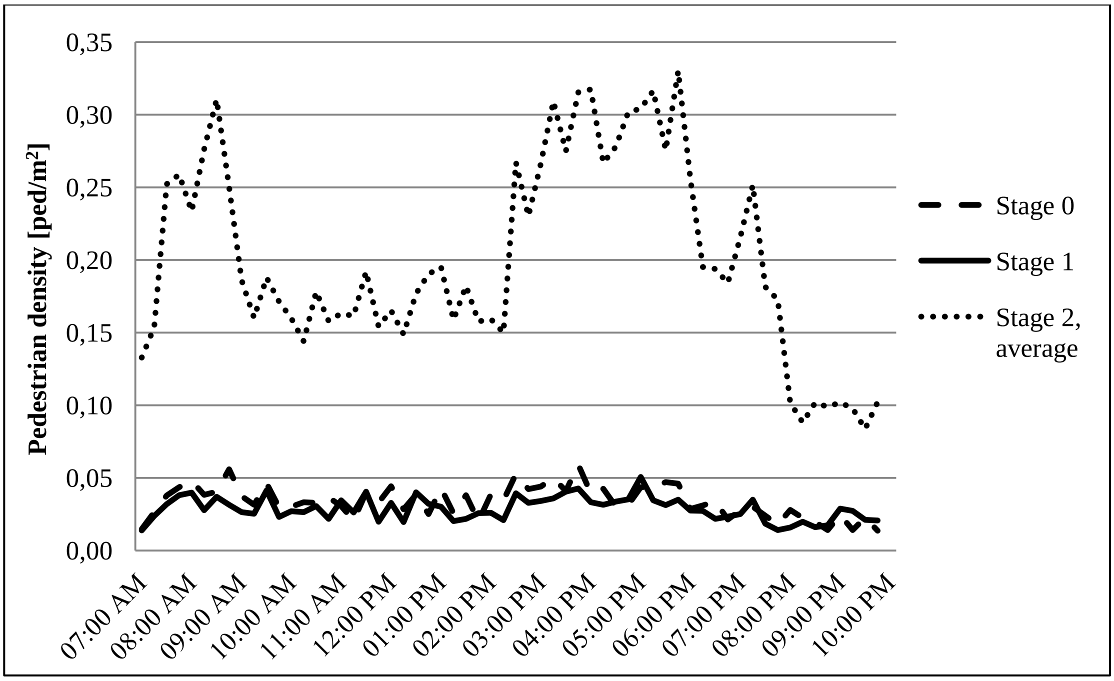

Figure 33 Pedestrian density at Site C and the average pedestrian density at all platforms at Stage 2.

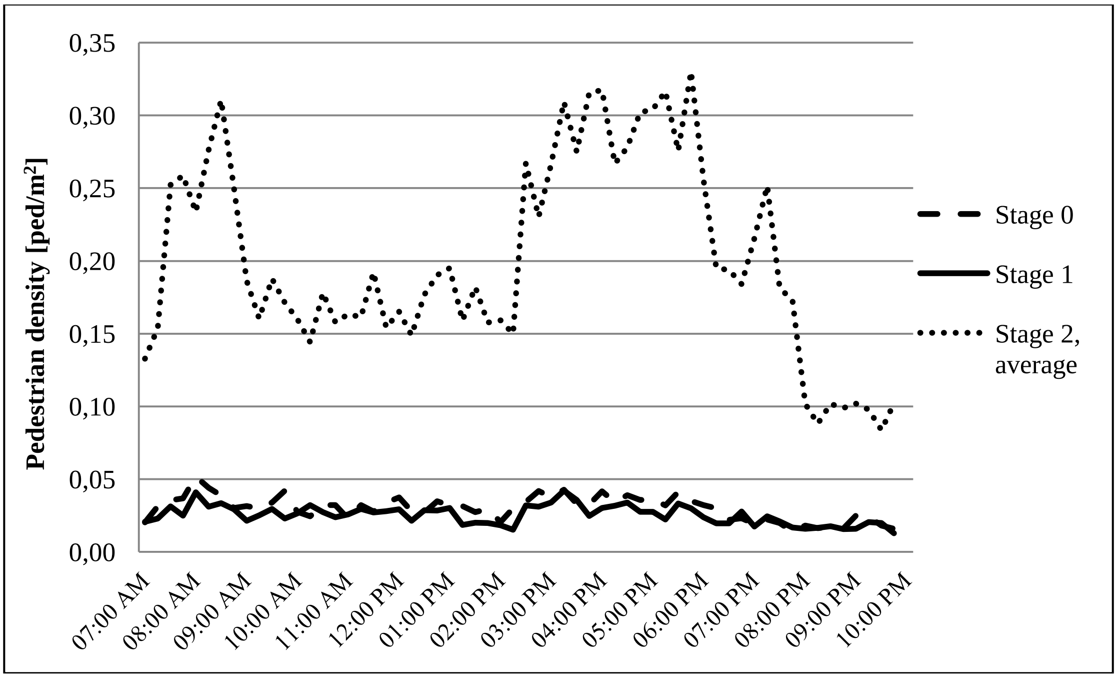

Figure 34 Pedestrian density at Site D and the average pedestrian density at all platforms at Stage 2.

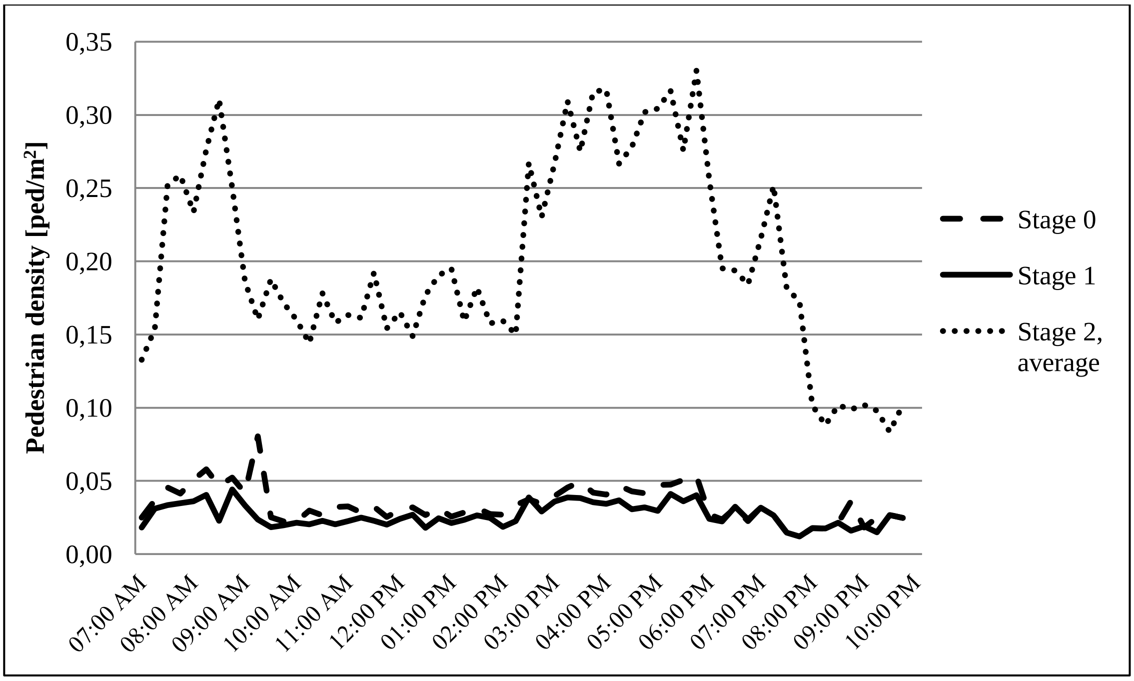

Figure 35 *Pedestrian density at Site E and the average pedestrian density at all platforms at Stage 2.*

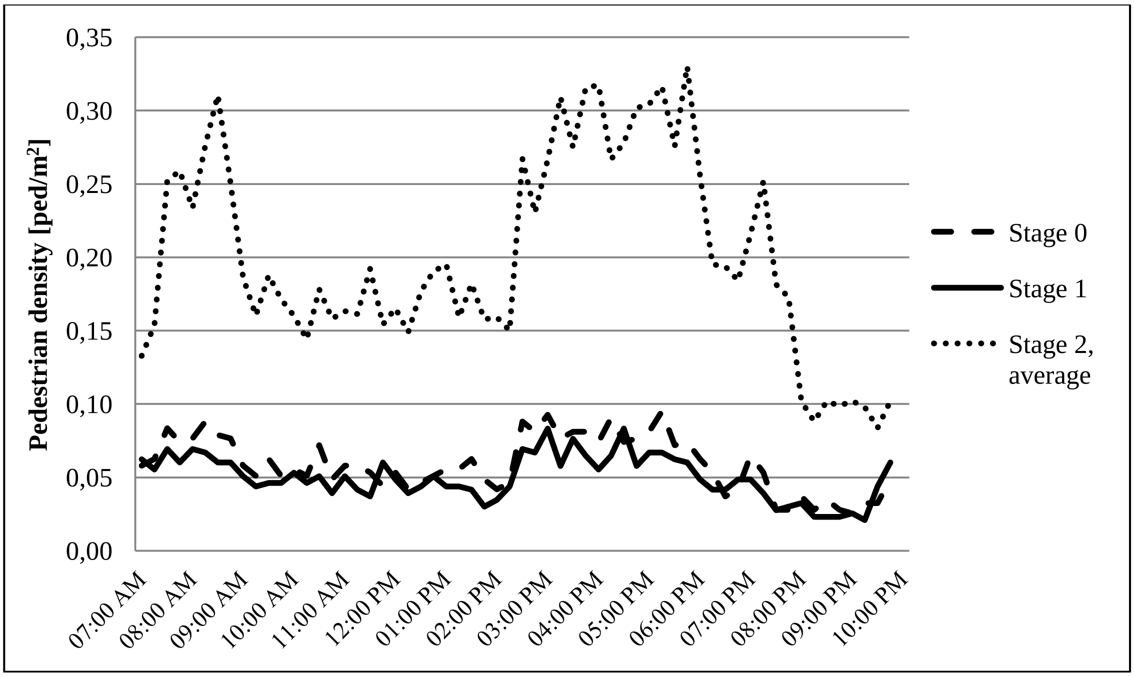

Figure 36 *Pedestrian density at Site F and the average pedestrian density at all platforms at Stage 2.*

Appendix E – Public Transport

The PT system of Korsvägen are shown in Table 11 and 12.

Table 11 The PT system of Korsvägen during Stage 0 and Stage 1.

Site	A	B	C	D	E	F	G	H
PT Line	4	4	5	5	2	2	100	100
	52	52	50	50	6	6	101	101
	758	758	513	513	8	8	300	300
			601	601	13	13	330	330
			605	605				
			610	610				
			753	753				
			RÖD	RÖD				
			GRÖN	GRÖN				
			FLYGBUSS	FLYGBUSS				

Table 12 The PT system of Korsvägen during Stage 2.

Site	1	2	3	4	5	6	7	8	9	10
PT Line	101	50	4	4	52	50	2	8	8	2
	300	52	5	5	300	100	6	6	13	13
	513	100			330	101				
	605	330			605	513				
	610	601			753	601				
	753	RÖD			758	610				
	758	GRÖN			FLYGBUSS	RÖD				
		FLYGBUSS				GRÖN				

Appendix F – Emission

Within the software of PTV Vissim, the following equations are used by the program to calculate emissions. By recording the four factors included in Equation 13, the fuel consumption can first be calculated.

$$F = Travel \times k_1 + Delay \times k_2 + Stops \times k_3 \quad (13)$$

$F = fuel\ consumption$

$Travel = total\ distance\ traveled$

$Delay = total\ signal\ delay$

$Stops = total\ stops\ per\ hour$

Equation 1 include the following variables:

$$k_1 = 0{,}075283 - 0{,}0015892 \times Speed + 0{,}000015066 \times Speed^2$$
$$k_2 = 0{,}7329$$
$$k_3 = 0{,}0000061411 \times Speed^2$$

$Speed = cruise\ speed$

The first term in Equation 13 describes the fuel consumption in relation to speed and total distance traveled. Function k_1 is a positive quadratic equation, which indicates that it will have its lowest value of fuel consumption at a specific speed. The lowest fuel consumption is reached at 85 km/h. The second term describes a linear relation between total delay and fuel consumption and the last term describes the fuel consumed by accelerating from zero speed to actual cruise speed.

The emission data is thereafter calculated by multiplying the following converting factors with the fuel consumption.

$$CO = F \times 69{,}9 \quad (14)$$

$$NOx = F \times 13{,}6 \quad (15)$$

$$VOC = F \times 16{,}2 \quad (16)$$