CHALMERS

Prediction and evaluation of traffic quality by static and dynamic simulation

Impact of new bus terminal at Myggenäs intersection

Master of Science Thesis in the Master’s Programme Geo and Water Engineering

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Department of Civil and Environmental Engineering
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CHALMERS UNIVERSITY OF TECHNOLOGY
Göteborg, Sweden 2011

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ABSTRACT

The Myggenäs intersection between the roads V160 and V169 is the only entry to Tjörn Island for vehicles from Stenungsund. The new bus terminal has been planned to be built there which makes the intersection geometry more complicated. This thesis is aimed to predict the congestion situation of left-turn lane in 2030 and give an economic evaluation for this intersection.

The simulation model bases on various sub-models, e.g. pedestrian model and real time signal control model. Finally, two simulation models are created, static assignment model and dynamic assignment model. The result of static model shows that the new construction will not produce worse congestion in 2030. The dynamic model gives more reasonable trip distribution decided by general cost.

The road sign in the Myggenäs intersection can be convinced as one reason of congestion. To avoid the congestion, more drivers will choose to go straight without road sign in 2030. In the meantime, the sensitivity analysis for route determination and the impact of the new bus terminal in Tjörn are discussed based on the view of microeconomic as well.

Key words: simulation model, real time signal control, VISSIM, VISVAP, LHROVA, RiLSA, CBA, sensitivity analysis, microeconomic, impact assessment

Contents

Preface

This thesis is a representation of our years as a master student of GEO and Water engineering program at Chalmers University of Technology. The thesis work started in September 2010 and finished in January 2011.

This master thesis belongs to a part of a feasibility study and a detailed study for road 160/169, Myggenäs Korsväg, which is proposed by Swedish National Road Administration.

We would like to express our deepest appreciation to all those who gave us help to complete this thesis.

We want to thank Gunnar Lannér, our thesis examiner. We couldn't get the chance to work on this project without his help, and in preparatory stage, he drove us to the Tjörn Island for site survey. Frankly speaking, his kind personality is one reason that we chose this research direction as master thesis.

We have furthermore to thank our supervisors. Stellan Tengroth and Martin Andersson at Trafikverket provide us with measuring data and documents. Johan Larsson from Tyréns consulting company gave us many valuable suggestions and supports of VISSIM application.

Last but certainly not least, we both would like to thank each other. The thesis can be finally finished by over-night work and innumerable debates. We all did hard work, and the author names of this thesis are listed according to the alphabetic order.

Göteborg January 2011

Miao Li and Tong Wu

Summary

The topic of this thesis is to evaluate and to predict the queue length for left-turning traffic flow and traffic quality for the whole intersection of Myggenäs Korsväg. This master thesis belongs to a part of *feasibility study* and *detailed study* for road 160/169, Myggenäs Korsväg. The *pre-study* which is already finished by Swedish National Road Administration at the time before this thesis had started.

This report is led by a question that if Myggenäs Korsväg will have sufficient capacity to bear turning traffic flow under the situation that the bus terminal was planned to be built in the south-eastern direction in 2030.

It is important to answer this question since the traffic flow will increase by about 12 percent from the current situation. Moreover, the intersection structure will become more complicated. Hence there is a high probability that the intersection would be involved in worse traffic congestion and delay.

However, this question is not easy to be solved for three reasons. Firstly, the increase of traffic flow density in 2030 compared with 2010 will influence the driver behaviour. Second, the intersection capacity depends on how dominated traffic signal stated and works. Besides, it is difficult to determine whether the trip distribution in 2030 will be the same as in 2010 when the traffic volume grows. For example drivers might change their route decision and avoid travelling on the congestive left-turn bay.

Different models are created in order to resolve these problems, including a micro simulation model supported by VISSIM, a real time signal control system based on VISVAP, and a dynamic traffic network based on VISSIM. These three models divide the thesis into three chapters, which are micro simulation model, traffic signal optimization, and dynamic experiment in the view of economic.

Three static scenarios and three dynamic scenarios for these researches are simulated respectively. The results of these models forecast the quality of intersection in 2030, and the impact of the bus terminal to the intersection in 2030 is acquired. The iteration programs which are car following model, vehicle actuated program and dynamic route choice network will adapt this simulation model into complicated reality.

The result shows, if the driver behaviours in 2030 follow what they are doing now, this intersection will confront to the challenge of congestion. However, if they choose the route as the rules of maximum personal benefit, it will rarely appear the congestion situation even in the peak hours. The economic parameters such as marginal cost, externalities and elasticity of bus terminal are also calibrated in this thesis. Finally, the thesis argues that the quality of intersection will between the thumb rules based condition, which is the pessimistic forecast, and the rational expectation based condition, which is the optimistic forecast. The recommendations to improve the social economic benefit include relative facilities improvement and a specific questionnaire.

1 Chapter I Micro Simulation Model

1.1 Introduction

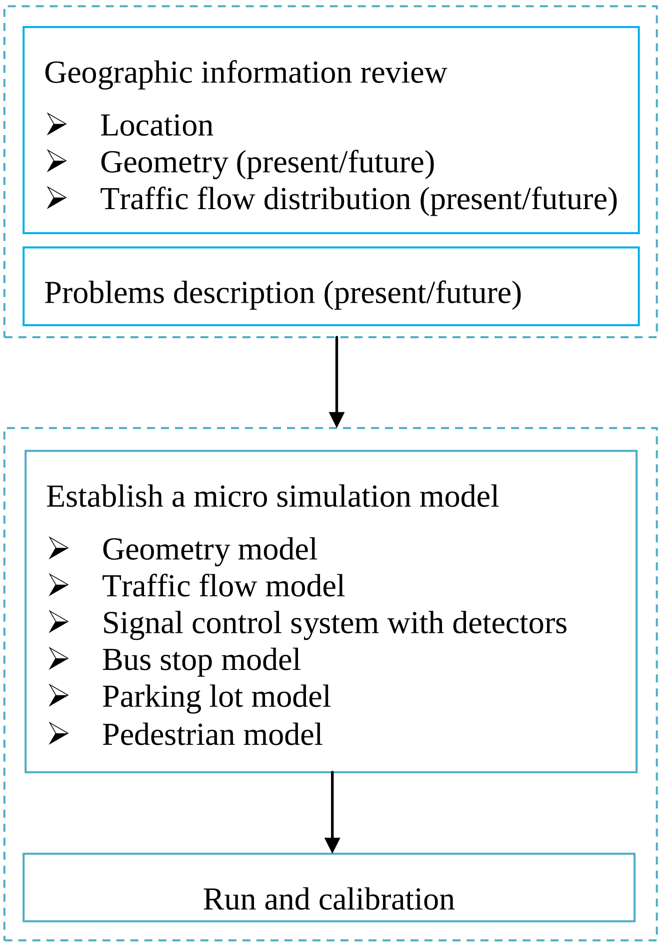
1.1.1 Aim

The aim of Chapter I is to create a micro simulation model in VISSIM based on available geographic information. This simulation model is the foundation of this thesis. Any other sub-model will be built on the ground of this model and data input will also process in the simulation model.

Even though the most critical part in the micro simulation model is expected to be the left-turn bay, other parts should also be carefully and correctly modelled, since every part in the intersection coordinates with each other.

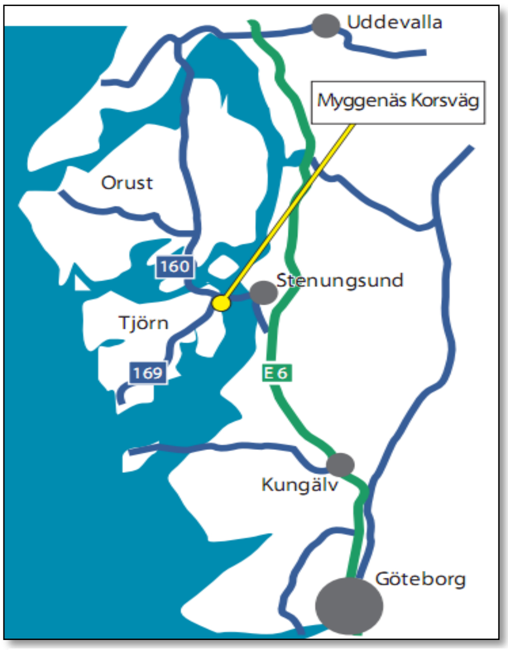
1.1.2 Structure of Chapter I

The structure of Chapter I can be seen directly at the flow chart below.



1.2 Geographic Information overview

1.2.1 Location



Myggenäs intersection is a *countryside junction* (*Landsbygd* in Swedish) which locates on the intersection between V 160 (road 160) and V169 (road 169). V160 plays as the unique artery that back up the daily commuting between Orust and Stenungsund, and V169 is constructed to support the traffic demand of TJÖRNS KOMMUN (Tjörn community). (See figure 1)

Moreover, compared to another path from mainland to island, which passes through Uddevalla, Myggenäs receives more traffic volume because it is closer to Göteborg, the second biggest city in Sweden.

Figure 1 Overview of Myggenäs intersection (Tyréns AB, 2009)

Besides, the last intersection before Myggenäs Korsväg on V160 is located on the Stenungsund 4.6 kilometer upstream to this intersection. Thereby Myggenäs Korsväg can be seen as the only entrance from Stenungsund to Myggnäs.

For these reasons Myggenäs intersection can be seen as the main entrance to Tjörn Kommun. According to Stellan Tengroth's observation, the peak hour traffic volume on this intersection can reach 1400 vehicles per hour in wintertime, which is also a conservative number because the traffic load will be heavier in spring and summer (Tengroth, 2010).

1.2.2 **Geometry of Myggenäs intersection**

1.2.2.1 Current situation

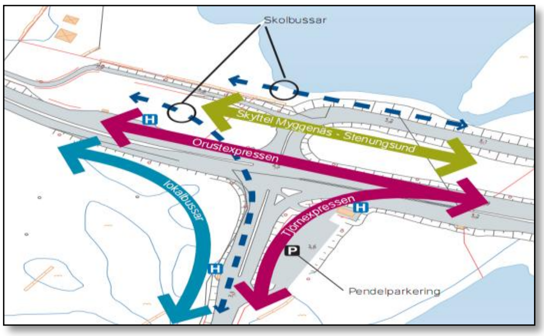
At the current situation, Myggenäs intersection is a typical countryside intersection, which can be divided into six parts. They are V160, V169, three bus stops, one parking lot and two pedestrian paths. Some conflict zone has been formed as a result of combination of these parts.

The configuration of Myggnäs intersection can be seen in figure 2. The road that Stenungsund is directed to Tjörn is expanded from single lane to two lanes at around 175 m of upstream east V160. These two lanes are expanded gradually to three lanes at around 130 m. In these three lanes, two is for the through vehicles towards Orust and one is for left-turning vehicles toward Tjörn community. The opposite approach on the western V160 has two lanes which includes exclusive left-turn lane towards V722 and shared right- through lane toward Stenungsund or Tjörn community. Besides, the approach on V169 has one exclusive right-turn lane and shared left-through lane. The vehicles share the single lane on the approach V722.

Figure 2 Configuration of Myggenäs intersection

1.2.2.2 Other facilities over the intersection

Bus stop



Three bus stops have been built around the intersection, which can be seen in figure 3.The capital letter H stands for bus stop (*Hållplatsen* in Swedish). These bus stops are built for the travellers taking Skyttel Myggenäs, Orustexpress, Tjörnexpress and local buses.

Figure 3 Bus stop location and bus lines (Tyréns AB, 2009)

Parking lot

The configuration of parking lot can be seen in the figure 4. The capacity of this parking lot is about 40 cars. There are also two shelters with 20 spaces for bicycles or motorbikes.

Figure 4 Parking lot location and capacity (Tyréns AB, 2009)

Pedestrians

Pedestrians are mainly produced by the bus stop and parking lot. Passengers cross the intersection with high frequency in order to changing the bus or taking the personal car.

1.2.2.3 Future planning

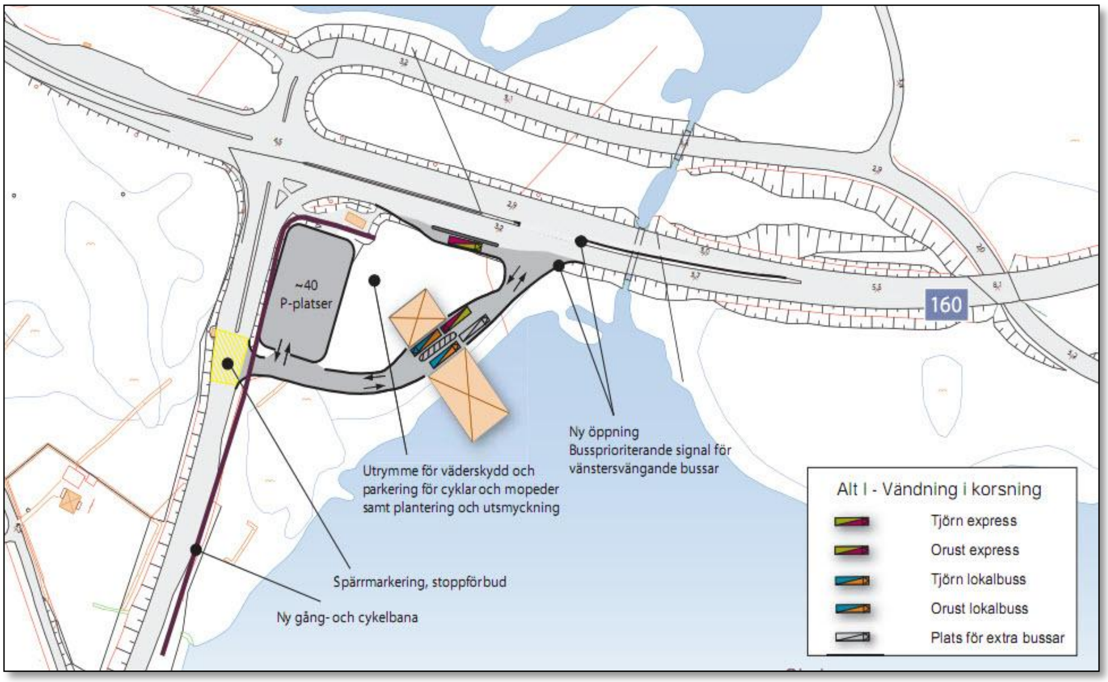


Figure 5 Intersection geometry in the future (Tyréns AB, 2009)

Following the new geometry, some improvements are shown in figure 5.

1. New opening, bus priority signal for left-turning bus
2. Expand the weather protection facilities and parking lot for cyclers and motorcycles
3. A stop forbidden mark at the exit of bus lane
4. New pedestrian and new cycle lane.

1.2.2.4 Traffic flow distribution

As the data of pre-study, the *Annual Average Daily Traffic* vehicle volumes (*AADT*) of V160 and V169 for current situation and future prediction are both shown in the figure 6 and table 1.

Table 1 Traffic flow statistics and prediction

	AADT 2010	AADT 2030	Heavy vehicles
V160 East	16770	18360	6%
V160 West	9900	10840	5%
V169 South	10250	11220	7%
V722 north	370	400	8%

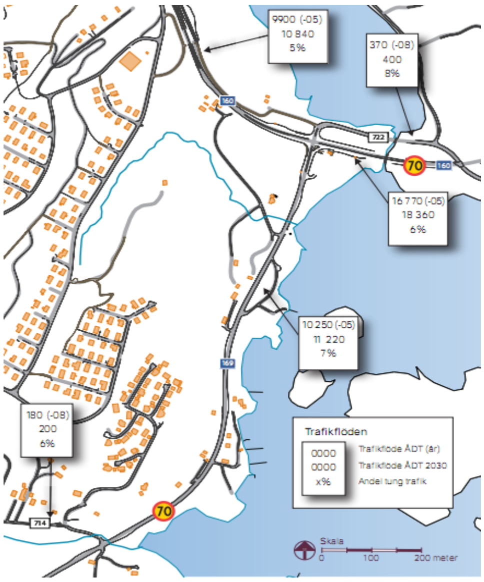


Figure 6 Traffic flow distribution (Tyréns AB, 2009)

From statistic data it can be seen that V160 East bears about 1.5 times more traffic load than V160 West and V169 South. It is also can be seen that the traffic load in the V722 North is about 50 times less than the other three sections. In this statistics, the traffic load is predicted 10% heavier than the load in 2010.

The traffic flow value in peak hours will be described in Chapter II.

1.2.2.5 Further investigation for Traffic growth

The increase of traffic load is still controversy even though it has been predicted in a pre-study. The agreement is that the traffic growth of West part of Västra Götland is slower than the National average level (Tyréns AB, 2009).

One of the interpretation of this slow increasing is the population growth of this area is slower than the national average level. If traffic growth is considered as the consequence of urbanization booming and population development, the lower population growth rate would reflect lower traffic growth. The population growth in Tjörn kommun from 2003 to 2009 is 0.5% (14891-14961), according to Helena Iveroth who is the planning architecter in Tjörn. This local rate is 8 times lower than the population growth for Sweden, 4% from 2003 to 2009 (Publicized by World Bank). This at least can express that the flows tends to be overestimated once the national traffic growth data is used in the future scenario.

As the latest research being carried out, the increasing rate of traffic growth of 10% is still underestimated. According to the recently report publicized by Tyréns AB, the total traffic flow is predicted to grow by **12%**, in which heavy vehicles will be **54%** more than in the present day (Tengroth, 2009). This project will follow this suggestion since the more convinced data are not founded.

1.3 Problem description and future plan

1.3.1 Present problem

Currently two problems decrease the efficiency of Myggenäs intersection, according to the pre-study.

Firstly, public transport route for Tjörnexpressen has limited accessibility for left-turning from Stenungsund to Tjörn. Longer travel time would decrease both the *traffic participant´s benefit* and *attractiveness for public traffic*, which would have negative effect on public transportation plans for Tjörn Community.

Secondly, the passengers produced by three bus stops will decrease the efficiency of communication capacity of this intersection and bring more risk for traffic safety. When they cross the intersection, more clearance time would be consumed hence congestion is more liable to be generated.

1.3.2 New generated problems in future

On one hand, the traffic flow in the 2030 will increase at this section, but the new terminal will shorten the left-turn bay and made the situation of the intersection more complicated than today. Considering this, the efficiency will be decreased. On the other hand, the adding bus lane will carry some bus traffic load. At this point it will decrease the probability of forming long queue. Besides, how the traffic flow influence the traffic distribution is also thought provoking.

1.3.3 **The challenge for optimization**

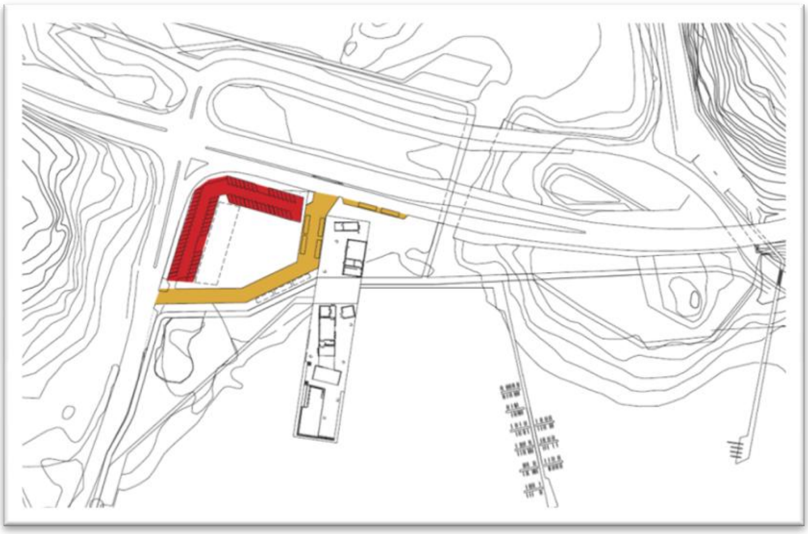


Figure 7 Future planning with other facilities (Tyréns AB, 2009)

The main challenge for optimizing this intersection is the geographic limitation. As figure 7 depicted, the left-turn bay is nearby the sea, and after upgrading the bus terminal, other facilities will occupy more space therefore it is impossible to prolong neither left-turn bay nor bus lane too much.

1.3.4 **Scenario definition**

Three scenarios are taken into consideration. The division can be seen in table 2.

Table 2 Scenarios definition

	Without new bus terminal	With new bus terminal
Year 2010	Scenario 1	
Year 2030	Scenario 2	Scenario 3

1.4 Modelling

1.4.1 **Geometry model**

1.4.1.1 Configuration

Each lane of the road and the connection part of each other are treated as link vectors, where vehicles comply with their route decision. The configuration of the geometry model is depicted as figure 8. Pink links are connectors of two abut lanes and blue links stands for lanes of the road. Bus stop (red line), pedestrian lanes and parking lot are integrated in the geometry model as well.

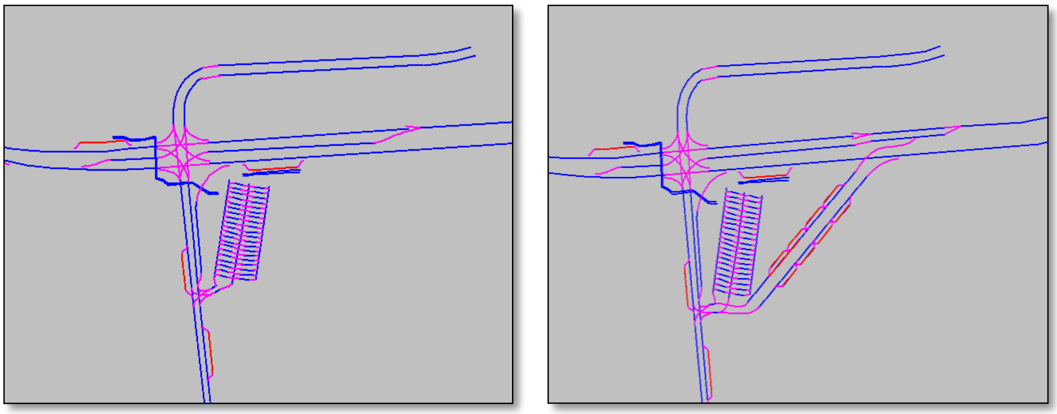


Figure 8 Configuration of intersection in VISSIM

1.4.1.2 Route decision

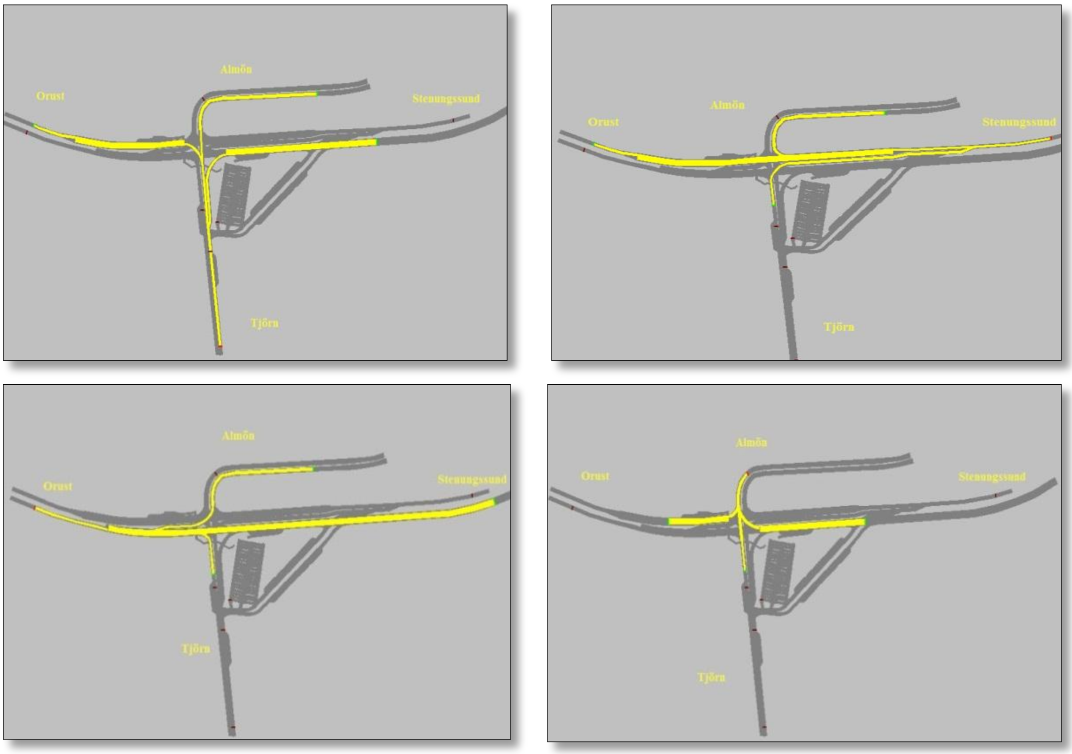


Figure 9 Route decision for each approaching

The route decision is defined according to the traffic flow statistics, as figure 9.

1.4.1.3 Preparation for Priority rules

Priority rules are necessary to be defined due to the conflict areas. A conflict area can be formed wherever two vehicular routes overlap. A yielding driver observes the approaching vehicles and considers the situation behind the conflict area. According to vehicle acceleration, the driver decides if he can cross the area or not. For the vehicles in the main stream, if a queue builds up from a signal downstream the conflict area, the vehicles will not stop in the conflict area in order to avoid blocking the yielding driver.

In this case, many priority rules need to be set in the conflict area. The details will be explained in the following bus stop model, parking lot model and pedestrian model.

1.4.2 Microscopic traffic flow model

Microscopic traffic flow model is applied to illustrate the behaviour of each discrete unit and the correspondence of each other in order to create continuous and steady traffic flow. The idea of *Monte Carlo simulation* is widely combined in microscopic models, because each unit is treated separately.

A microscopic traffic flow model correlated with intersection can be divided into 3 stages; they are *Traffic generation*, *Vehicle reaction in same lane*, *Intersection influence*. Note that vehicle reaction between different lanes is not included in the model for this project. Same method is used for building the traffic flow model in both Scenario 2010 and Scenario 2030.

1.4.2.1 Traffic generation

Poisson distribution model (Webster, 1958) is the most common used model for traffic generation at an intersection as traffic arrival model. Even many other models have been developed Poisson model is still the most practical car arrival model and is used in this thesis (Senborn et al. 2008). For this model, the time interval Θ_i is dominated by a coincidence or random number:

$$\Theta_i = -\ln\left(\frac{\text{random}_i}{100}\right) * \frac{1}{q}$$

In the formulas the range random number is 1 to 100. Basically, the vehicle arrival would follow this simulated time interval.

1.4.2.2 Vehicle reaction in lane

Wiedemann model is applied to simulate the driver and car behaviour in this project. This model abstracts the activities of single vehicle in the traffic flow as four modes, which are *free driving*, *approaching*, *following* and *breaking* (PTV, 2009).

One of the advantages of Wiedemann model is that it takes human behaviour as functions to build a psycho-physical model. In this model, vehicle and its driver are together treated as a single element in the simulation process. This element is termed as *Driver Vehicle Element* (*DVE*) (Fellendorf, 1994).

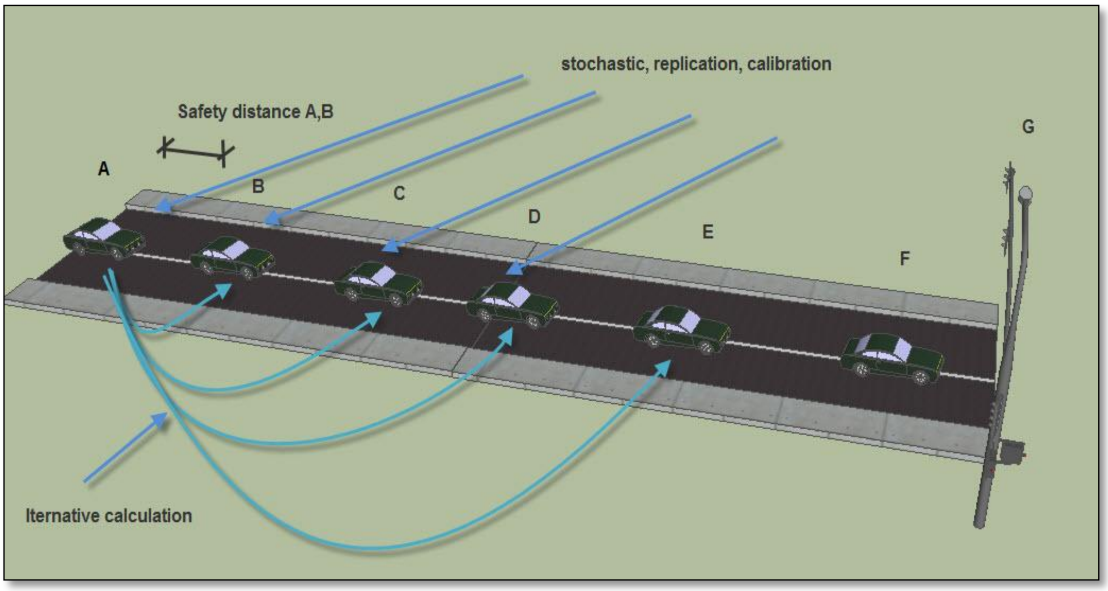


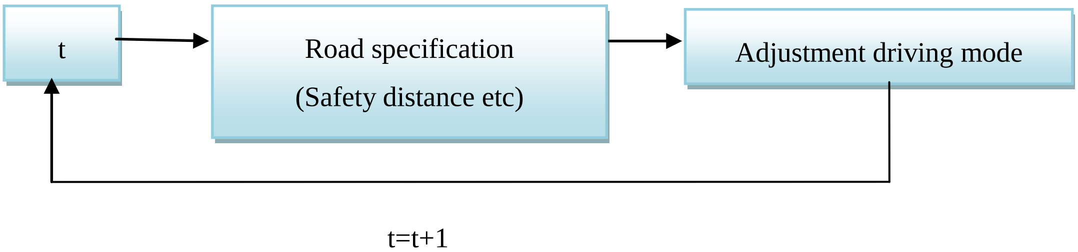
Figure 10 Wiedemann car following model

The illustration of Wiedemann model is depicted in figure 10. For example, *DVE* A will hold the safety distance between itself and *DVE* B based on criteria below:

$SD_{A,B} = f\,(Tech_A, Tech_B, Tech_C, Tech_D, Tech_{E,}$ characterize of *DVE* A)

Where, $SD_{A,\ B}$ is safety distance between *DVE* A and B; *Tech* is technical specification of vehicle, e.g. Vehicle length, position, speed and acceleration; *Characterize of DVE A* is the description of varieties of driver thresholds, e.g. sensitivity, memory and desire, in which calibration data are used in stochastic way as parameters.

At each time step, *DVE* A will check the circumstance and make a decision to adjust the driving mode. Then the adjustment will change the current circumstance. Thus iteration is formed and meanwhile the stochastic parameters are replicated to approach the reality, as the flow chart below. If every *DVE* performance as *DVE* A, a continuous and steady traffic flow is created.



1.4.2.3 Intersection influence

The traffic flow is broken suddenly and frequently by signal. This implies traffic flow is also influenced by traffic signal. To bring this correlation into the traffic flow model, the solution is that the amber time is treated as the behaviour of single *DVE* segment (PTV, 2009). As figure 11 depicted, the message from signal will affect the receptor vehicles.

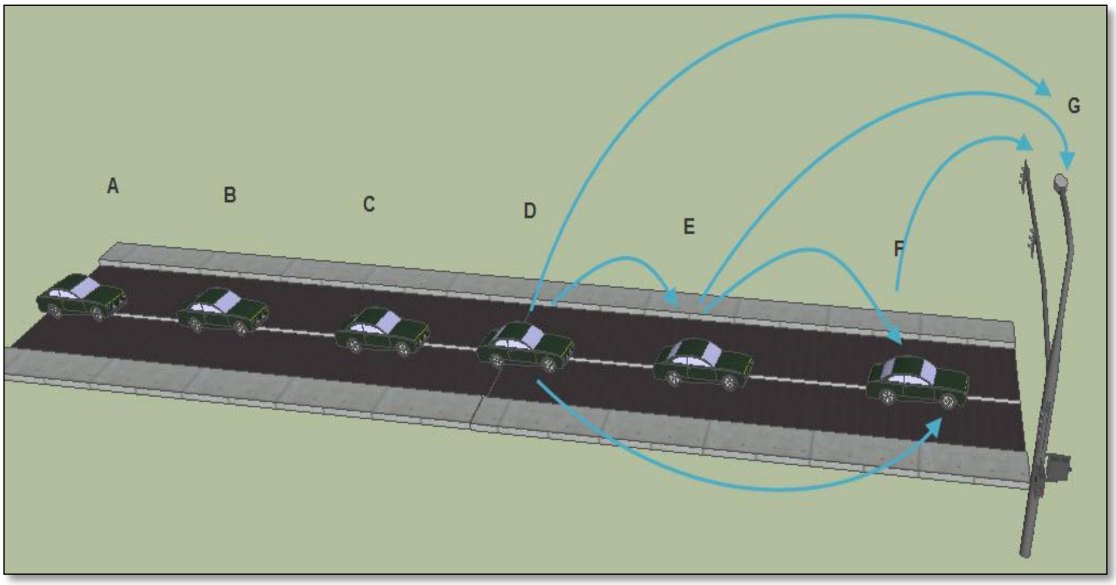


Figure 11 The influence from traffic signal in Wiedemann model

1.4.3 Signal control model

In the real intersection, the risks of dilemma zones are reduced by the real time signal system with LHOVRA technique. In the simulation model, this process will be reproduced and further developed to deal with future challenge.

1.4.4 Dilemma zones

According to the different leading conflict, dilemma zone can be divided in two types.

1.4.4.1 Dilemma zone 1 and risk inside the intersection

Safety aspect is critical for intersection because the serious accidents are frequency happened at crossing zones. For example, the investigation has expressed that almost every 5th casualty with deadly outcomes in urban area is intersection accidents (Inrikesministeriet, 2004).

The reason *Dilemma Zone* 1 formed is the vehicle comes from horizontal section unable to stop on time while other vehicles passing through vertical section, visa versa. This type of dilemma zone is predicted to produce latent conflict areas, which are so-called *Left Turn Across Path/Opposite Direction* zone (*LTAP/OD*) and *Left Turn Across Path/Lateral Direction* zone (*LTAP/LD*), as see figure 12 shown (Howard et al, 2008). In signal controlled intersection, the threat is significant during the inter-stage of two phases or amber onset (Gazis et al, 1960).

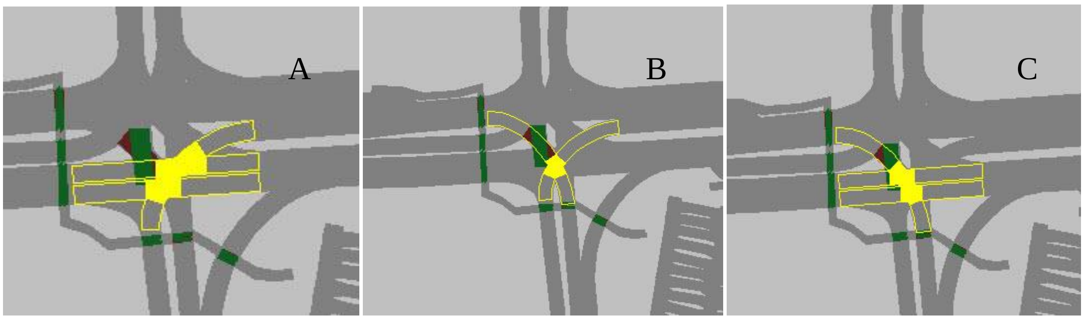


Figure 12 Conflict zones inside the intersection. A and C: LTAP/LD. B: LTAP/OD

1.4.4.2 Dilemma zone 2 and risk on each branch of the intersection

In a signalized intersection, those segments located before the stop line of each approach are termed as *dilemma zone 2*, which can be seen in the figure 13. Dilemma zones are often protected by multi-detector green extension system with the intention of decreasing the risk they would have caused.

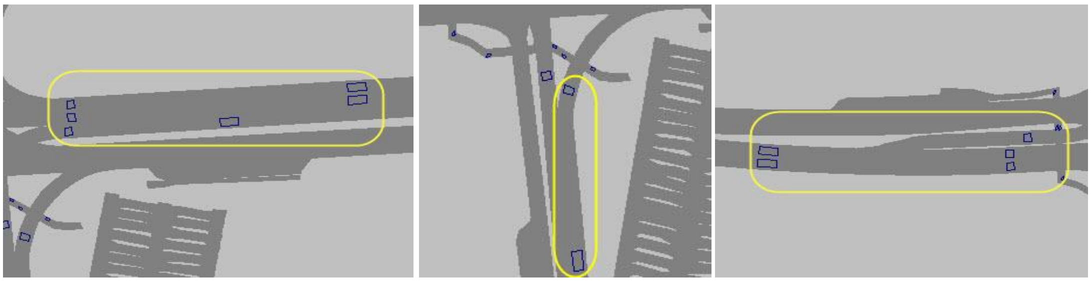


Figure 13 Dilemma zone before the stop line

The *dilemma zone 2*, also called alternative zone (*Valområdet* in swedish), is the lane in the cruise where driver can choose either to stop or to go ahead when the signal changes or going to change into amber (Trafikverket, 2004). The alternatives of drivers in this area may lead to rear-end crash.

Detectors and real time control signals is already working in Myggnäs Korsväg as EOVRA, which means the intersection is type E (signal controlled intersection), and OVRA principles of LHOVRA Technique have being applied.

The LHOVRA technique as an excellent toolbox is introduced briefly here, and explains and application in this project will be described in Chapter II.

1.4.5 LHOVRA Technique

LHOVRA technique is the leader strategy for cross signal designing in Sweden (Trafikverket, 2004). It aims to protect dilemma zones by multi-detectors real time systems. The letter LHOVRA is the acronym in Swedish for five priority principles that should be fulfilled in the signal design. These principles are:

L: *Truck priority* (*Lastbils-prioritering*). This function gives priority to trucks and buses in major road. The technique works as detecting the trucks or bus earlier before they enter the intersection in order to give them priority.

H: *Major road priority* (*Huvudledsprioritering*). Under this function all vehicles are encouraged to pass through major road. To apply this function, the detector placed in upstream the major road is also needed as L-function does.

O: *Incident reduction* (*Olycksreduktion*). The aim of this function is to decrease the frequency of *red light running* and *rear-end collision*. This function ensures the drivers determine whether they are going to stop or to go ahead.

Signal controller gives the vehicles in dilemma zone an extension of green period so that the vehicles will catch up to pass through before the amber signal quenched. The accident frequency will be decreased.

V: *Variable amber* (*Variabelt gult*). This function aims to reduce the lost time which is usually happens during the course of signal changing without effective traffic at the intersection. If the signal changing to amber does not give more accessibility for coming vehicles, part of amber time would be subtracted.

R: *Reduction of red light infringement* (*Rödkörningskontroll*). This function purposes to reduce the accident risk of red time running. It processes as function to express traffic situation shift to green light in conflict moment.

A: *Green-yellow-red-green sequences* (*Allrödvändning*).This signal sequence will decrease arrival problems in major road when using “All red” as rest state. The goal of this function is to reduce the so called nervous turning in all red time if there are vehicles coming late, and to ensure there is more possibility of access. It will create more smooth behaviour upstream the stop line (Engström, 1994).

Among six principles, L and H functions are used for support of the priority for specific vehicles or main road. OVRA functions are used for prevent the danger caused by dilemma zones.

1.4.6 **Detectors placement**

To complete LHOVRA and other rules for real time signal control system, the detectors need to be placed in the model. The position and function of detectors in the model remain the same as in the field.

Two series of numbers are used to nominate detectors, which are shown in figure 14 and 15 in order to make them clear.

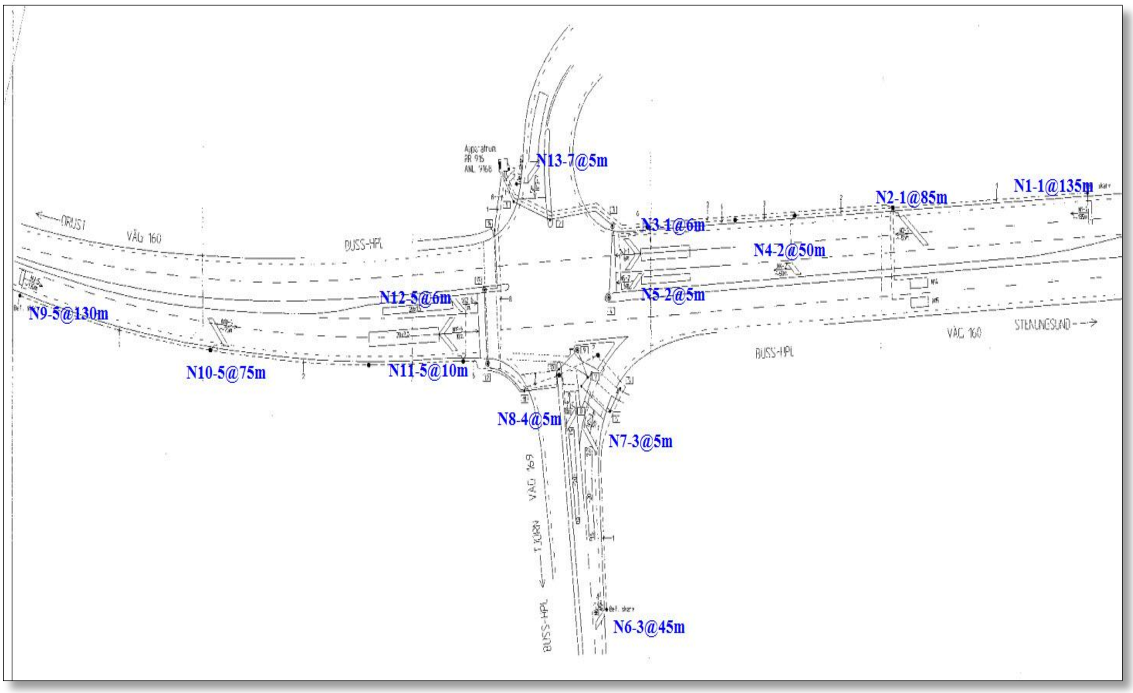


Figure 14 Detector positions in the field (Abrahamsson, 1995)

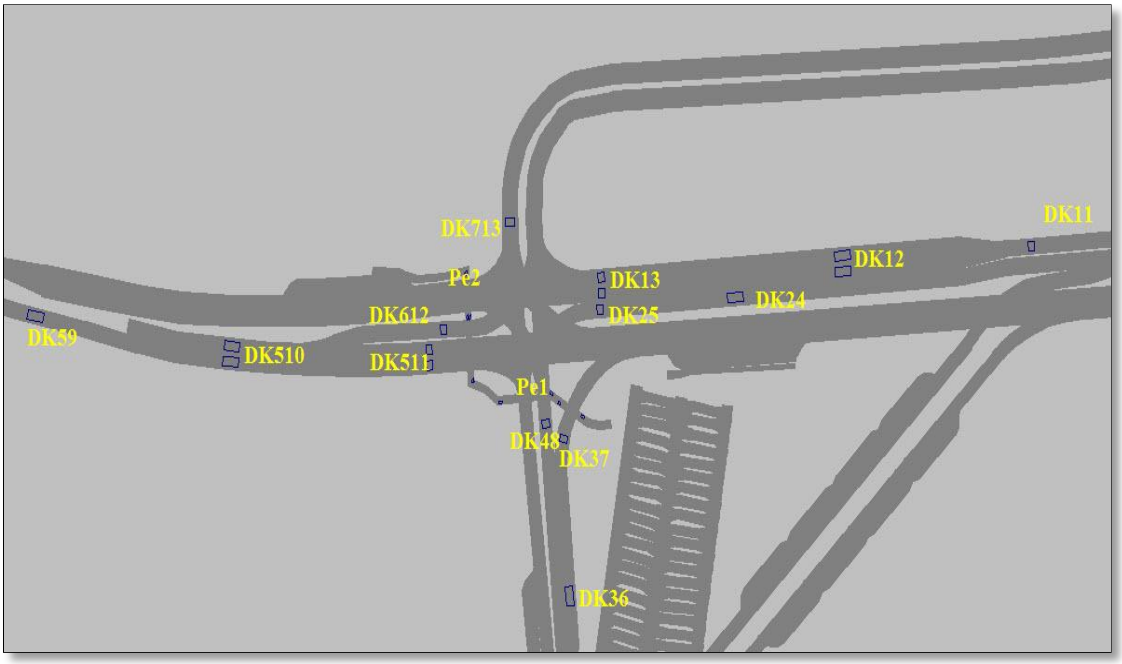


Figure 15 Detector positions in the model

Table 3 The names of the detectors

Real world	N1-1	N2-1	N3-1	N4-2	N5-2	N6-3	N7-3
Model	DK11	DK12	DK13	DK24	DK25	DK36	DK37
Number	1	2	3	4	5	6	7
N8-4	N9-5	N10-5	N11-5	N12-6	N13-7		
DK48	DK59	DK510	DK511	DK612	DK713	Pe1	Pe2
8	9	10	11	12	13	14	15

In the real intersection, the detectors for pedestrian are *hand touching detectors*. But in the simulation model, these detectors are set as loops detectors Pe1 and Pe2. Pe1 stands for the series of *loop detectors* along the pedestrian crossing V169, and Pe2 stands for the series of loop detectors along the pedestrian crossing V160.

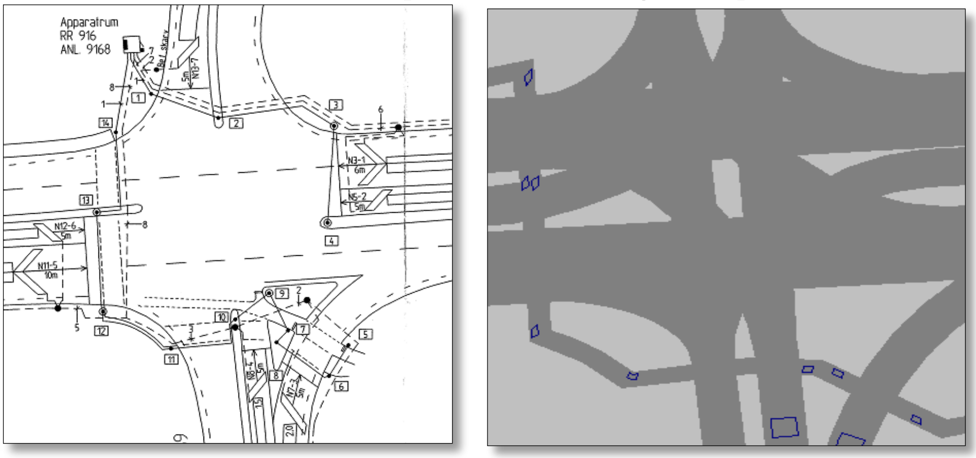


Figure 16 Position of pedestrian detectors

1.5 Bus stop model

1.5.1 Scenario 1 and 2

Three bus stops are located along V160 and V169 in the east, south and west direction. Currently, nine bus lines including local buses and express coaches are operated. The time-table is available from pre-study. Indeed, during the rush hour, many school buses are added to regular scheduled services.

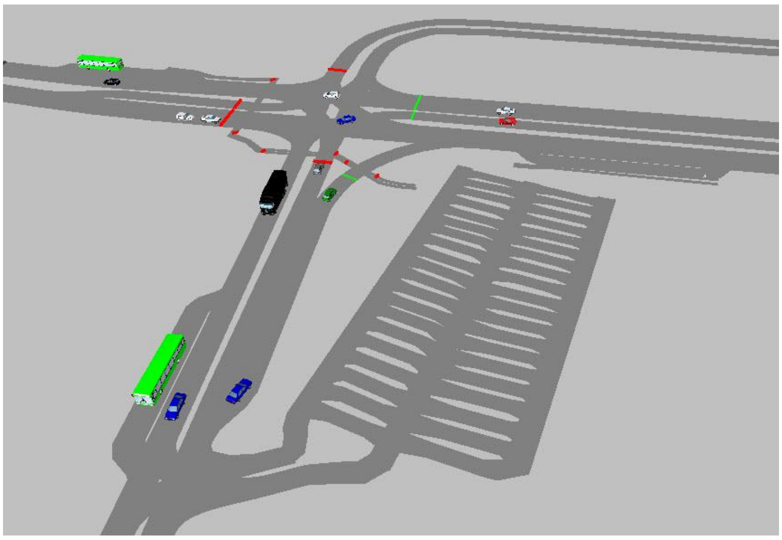


Figure 17 Three platforms in 2010

1.5.2 **Scenario 3**

In 2030, platforms will be located in the bus terminal which is mainly used to transfers. It leads to that passengers don't have to cross the road for bus exchange. Västtrafik plans to make the bus have a common departure time and frequencies in fixed intervals, which is about 15 minutes during peak hour. Besides, the school buses can also serve in the bus terminal.

At entrance and exit of bus lane, where the bus and car cause conflict area, the coming bus will give way to the vehicles on the V169. (See figure 18)

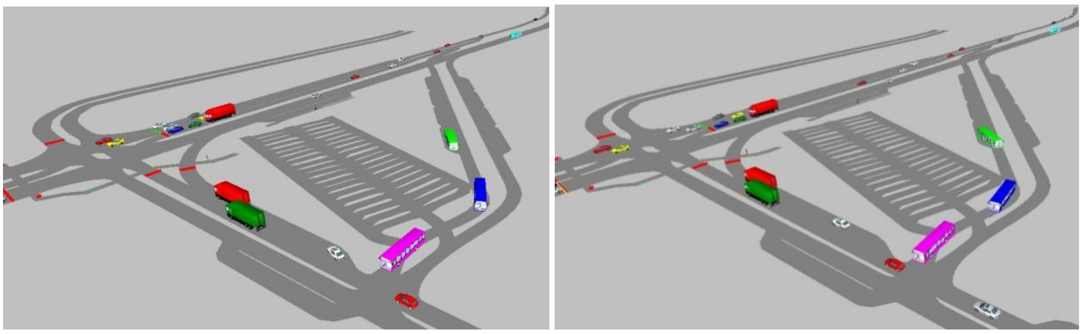


Figure 18 Priority rules for bus terminal in 2030

1.6 Parking lot model

There is a parking area with 40 parking spaces in the southeastern part of the intersection. It is possible that the vehicles coming from both directions along V169 can enter the car park. It is assumed that 2% of the vehicles from north and 1% of the vehicles from south will park here.

Both in 2010 and 2030, it is assumed that the passenger cars give a priority to vehicles coming from 160 Road.

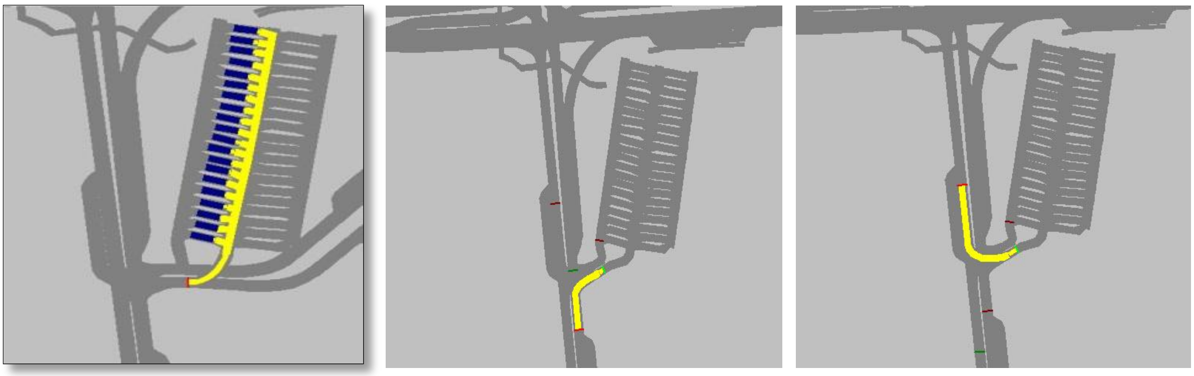


Figure 19 Route determination for parking lot

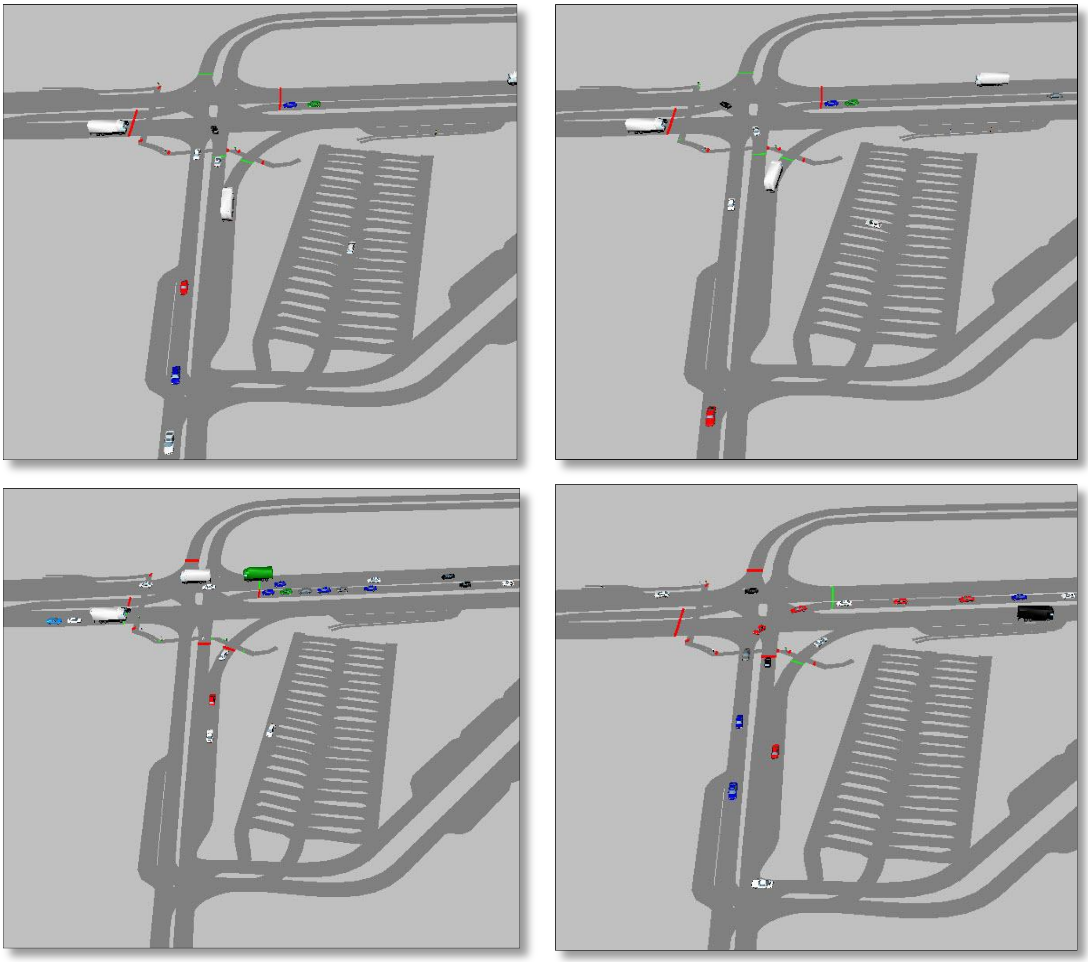


Figure 20 Example of routes inside parking lot

1.7 Pedestrian model

The two pedestrian crossings are existed in the western V160 and V169 and regulated by pedestrian signal, in all three scenarios. The rule of pedestrian signal is detailed in signal control section. It is assumed that 20 pacers would like cross the road per hour, walker generation is also subject to Poisson distribution which is the same as vehicle generation.

Since walkers' speed is much lower than vehicles, sometimes they will be still involved in dangerous road sections after the traffic signal changing. At this situation, the vehicles will give the priority to pacers based on the setting in the geometry model. There is one example how Pedestrian Priority Rules works in the VISSIM model, which can be seen in the figure 21.

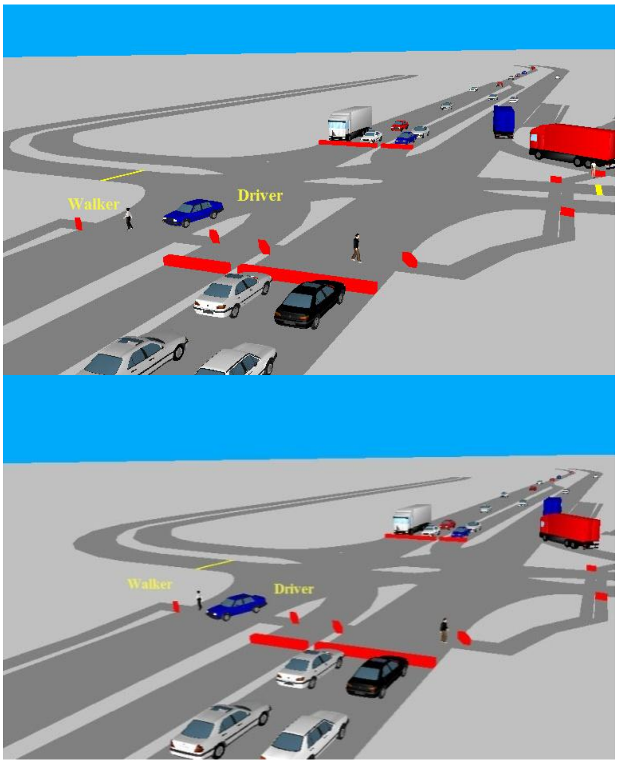


Figure 21 Priority rules for pedestrian

1.8 Discussion and calibration

1.8.1 Delimitation

Even though Monte Carlo method is taken and ambitious calibration are carried out, however in this model, the real parameter value is often not agreeable to the default value, and this deviation level often makes a distinction between simulation data and observed data (Archer, 2004). Therefore the parameters used in model are finally determined after field observation had been carried out in 2010-12-03.

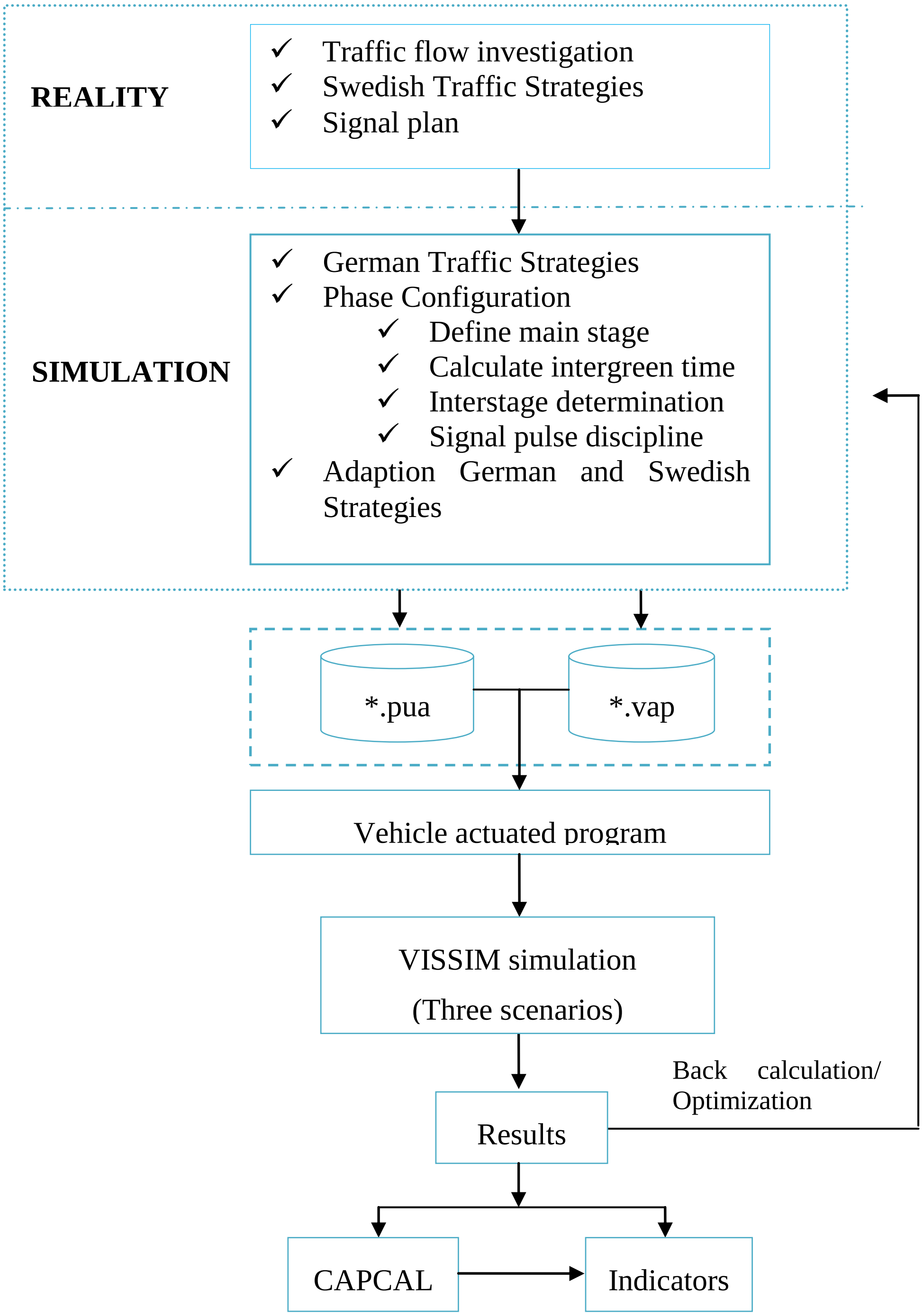
2 Chapter II Signal Optimization and Static simulation

2.1 Introduction

2.1.1 Aim

In this chapter, the signal control model will be generated which is based on the Swedish LHORVA and German signal control strategies. With other sub-models mentioned in Chapter I, the static model can be accomplished and give the indicators for three scenarios. Besides, the possible recommendation for congestion situation needs to be proposed.

2.1.2 Structure of Chapter II



2.2 Methodology

The methodology of this part can be seen in the flow chart above, which can be divided into four steps.

2.2.1 Step 1 Reality investigation

In this step, the information of present intersection should be realized as much as possible. In this project, the obtainable information includes

1. Traffic flow investigation data, which is supported by Stellen Tengroth.
2. Related Swedish Traffic strategies.
3. Signal plan, which is supported by Stellen Tengroth.

2.2.2 Step 2 Simulation for signal control

In this step, a signal model is built based on the information from Step 1. However, the basic idea and configuration of this model originate from German traffic strategies. Therefore in this step, some differences between these two strategies will be revised or discussed, in order to adjust the model to Swedish situation better. This step includes:

1. Overview of related German Strategies
2. Phase configuration, which contains:

(1) **Define main stage**. The definition of *stage* is the same as the term *phase*. The stage sequence and the setting of each stage will be defined as well.

(2) **Calculate inter-green time**. The definition of inter-green time is similar with the Swedish term *säkerhets tid,* based on the default in *Capcal*. But for an intersection works with LHOVRA technique, these two terms are not exactly equal, see chapter 2.4-2.6.

(3) **Interstage determination**. Interstage comprises part of the before stage, whole inter-green time and part of next stage. In this project, the lengths of interstages are assumed as 8s or 9s.

(4) **Signal Pulse Discipline**. Determine the way how the detector pulse effecting traffic signal pulse.

(5) **Adapt German and Swedish Strategy**. Testify if the real time signal control program is acceptable in Swedish intersection.

2.2.3 Step 3 Create Vehicle Actuated Program and VISSIM simulation

In this step, a Vehicle Actuated Program will be created based on the information acquired after Step 2. This program comprises two file, **.vap* and **.pua*, in which **.vap* file contain the logic information of phase conversion and **.pua* is responsible for timing information like inter-green time. The VAP program is then be introduced into VISSIM simulation model as *real time signal controller*, for each three scenarios.

Thus, a complete simulation model is achieved with real time signal controller. The results from this simulation model are used as the indicators to evaluate the traffic quality of the intersection. Some of the result will be further calculated in software *Capcal*.

2.2.4 Step 4 Back calculation and optimization

Usually at the beginning, the result is not according to the real data, due to some assumptions and simplification during modelling which might not accord the reality.

Therefore the simulation model often requires to be adjusted in order to approach the reality value. This process is so-called *back calculation*.

After back calculation, the model will be applied for evaluating the condition of scenario 2030. But it is probable that the current setting will not fulfil the future demand, thus the settings should be optimized.

2.3 Traffic flow analysis

Traffic flow volume collection has already been finished. The volume was collected per 15 minutes from 01-12-2009 to 10-12-2009. The records of number of vehicles came from eleven points set up in three approaches.

The regularity is found by analyzing the available data. It shows that the evening peak hours in the weekday appear from 16 to 17. Compared with morning peak hour, more vehicles run toward Tjörn Island during the nightfall. During the weekend, the traffic volume is reduced obviously and distributed evenly by day. Thereby, the traffic volume in the weekday is selected as vehicle input for simulation.

As figure 22 showed, there are three approaches signed as A, B, C here. The average value of traffic volume during peak hour is calculated, which will be used in this project, shown in table 4. The detailed calculation process is attached in Appendix 1.

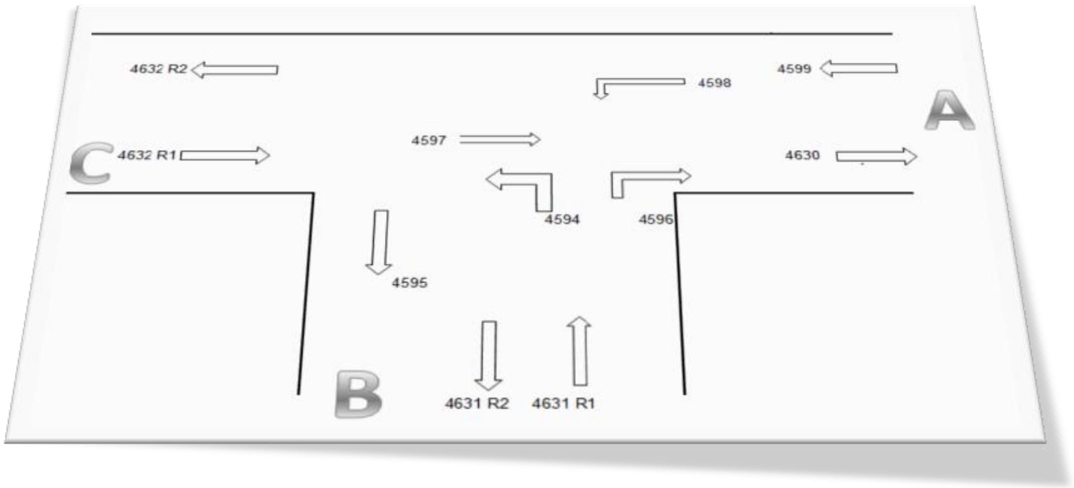


Figure 22 Sections of crossing Myggenäs (the numbers are the names of counting devices)

Table 4 Traffic volume enter crossing during evening peak hour (vehicles/hour)

	12-02	12-03	12-04	12-07	12-08	12-09	12-10	Average	**2030**
Approach A	1232	1139	1201	1248	1184	1211	1248	1209	1354
Approach B	409	404	407	395	396	422	479	416	466
Approach C	280	294	286	297	276	313	356	300	336

The forecast of traffic growth 2010-2030 has been mentioned in Chapter I.

2.4 Swedish Signal Strategies

The operation of this intersection is mainly dominated by OVRA signal control strategies, which is part of LHOVRA technique.

2.4.1 LHOVRA technique: The operation of O function

Passive green time (*passivt grönt* in Swedish) and *extra green time* (*Fråntid in Swedish*) are supplemented to answer detector pulse during the operation of O function, in order to reduce the risk in the *alternative zones* (*valområdet* in Swedish). The information about how O function is being operated can be seen in the figure 23 and related illustration.

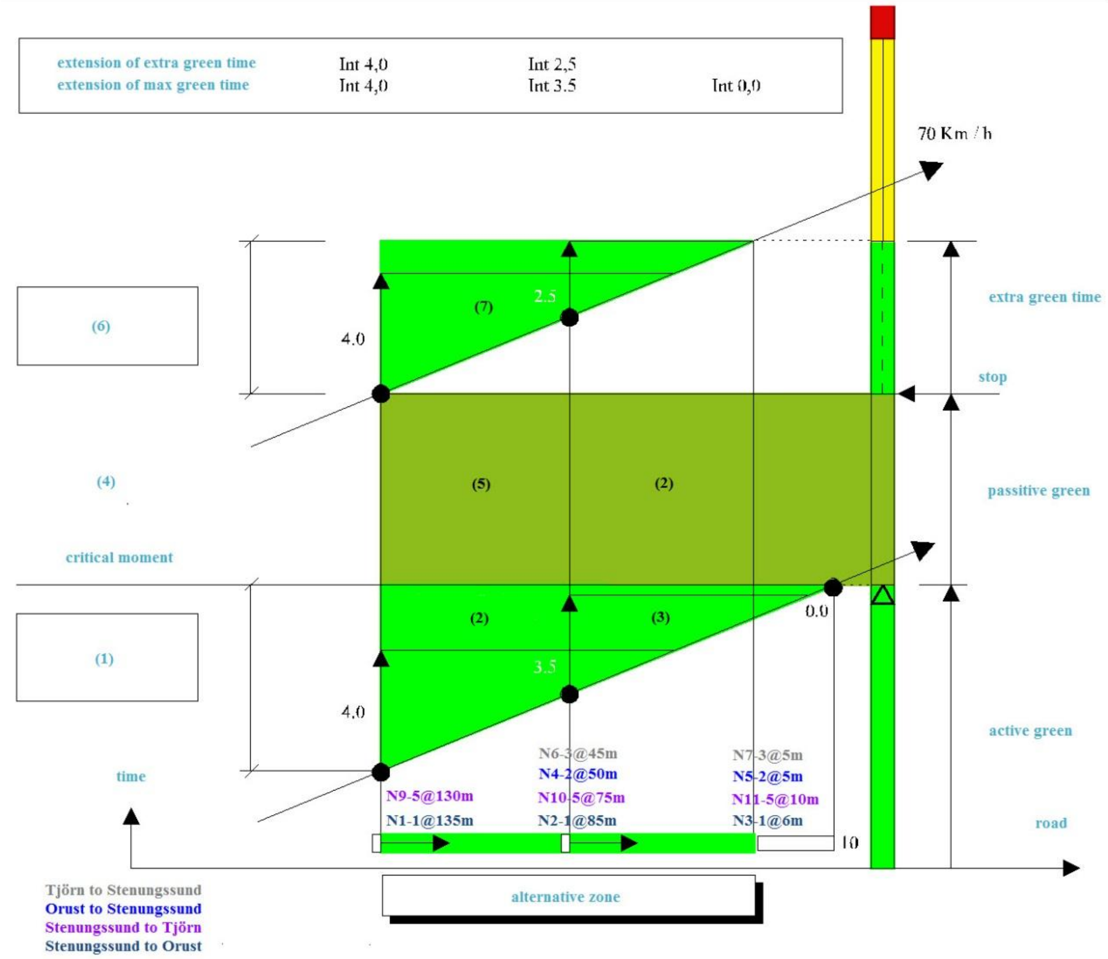


Figure 23 O function in LHOVRA (Trafikverket, 2004)

(1) Vehicles that coming late makes the green time remaining for a time gap less than 6.2s.
(2) Traffic signal can change to amber anytime here
(3) No changing here
(4) Require the green time increasing in the end of green time period
(5) Here received passive green time because for example the vehicles on the opposite directions need green time.
(6) Vehicles that coming late makes the green time remaining for a time gap less than 5.1s.
(7) Alternative zones with activate green time

2.4.2 LHOVRA technique: The operation of V function

In V function, amber time are divided into two parts, they are *fix amber time* (*fast delen* in Swedish) and variable amber time (*variabelt* in Swedish). When the signal beginning to change to amber, the detector on the branch will measure and make decision if the vehicle passing by has possibility to cross the intersection in the span of *max amber time* (*fulltid* in Swedish). Otherwise, the amber has to be quenched as fix time (3s in figure 24) instead of full amber time (5s in figure 24). The information about how V function is being operated can be seen in the figure 24 and related illustration.

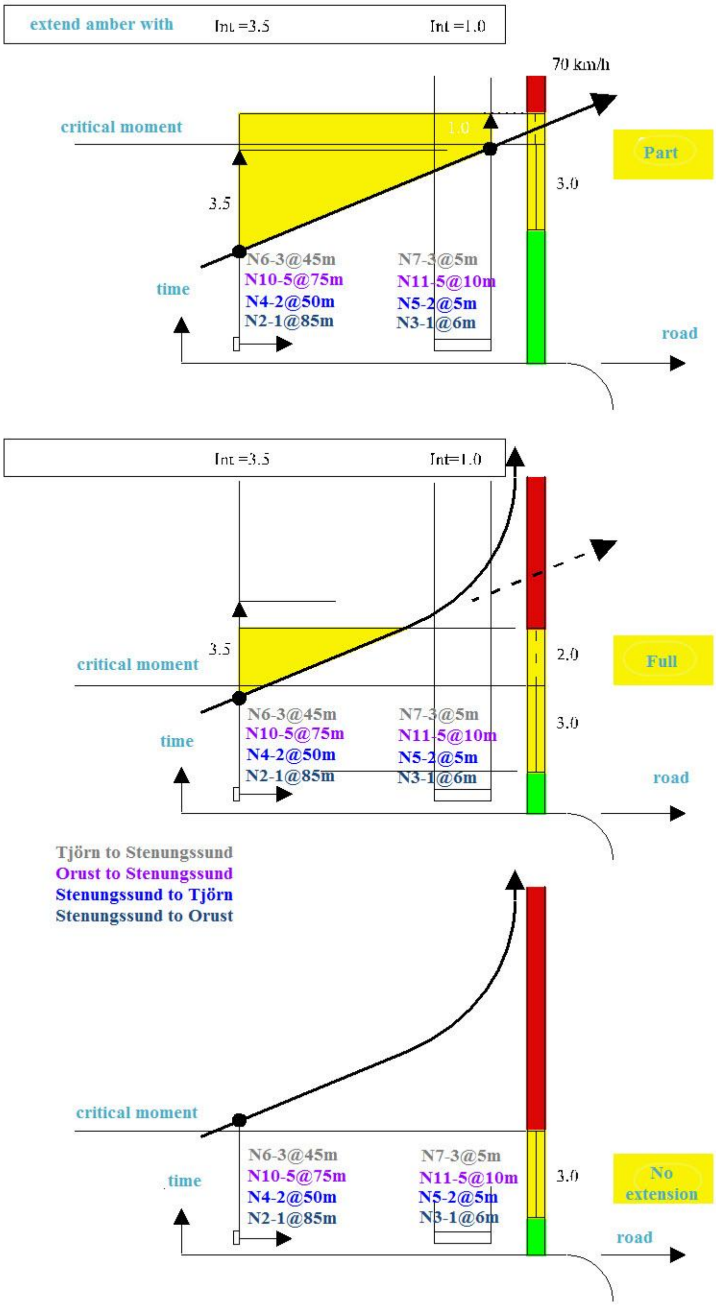


Figure 24 V function in LHOVRA (Trafikverket, 2004)

2.4.3 LHOVRA technique: The operation of R function

R function aims to extend the red time of the previous phase in order to avoid red light running in the end of this phase, since this function create a relative long time span(*Spärrtid* in Swedish) for both conflict sections remaining red signal.

The information about how R function is being operated can be seen in the figure 25 and related illustration.

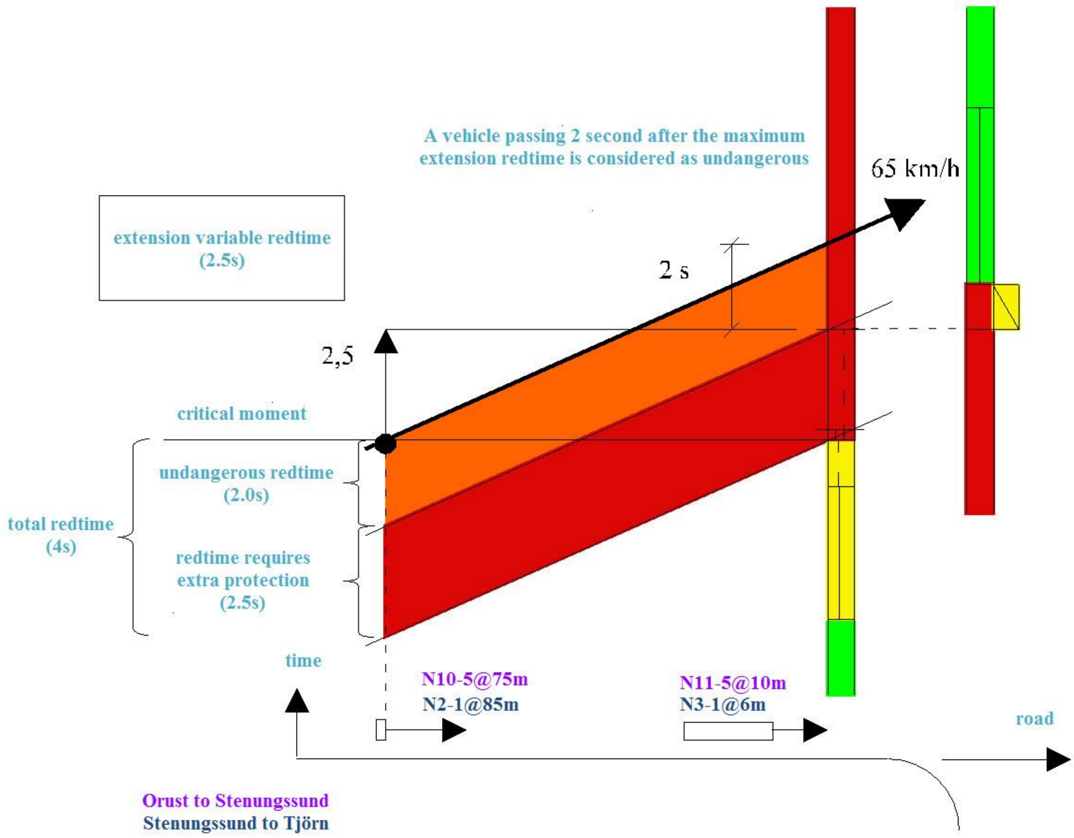


Figure 25 R function in LHOVRA (Trafikverket, 2004)

2.4.4 LHOVRA technique: The operation of A function

While no vehicles passing the intersection, the intersection would hold the *hibernation mode* (*viloläge* in Swedish), where all the traffic signal returns to amber, and then red. But if A function being applies, a coming vehicle will stop this mode and the signal phase will change to green with minimum green time, as figure 26 shown. In this figure it is can be seen that part of the amber is be skipped.

However, the R function is seldom performed during peak hours, since the hibernation mode is rarely reached

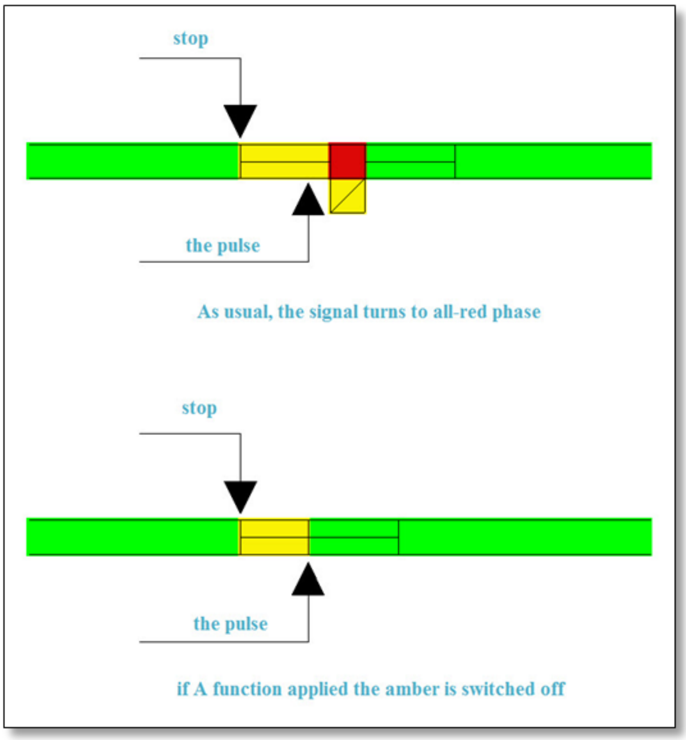


Figure 26 A function in LHOVRA (Trafikverket, 2004)

2.5 Present signal plan

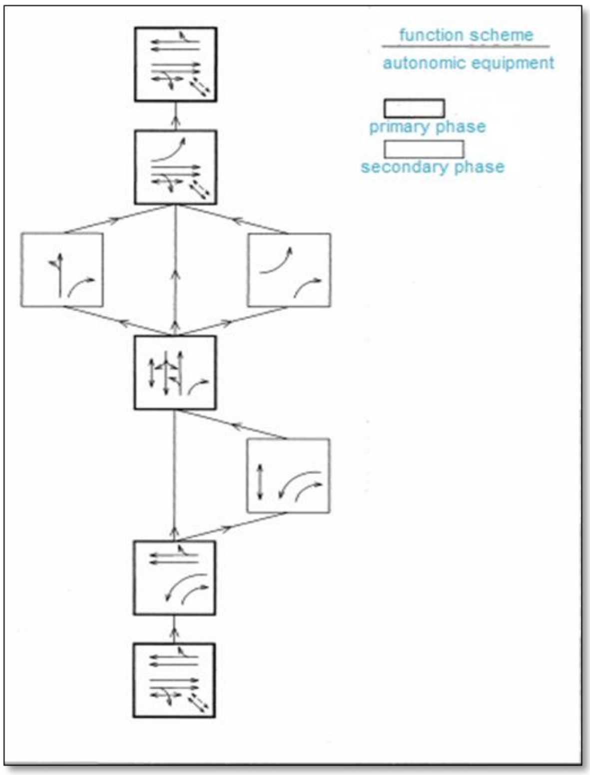


Figure 27 Current phase plan (Abrahamsson, 1995)

Phase plan is critical part of signal timing, including the number of phases and the sequence of phases. Multiphase is used here since the traffic flow of left-turning and right-turning movements in this intersection require a protected phase (American

National Research Council, 2000). Four *primary* phases (*primära phase* in Swedish), three *secondary phases* (*sekundära phase* in Swedish) and one *all-red hibernation* phase (*viloläge allrött* in Swedish) have been settled in this intersection.

Among four main phases, the time span of phase two is relative long, and the time span of phase three is short. This setting depends on the traffic flow investigation, which shows the section Almön has very low AADT flow and there is very high AADT flow between Stenungsund and Tjörn.

Three *secondary phases* used here mainly for the purpose of extending the green time of direction S-T to fulfill the left-turning demand, and extending the green time related to Almön Section, which are of very short span.

Hibernation phase will be activated if no vehicle passing through detectors/intersection. But this situation rarely appears in the peak hour times.

The phase cycle can be seen as figure 27, note that hibernation phase is not shown in this figure.

2.6 Germany Signal Strategies overview

The configuration and idea of simulation model is originated from German traffic strategies.

The leading German traffic signal strategies are parts of *RiLSA* or LSA. The main idea of German signal control strategies is the same as Swedish ideas, but there are also some differences between each other:

1. **Phase order**: In German strategies, the function of lagging phase is often achieved by adjusting the span between two phases. *Secondary phases* are not often used.
2. **The time span between phases**: In Sweden, the time span is dominated by LHOVRA, whereas in German, the time span is based on inter-green time calculation. These two techniques are supported by different measurement data.
3. **Different Safety requirement.** In Sweden, the safety requirement between phases is more strictly than which in German. For instance, in German, the span of *departure time* (*Einfahrzeit* in German) in the next phase is allowable to overlap the clearance time (*Räumzeit* in German) in the previous phase, which can be seen in the figure 28.

But in the Swedish strategies, the *clearance time* (*säkerhetstid* in Swedish) is seldom overlapped by the departure time, which can be seen in the figure 28, according to the R principles in the LHOVRA technique. Therefore in Sweden intersection, there are longer time span that both of the intersection are locked. This can decrease the risk of red signal rushing.

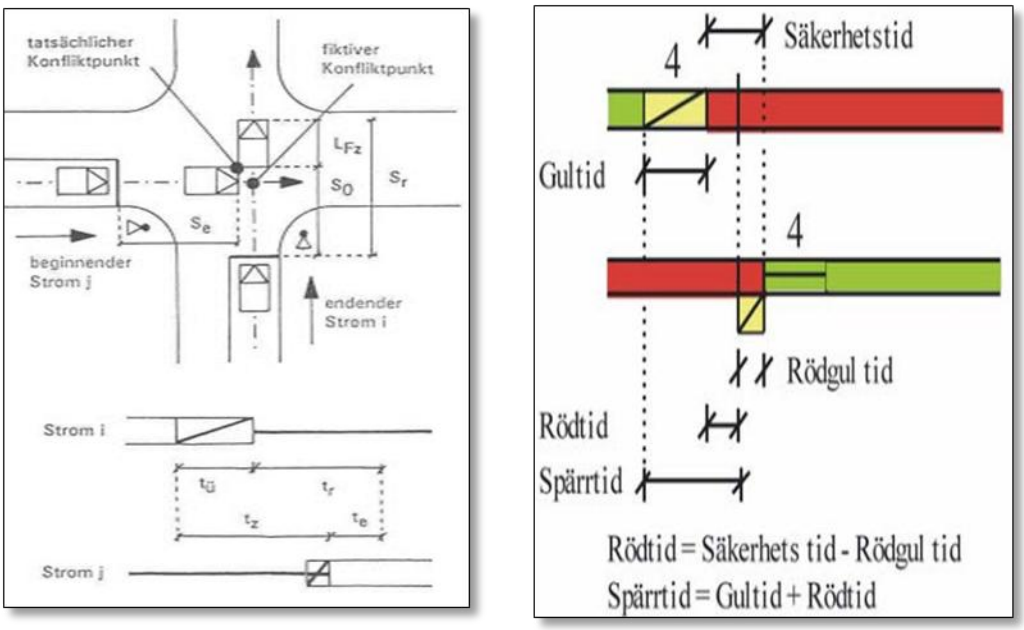


Figure 28 Clearance time calculation in Sweden (right) and Germany (left). (Bosserhoff, 2008 and Trafikverket, 2004)

2.7 Signal control model

2.7.1 Phase plan

In the simulation model, four primary phases in the present situation are applied. The phase diagram is shown as below. The phase of all red signals is also not included in the simulation model since this phase is not common in the peak hours.

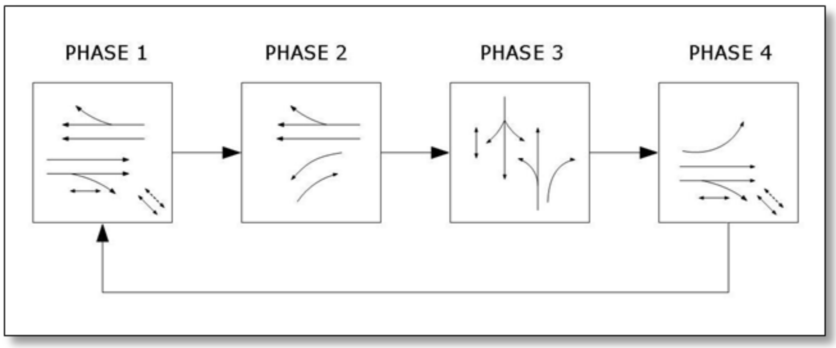


Figure 29 Phase plan in the signal control model

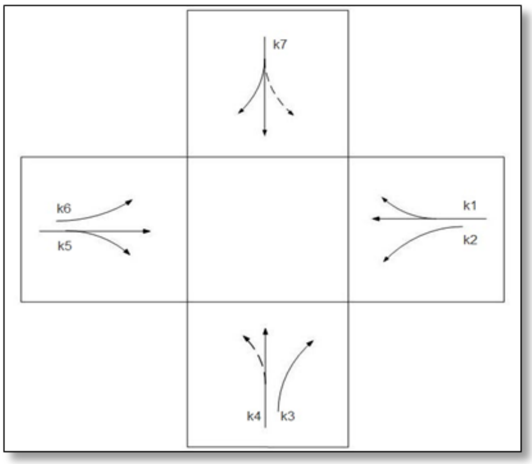


Figure 30 Lane Groups definition (The pedestrian lane group is not shown here).

Besides， for analyzing the signalized intersection, it is considered into individual intersection approaches and individual lane groups. According to the geometry of the intersection and traffic movements, there are seven lane groups generated for describing vehicles operation. The segment rules refer to highway capacity manual chapter 16. When two or more lanes are included in lane group, they are treated as single entry for computation purpose (American National Research Council, 2000).

2.7.2 Signal timing

Controller setting refers to the operating parameters that must be physically set in controller with electrical means. The following settings play significant roles in the controller operation and they must be specified for each phase.

2.7.2.1 Minimum green time

Minimum green time should be long enough to ensure that the queue of vehicles can be discharged at the beginning of green indication. How to determine the minimum green time is dependent on the method of detection. When the long detector is near stop line, the vehicle lane group is normally given 4.0-6.0 seconds green time at least (FSGV, 2005).

Because pedestrians are present in this case, the minimum green time need to be checked for its ability to provide enough pedestrian crossing time. If the green times are too short or road are too wide, the pedestrian may be caught in the middle of intersection (Mannering et al, 2008).

$$G_p = 3.2 + \frac{L}{Sp} + (0.27N_{ped}) \text{ for } W_E \leq 3.05\text{m}$$

$$G_p = 3.2 + \frac{L}{Sp} + (2.7\frac{N_{ped}}{W_E}) \text{ for } W_E \geq 3.05\text{m}$$

Where

G_p= minimum pedestrian green time in seconds

3.2= pedestrian start-up time in seconds

L= crosswalk length in m

S_p=walking speed of pedestrians, usually taken as 1.2m/s

N_{ped}=number of pedestrians crossing during an interval, and

W_E= effective crosswalk width in m

The crosswalk length should be the half of road width at least. Finally, the pedestrian crossing time is **11 s** by calculating.

2.7.2.2 Maximum green time

The maximum green time is finally set as **30 s** for phase 1 and 2. For phase 3 and 4, the maximum green time is defined as **15 s** that also fulfil the pedestrian crossing time mentioned above. The default is checked during the field observation 2010-12-03.

2.7.2.3 Amber time

Amber time is also referred to as the change interval which alerts divers that green light will be changed to red. The amber time is determined by maximum allowed speed in approach. **3 s** is setting as default because due to the vehicle speeds is assumed 50km/h around the intersection (FSGV, 2005). In Sweden, variable amber which is 3-5 s is used, according to V principle in LHOVRA technique (Trafikverket, 2004).

2.7.2.4 Amber/red

Amber/red is set as **1 s** (FSGV, 2005). This default is the same between German and Sweden suggestion (Trafikverket, 2004).

2.7.2.5 Allowable gap

The time gap means the elapsed time between the departure of the first vehicle from the detector and the arrival of the second. The allowable gap gives the threshold for the gap length in traffic flow. When the measured time gap less than the allowable gap, the current phase has to be extended (American National Research Council, 2000). The value is set as 3 seconds as the suggestion of RiLSA (FSGV, 2005). In Sweden, this value is set less than 5.6 s, and 4.0 s is the suggestion value, as O principle in LHOVRA technique.

2.7.2.6 Calculate Inter-green time

The *inter-green time* is the time interval between the end of a green indication for one phase and the beginning of green for the subsequent phase. The inter-green interval comprises the yellow change interval and all-red clearance interval which should set into controller separately. These two intervals are combined here to simplify the analysis (Mannering et al, 2008).

As it is mentioned before, OVRA gives some suggestive ranges to set inter-green time. But in the simulation model, fixed values of inter-green time require to be calculated. Therefore, the German signal standard *LSA* is used here as the tools for inter-green time calculation.

In LSA, the minimum inter-green interval is determined by:

$$t_z = t_{ü} + t_r - t_e$$

$t_{ü}$: *Crossing time* (*Überfahrzeit* in German) is the time span between the beginning of amber time and the start of the clearance time of the last vehicles in the end of previous phase.

t_r: *Clearance time* (*Räumzeit* in German) is the time span from the vehicle entering the intersection to leaving conflict area.

t_e: *Departure time* (*Einfahrzeit* in German) is the time span from the first vehicle in the next phase entering the intersection to crossing the conflict area successfully.

For understanding easily, the parameters above are dimensioned in figure 31. The t_r depends on the vehicle speed and clearance distance which include basic clearance distance (S_0) and length of car (l_{Fz}). The departure time is calculated by enter distance (*Einfahrweg* in German). The inter-green time can be obtained according to diagram.

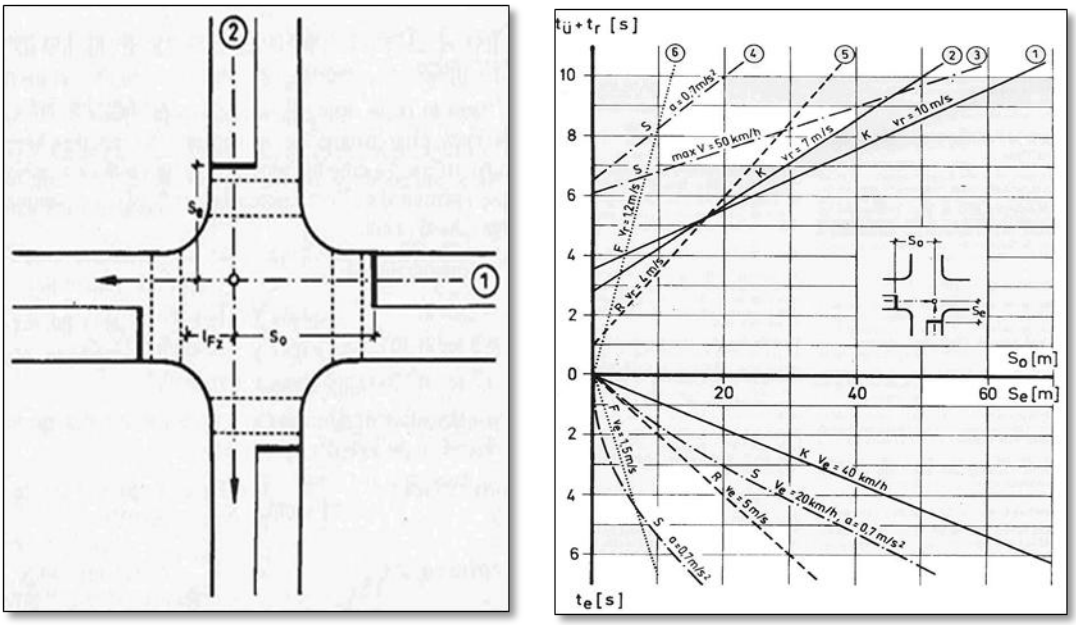


Figure 31 Dimension of parameters and inter-green calculation diagram (FSGV, 2005)

The inter-green matrix makes the results clear, shown in the table 5. For example, the value **5** with red mark stands for the minimum green time when the k5 is ended and following k4 will display. The f1- k7 are vehicle lane groups and f1- f4 are pedestrian lane groups.

Table 5 Inter-green matrix for vehicle and pedestrian lane groups

	k1	k2	k3	k4	k5	k6	k7	f1	f2	f3	f4
k1	0	0	0	5	0	5	4	0	0	0	0
k2	0	0	0	2	2	0	5	1	1	0	0
k3	0	0	0	0	0	0	0	4	4	0	0
k4	3	4	0	0	5	0	2	8	8	0	0
k5	0	4	0	3	0	0	5	1	1	9	9
k6	1	0	0	4	0	0	1	0	0	9	9
k7	5	0	0	4	3	4	0	0	0	2	2
f1	0	7	0	0	7	0	8				
f2	0	7	0	0	7	0	8				
f3	8	0	0	9	0	0	6				
f4	8	0	0	9	0	0	6				

2.7.3 **Define the interstage**

The lengths of interstages are defined as table 6. The interstage should not less than the related intergreen time.

Table 6 Lengths of interstages

	Stage 1	Stage2	Stage3	Stage4
Stage 1		8s	9s	8s
Stage 2	8s		8s	8s
Stage 3	8s	8s		8s
Stage 4	8s	8s	9s	

After finishing the phase plan and inter-green calculation, the information are recorded into the *.pua file, which can be seen in the Appendix 2.

2.7.4 **Applied strategies**

A real time controlled intersection usually followed the principles mentioned below:

1. Each phase has to go through with minimum green time before converting to next phase. When more vehicles coming are detected after minimum green time, the green light should be extended.
2. If the phase reaches to the preset maximum green time, the current phase should be terminated.

3. The phase sequence is conducted on the basis of general order, whereas the time of the phase would be cut or the phase stage would be skipped, if no traffic demand is detected.
4. The vehicle and pedestrian at the same direction have green time simultaneously even if only vehicle or pedestrian requires green time.

2.7.5 Signal pulse discipline

In VISVAP program, the detector signal pulse would affect the traffic signal statement, if the function/criteria described below must be achieved (PTV, 2007):

Time span limitation: The minimum limit of time spans i.e. min green time should be guaranteed, and the maximum limit of time spans should not be surpassed. For example, **Tg(K_N) >= Tgmin(K_N)** implies the green time of signal group N is equal or more than the minimum green time of group N.

Presence*:* Under this function, the signal pulse will be transmitted to the signal if a vehicle passing through the detector. In this project, the criteria **Presence (DK_N)** or **PDK_N** implies that, a vehicle passing through the *N*.th detector.

Occupancy: Under this function, the signal pulse will be transmitted to the signal if any vehicle has passed through the detector during last short time step. In this project, the criteria **Occupancy (DK_N) > 0** implies that, at least one vehicle has passed through *N*.th detector during the last short period.

Headway or ***time gap*** (*Tidsavstånd* or *Tidsluckor* in Swedish): The time interval between two successive vehicles passing the point where detector is sited. In this project, **(Headway (DK_N) <= MAX_GAP)** implies that the *N*.th detector has not detected any vehicle within the maximum time gap.

The detail of signal pulse discipline is attached in the Appendix 3.

2.7.6 Adaptation German Strategies vs. Swedish Strategies

As mentioned before, both Sweden and German strategies will consider the similar issues in their traffic signal strategies. Two groups of strategies is be compared in table 7, assumed no phase is skipped and the maximum green time is not reached.

Table 7 Comparasion between German and Swedish Strategies

Function	Olycksreduktion		Variabelt Gult		Rödkörningskontroll		Allrödvändning	
Extension	Reality	Simulation	Reality	Simulation	Reality	Simulation	Reality	Simulation
P1→P2	4s	3s	3-5s	3s	6.5s	4s	0	0
P2→P3	4s	3s	3-5s	3s	6.5s	5s	0	0
P3→P4	4s	3s	3-5s	3s	6.5s	9s	0	0
P4→P1	0s	3s	3s	3s	6.5s	5s	0	0
TOTAL	12s	12s	12-15s	12s	26s	23s	0	0

In the simulation model, the green time extension is achieved by applying signal pulse discipline ***HEADWAY***, which is 3s for each phase. In O function, 4s is recommended for phase 1, 2 and 3, but for phase 4, the O function is not planned.

In the simulation model, the amber time is fixed 3 second per phase, and in V function, the variable amber is about 3-5 second for the first three phases, but for phase 4, V function is not planned.

In the simulation model, the inter-green time for vehicles is less than which in the R function. But from phase 3 to phase 4, the time duration is longer than of which R function is applied because the pedestrian crossing time is considered.

A function is not a considerable issue during the peak hours neither for simulation model nor for reality.

Overall, the cycle time of the model is about **6 s** less than the present function at daily hours. However, the maximum green time are often reached in the peak hours and phase 3 sometimes had been skipped due to few vehicles back and forth through section Almön, the error will be diluted. In this project, the simulation model can adapt the reality.

2.8 Vehicle actuated program (VAP)

After the simulation pre-requisite has been planned down, the *.pua file and *.vap file can be generated, which can be seen in the Appendix 2 and 3. The grammar of VAP program can known from VISVAP MANUAL (PTV, 2007).

2.9 Result analysis

Combined with VAP program, the results are produced by VISSIM model. VISSIM simulate the traffic flow in peak hour (15:00-16:00). The data collection and evaluation are processed from 900 s to 2700 s. The reason is that the traffic flow don't reach the stable situation at the very beginning of simulation, besides, the traffic volume is larger during 900 s to 2700 s. The result can be obtained for worst case.

The static models are used to assess the scenarios below, these are:

Scenario 1: the Myggnäs intersection without bus terminal in 2010

Scenario 2: the Myggnäs intersection without bus terminal in 2030

Scenario 3: the Myggnäs intersection with bus terminal in 2030

In order to assess the various scenarios, the data need to be selected to indicate the performance of each scenario. The parameters that are used to assess this junction are detailed below.

- ***Travel time*** – it is defined as the average time for one vehicle passing two user-defined points on one route.
- ***Delay time*** – The delay segment is based on one or more travel time section. The total delay time is calculated by subtracting the *ideal travel time* from the *real travel time*. The *ideal travel time* is the time that vehicle takes to pass two points under the situation of no signal controls and no other vehicles
- ***Queue length*** – The average and maximum queue length can be provided on each approach during defined time interval. A vehicle is in queue condition when its speed drops below the Begin speed and has not exceeded the End speed.
- ***Degree of saturation*** – It is defined as the traffic flow rate divided by capacity, (B=q/K) (Olstam et al, 2010). It can be calculated approximately by CAPCAL with supportive outputs from VISSIM model. This parameter is to be used only as a comparison between the models rather than to determine the practical traffic flow condition.
- ***Delay at intersection*** – it means the average delay of all vehicles that pass by intersection. Meanwhile, the Level of Service based on HCM is also acquired.

2.9.1 Travel time

The results reveal that compared with Scenario 2, travel time can be saved by new construction in 2030 for the routes of Stenungsund to Orust, Stenungsund to Tjörn and Tjörn to Stenungsund, which is 9.7 s, 2.3 s and 1.6 s, respectively. (22.2%, 2.6%, 4.1% will be reduced in scenario 3) But on the other hand, the new construction will result in more 6.5 s travel time for the direction of Orust to Stenungsund. (14% more than in Scenario 2).

Overall, the new bus terminal can save 7.1 second totally for four routes in 2030.

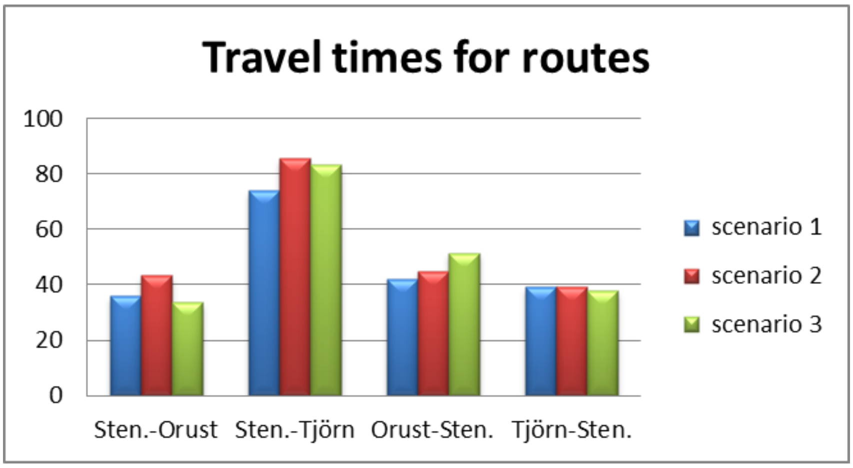


Figure 32 Travel time for different routes produced by static model

Table 8 Travel times and Saving times by scenario 3

	Scenario 1	Scenario 2	Scenario 3	Saving
Sten.- Orust	35.9s	43.3s	33.6s	9.7s
Sten.-Tjörn	73.9s	85.6s	83.3s	2.3s
Orust- Sten.	42.2s	44.9s	51.4s	-6.5s
Tjörn- Sten.	39.1s	39.3s	37.7s	1.6s
TOTAL	191.1s	213.1s	206s	7.1s

2.9.2 **Delay time**

The result of delay time have same trend as the results of travel time, but the improvement after building bus terminal is more evident. On the whole, the total delay times for these routes are decreased by 15.1 s.

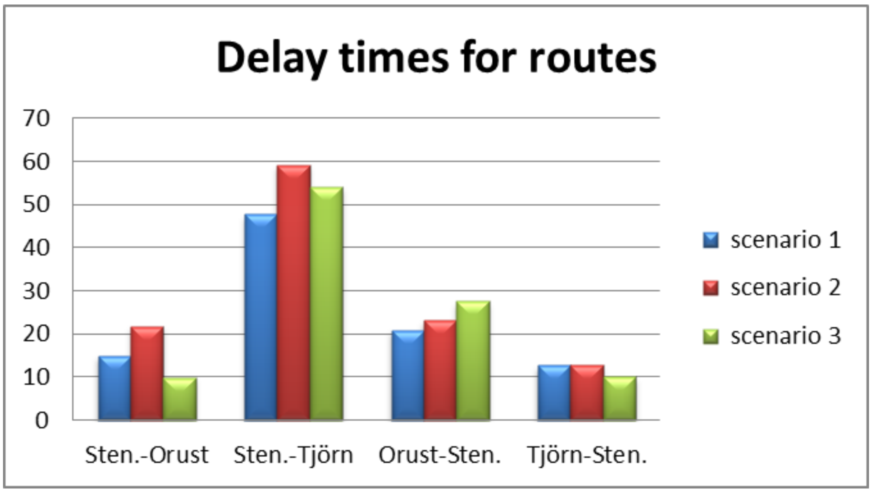


Figure 33 Delay times for different routes produced by static model

Table 9 Delay times and Saving times by scenario 3

	Scenario 1	Scenario 2	Scenario 3	Saving
Sten.- Orust	14.9s	21. 8s	9.9s	11.9s
Sten.- Tjörn	44.7s	59.1s	54.1s	5s
Orust.- Sten.	20.8s	23.1s	27.5s	-4.4s
Tjörn - Sten.	12.7s	12.7s	10.1s	2.6s
TOTAL	93.1s	116.7s	101.6s	15.1s

2.9.3 Queue length

The queue is governing factor for left-turn lane. The data is collected in three aspects, average queue length, maximum queue length and the times of queue formed.

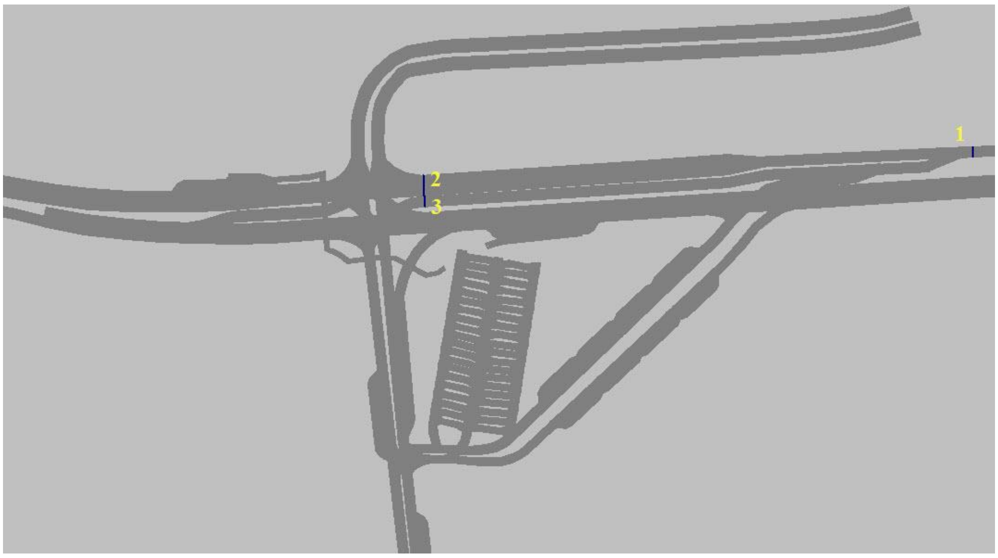


Figure 34 Positions of queue counters

Table 10 Average and maximum queue length

	Through lane(point 2)		Left-turn lane(point 3)		Times of queue formed at point 1
	AVG.	MAX.	AVG.	MAX.	
Scenario 1	5	41	56	251	4
Scenario 2	6	48	132	510	13
Scenario 3	3	32	99	505	9

Three queue counters are placed in the VISSIM model, as figure 34. The results are detailed in table 10. If the queue is formed at point 1, the through or left-turning traffic flow would be blocked. In the evaluation period, there are queues formed 4 times here in scenario 1 which means the traffic is blocked 4 times. In 2030, the scenario 3 provides better situation even the traffic volume grows.

Compared with 2010, both average and maximum queue length in left-turn lane will be approximately doubled in 2030. It can be said the growth of traffic volume is main reason. Building bus terminal reduces average and maximum queue length in a certain level. However, for the through lane, it can be seen that if the bus terminal will be built in 2030, average and maximum queue length would be even shorter than in 2010.

2.9.4 Degree of saturation

The degree of saturation of each approach is obviously increased in 2030 as the traffic volume growth. In 2030, the bus terminal will influence the turning-right lane of 169 road because more buses in and exit.

The saturation degree shows, the traffic quality for direction Stenungsund to Tjörn in all of three scenarios are under very low standard (Olstam et al, 2010), and the new construction is unable to improve this situation.

Table 11 Degree of saturation for static assignment

Approach	160 west			160-east			169-north	169-south	
Movement	RT	T	L	RT	T	L	RTL	R	TL
Scenario1	0.37	0.37	0.02	0.27	0.27	**0.78**	0.11	0.38	0.48
Scenario2	0.42	0.42	0.02	0.30	0.30	**0.89**	0.12	0.43	0.54
Scenario3	0.42	0.42	0.02	0.30	0.30	**0.89**	0.12	0.51	0.54

2.9.5 Delay at intersection

It can be seen that the new construction can reduce the delay time about 3s for each cycle.

Scenario 1 24 s

Scenario 2 25.3 s

Scenario 3 22.2 s

The Level of Service of the intersection is C for all of three scenarios, which based on Highway Capacity Manual (HCM) LOS categorization.

2.10 Back calculation

The original maximum green time is set in this intersection following the suggestion in the LHOVRA, which is the standard of back calculation.

2.11 Cost and benefit

General cost is used for evaluating the economy cost and benefit. The term *general cost* is defined as a combination of distance, travel time and supplement costs (e.g. tolls) (Slinn et al. 2005).

$$\text{General cost} = \alpha\ \text{travel time} + \beta \cdot \text{travel distance} + \gamma\ \text{financial cost} + \sum \text{supplement}$$

- The coefficients α is the value of time (*Tidsvärden* in Swedish). The value of time is not the same between difference suggestions, as table 12. The value is calculated based on the SIKA´s suggestion (SIKA, 2005). Assume all of the heavy vehicles belong to group of business travel and all of the personal cars belong to group of private travel. CPI is considered as 1.3 % per year based on the data publicized by GLOBAL RATES.

Table 12 Suggestive value of time

Suggestive value of time	Personal travel	Bussiness travel
SIKA 2001 (SIKA, 2005)	0.008 SEK/s (4 person in one vehicle)	0.07 SEK/s
Stockholm 2006 (Börjesson et al. 2007)	0.048 SEK/s	0.05 SEK/s
Heßischen 2007 (Bosserhoff,2007)	0.016 SEK/s	0.06 SEK/s

Table 13 Value of time in 2010 and 2030

	Year	Business travel	Private travel
Time value (SEK/vehicle second)	2001	0.07	0.008
Average Consumer Price Index (per year)	2001-2010	1.3%	1.3%
Coefficients α	2010	0.08	0.01
Coefficient α	2030	0.10	0.01

- In this case, the distance depended cost is not taken into account. This simplification is supported by two reasons. Firstly, this cost is directly reflected by the travel time. (*Distance*=$\int velocity\, dt$,). Besides, distance depended cost is much less than time depended cost, e.g. distance depended value 40 times smaller than time depended value (SIKA, 2005). Therefore, in a small region as Tjörn Island, the distance depended cost is a slight issue compared with travel time.

- The financial cost is not considered in this project, because vehicles under three scenarios are supposed to have same financial cost.

- The supplement cost is on the list in order to express the cost which is difficult to be measured. One of the examples is, the time duration in the queue feels longer than the times duration on the freeway, for the psychological view of drivers. Another example is, the saving of delay time is more welcomed than the saving of travel time, because the savings of delay time implies that the travel is easy to expect for drivers (Maister, 2005).

From the result, the difference of travel time before and after adding new construction can be seen, but the supplement price is hard to measure. Therefore, more advantage method should be carried out to calibrate this price, which will be mentioned in Part III

2.12 Recommendation for congestion solution

2.12.1 Delimitation of presenting model

From the result and cost-benefit calculation it can be seen that the congestion sometimes happens during the peak hours in 2030, and this phenomenon gives the economy negative effects. Therefore it is better to suggest some recommendation for the intention of solving this congestion problem.

It is difficult to give a recommendation based on the presented model. The explanation is that a regulation will influence the driver's decision for route alternating and thereby the traffic flow distribution might change as well.

However, in this static model, the distribution of traffic flow in given time interval is manually defined in the model in advance, which is not affected by any other influence. It also means that the driver has no right to choose the route from origin to destination. In other words, vehicles will not be able to choose to go direct next time if they choose turn left this moment, vice versa.

Thereby, the potential traffic flow distribution that could have been formed is also required to be focused for getting a better model. Indeed, if in the potential flow distribution, more vehicles would choose to go straightforward instead of turning left when passing through this intersection, the burden of the left-turn bay would be relaxed.

2.12.2 A hypothetic recommendation

So as to discover the potential traffic flow pattern, we did an in-depth field observation. Finally, we raised a hypothesis that: the revised local road sign may solve the congestion problem in 2030.

In order to display our hypothesis, a dynamic experiment will be carried out from the beginning of part III.

3 Chapter III Sensitivity and impact assessment

3.1 Introduction

In this Chapter, the impact of supplement price brought by new bus terminal will be discussed, according to the results of dynamic model. The relationship between the trip distribution and supplement price needs to be displayed. Finally, a hypothetic recommendation can be confirmed.

3.2 Field observation and Hypothesis

From the field observation, it has been found that there are two routes between Myggnäs and Skärhamn which contains most of the residents of Tjörn Kommun. They are V169 (managed by Trafikverket) and V710 (managed by Tjörn Kommun) (Tjörn Kommun, 2010). They have analogues distance between Myggenäs Korsväg and Skärhamn, but only a few drivers choose to go to Skärhamn through V710.

This riddle is shown clearly in the traffic flow map published by Trafikverket (Appendix 4). The AADT flow passing through V169 is around **10000** as mentioned in Part 1. But at same time, V710 only contains about **1000** AADT flow, ten times less than the flow of V169. The interpretation of why V710 contains so small amount traffic flow is not its capacity limit: V710 is also a two-lane and double direction road, the same as V723, which contains **3000-4000** AADT flow.

Figure 35 V710 (left) and V723 (right)

The answer for the reason why obvious difference of traffic flows passing through the roads sections with same scale is not certain. But one of the hypothetic interpretations is how the road sign effects on the alternatives chosen by the drivers.

As figure 36 shown, the information of the road sign on the section Stenungsund indicates that the only way to Skärhamn is to turn left. No information indicates drivers that they can also arrive at Skärhamn by passing V710 on the intersection at the entrance of V710, as figure 37 shown.

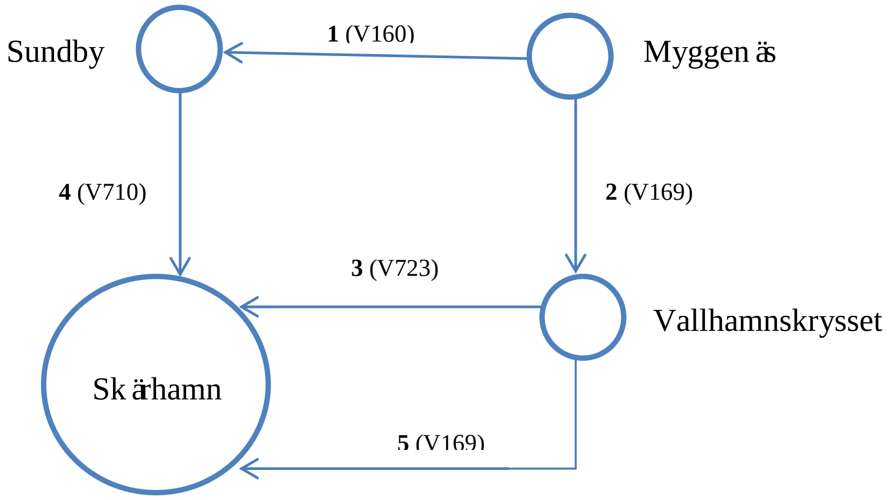
Figure 36 Road sign on the intersection

Figure 37 Entrance of V710

Because V710 also has capacity to carry more traffic load, the traffic flow distribution is able and possible to be changed. It is feasible to let the V710 carry out more traffic load than which of current situation, hence more vehicles would go direct instead of turning left to V169. In other word, **the traffic accessibility is sensitive to external impact**.

In order to display this process, a traffic network is going to be built and the sensitivity analysis will be carried out. The further social economic analysis will base on the sensitivity analysis.

3.3 Sensitivity analysis for network



At the beginning, a simplified network is considered. Firstly, it is assumed in this model, the drivers will choose the route from Myggenäs to Skärhamn as the principle of *rational expectation* where *maximum personal benefit will be fulfilled* (Sargent, 2008). Besides, the traffic demanded from Myggenäs is only considered into the network.

The traffic flow starts from *Orientation* Myggenäs Korsväg and stop at *Destination* Skärhamn is shown as:

$$Q_1 + Q_2 = Q_{MS}\ ; Q_1 = Q_4\ ; Q_2 = Q_3 + Q_5$$

Where Q_{MS} stands for the related traffic demand of Skärhamn via Myggenäs Korsväg, therefore the formulas can be arranged as:

$$Q_1 + Q_2 - Q_{MS} = 0;\ \ Q_1 + Q_3 + Q_5 - Q_{MS} = 0;\ \ Q_2 - Q_3 - Q_5 = 0$$

On the other hand, the equation of total cost can be written as:

$$\mathrm{TC} = \int_0^{Q_1} P_1(Q) \cdot dQ + \int_0^{Q_2} P_2(Q) \cdot dQ + \int_0^{Q_3} P_3(Q) \cdot dQ + \int_0^{Q_4} P_4(Q) \cdot dQ + \int_0^{Q_5} P_5(Q) \cdot dQ$$

To simplify the problem, assume that originally, the prices for all road are the function of travel time and the equation of price is $\mathrm{P} = \alpha t \cdot \mathrm{Q}$. This indicates that the price is going to be higher companying with the traffic flow increasing.

The encouragement of road sign makes the price equation for route 2 changes to:

$\mathrm{P}_2 = \alpha t \cdot \mathrm{Q} - \Delta\mathrm{P}$, in which $\Delta\mathrm{P}$ stands for the priority that road sign gives the left-turn lane.

With the combination of traffic flow equation, the minimum cost under the traffic distribution situation can be calculated by *Lagrange multipliers method*. The method implies, **the total cost reaches the minimum when the traffic flow from Orientation to Destination is fixed**.

$$\left.\begin{aligned}
&TC'_{Q_1} + \lambda(Q_1+Q_2-Q_{MS})'_{Q_1} + \eta(Q_1+Q_3+Q_5-Q_{MS})'_{Q_1} = 0\\
&TC'_{Q_2} + \lambda(Q_1+Q_2-Q_{MS})'_{Q_2} + \eta(Q_1+Q_3+Q_5-Q_{MS})'_{Q_2} + \varepsilon(Q_2-Q_3-Q_5)'_{Q_2} = 0\\
&TC'_{Q_3} + \lambda(Q_1+Q_2-Q_{MS})'_{Q_3} + \eta(Q_1+Q_3+Q_5-Q_{MS})'_{Q_3} + \varepsilon(Q_2-Q_3-Q_5)'_{Q_3} = 0\\
&TC'_{Q_5} + \lambda(Q_1+Q_2-Q_{MS})'_{Q_5} + \eta(Q_1+Q_3+Q_5-Q_{MS})'_{Q_5} + \varepsilon(Q_2-Q_3-Q_5)'_{Q_5} = 0
\end{aligned}\right\}$$

The term TC'_{Q_i} indicates the ***marginal cost***. Before the road sign was built, the equations are written as:

$$\left.\begin{aligned}
&\tfrac{1}{2}\alpha t\cdot 2Q_1\cdot 2+\lambda+\eta=0\\
&\tfrac{1}{2}\alpha t\cdot 2Q_2\ +\lambda+\varepsilon=0\\
&\tfrac{1}{2}\alpha t\cdot 2Q_3+\eta-\varepsilon=0\\
&\tfrac{1}{2}\alpha t\cdot 2Q_5+\eta-\varepsilon=0
\end{aligned}\right\}$$

After the road sign was built as transportation facility, the equations are rewritten as:

$$\left.\begin{aligned}
&\tfrac{1}{2}\alpha t\cdot 2Q_1\cdot 2+\lambda+\eta=0\\
&\tfrac{1}{2}\alpha t\cdot 2Q_2-\Delta p+\lambda+\varepsilon=0\\
&\tfrac{1}{2}\alpha t\cdot 2Q_3+\eta-\varepsilon=0\\
&\tfrac{1}{2}\alpha t\cdot 2Q_5+\eta-\varepsilon=0
\end{aligned}\right\}$$

Without the supplement price Δp, the solution for the equation group is that while $\frac{Q1}{Q2}=\frac{3}{4}$ and $Q_3 = Q_5$, the total cost will reach the minimum value, $\mathbf{0.34\alpha t Q_{MS}^2}$. After adding the supplement price, the solution is while $Q_1=\frac{3}{4}Q_2-\frac{\Delta P}{\alpha t}$, and $Q_3 = Q_5$, the total cost will reach the minimum value.

Compared the solutions of two groups of equations, it is shown that adding supplement price will influence the traffic flow distribution and the minimum cost.

The changing of the price value might lead unpredictable negative effect. For example, if the road sign will decrease the supplement price of road 2 as $\frac{\Delta P}{\alpha t}=0.25Q_2$, therefore $\frac{Q1}{Q2}=\frac{1}{2}$ and the total cost will become $0.44\alpha t Q_{MS}^2$, which is more than the situation without the road sign. On the contrast, if the road sign increase the supplement price of route 2 as $\frac{\Delta P}{\alpha t}=-0.25Q_2$, therefore $\frac{Q1}{Q2}=\frac{1}{1}$, and the total cost will become $0.875\alpha t Q_{MS}^2$, which is more than the situation without road sign as well.

If the road sign is treated as a resource, a paradox is shown from the results, that is, **an adding resource might lead to more social cost**. This thought-provoking phenomenon is the so-called ***Braess Paradox*** (Braess, 1968).

The interpretation of this paradox formed in this project is, if the supplement price decreasing for road 2 will lead more traffic flow going through this way. But this part of flow will distribute into road 3 and road 5, as the situation that supplement price is not changed. This excess flow will increase the travel time and the cost related to road 3 and road 5, thereby the total cost is increased.

If the supplement price increase for road 2 it will lead to more traffic flow going through road 1 and road 4. This excess flow will increase the travel time and cost related to road 1 and road 4, thereby the total cost is increased.

In this model, the isolated intersection is replaced by coordinated traffic network. Therefore the variation of traffic distribution could be reflected by a new regulation or recommendation. From this perspective, the model can be regarded as a ***traffic flow sensitivity model*** as well.

3.4 Experiment design

3.4.1 Challenge for the experiment

In order to apply the sensitivity model to solve the practical problem, three delimitations should be overcome:

1. The *rational traffic distribution* is not easy to define.
2. Even though the rational traffic distribution is already known, the drivers not always follow it because they don't always make the proper decision.
3. The *supplement price* is difficult to measure. The supplement price sometimes could be the driver's evaluation (i.e. how driver dislike the congestion could be expressed as supplement price) or the adjustment of the model (an extra supplement price can be seen as extend of travel time).

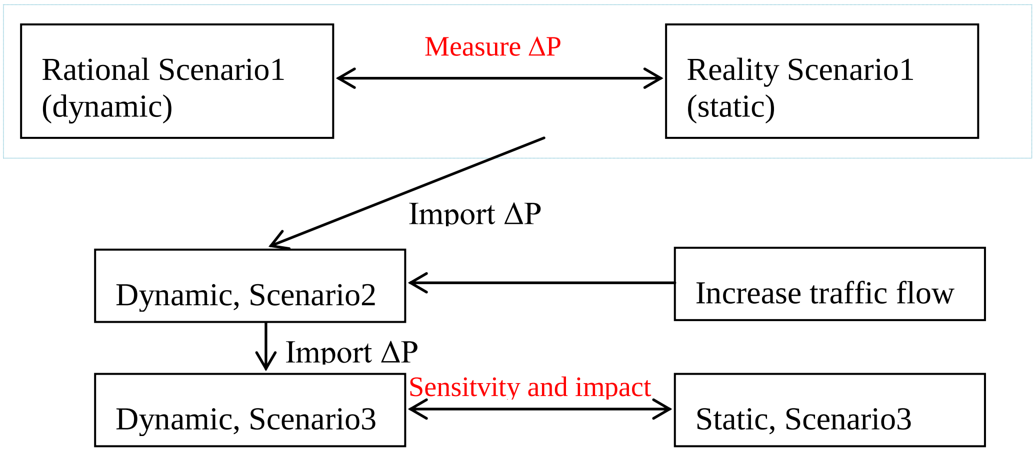
3.4.2 Specific of this experiment

Table 14 Example to explain the difference between fix-time and real time signal

	Step1	Step2	Steady flow
Fix time signal	3car:3car	2car: 4car	3car:3car
Real time signal	3car:3car	2car: 4car	2car:4car

This experiment combines the real time signal and real time route choice together. The real time signal will influence the real time route choice. For example, at the first time step, 3 cars pass through straight route and 3 pass through left-turn lane. At second time step, after more optimal choice, 2 cars pass through the straight route and 4 cars pass through left-turn lane. But at this situation, the 4 cars have high probability of congestion and forming queue. This would lead the optimal choice returning to the ratio of 3cars: 3cars at the third time step. However, if the vehicle actuated program applied, this four cars have higher probability enable to pass the left-turn lane without congestion under the real time control signal. Therefore, the optimal ratio of traffic distribution at the third time step will also remain at 2cars:4cars.

3.4.3 Experiment plan



1. Develop the static models which have been built in Part I and Part II to dynamic network models. The vehicles generated at Stenungsund are partitioned based on the number of residents of each sub-community. Traffics generated on opposite directions remain the same as before. **The traffic distribution in the dynamic network model for Scenario 1 is assumed as rational traffic distribution and the difference between drivers' decision and rational model is covered by iterative process supported by VISSIM algorithm**.

2. Add and adjust the supplement price Δp until Dynamic (Rational) Scenario 1 has the same traffic distribution as Static Scenario 1. Then record Δp, this supplement price implies the synthesis of two issues:

   (1) **The adjustment of model limitation**. An Adding price could be equivalent to move the place of sub-communities to a further location.

   (2) **Reflect the efficiency of externalities**. The externalities mainly include the psychological congestion aversion and the road sign effect for drivers under present situation.

3. Import this supplement price Δp into Dynamic Scenario2 with more flow added, and ensure that intersection configuration and supplement price are maintained. Then, this supplement price is going to be imported into Scenario 3.

   Compare the traffic distribution and the quality of intersection with Static Scenario 3 to analyze the sensitivity of traffic flow distribution and the impact of the new construction.

3.4.4 The definition of externalities of being measured

The reason we compare the Dynamic Scenario 3 with Static Scenario 3 is to calibrate the impact and sensitivity from the externalities of new bus terminal. Externality stands for the value which not transmitted through price. For example, as a factory, the goods they produce is not its externalities, the externality is like the air pollution they causes.

In this project, the externality is defined as a psychological value, which expresses how the new bus terminal impacts the travellers' behaviour. Other factors, such as time value, are not included because they have already been evaluated.

Here in Static Scenario 3, the bus terminal is effective only after the traffic has been already assigned as 1:1 into the system. But in Dynamic Scenario 3, the bus terminal would impact the decision of the drivers. In this way, the externalities can be calibrated.

3.4.5 Algorithm

The algorithm is supported by VISSIM DYNAMIC MODEL. With this model, the simplified model mentioned in Chapter 3.3 is in-depth developing.

Step 1. ***Build network*** including *Orientations*, *Destinations*, *Links* and *Nodes*.

Step 2. ***Evaluate Traffic Demand***. The collection of OD pairs can be written as *OD matrix*. Gravity formula is used here.

Step 3. ***Route Search***. Route search is based on the ***principle of minimum cost***.

Step 4. Route choice. However, in the reality, drivers are not hundred percent choosing the route with minimum cost. This human behaviour is simulated by ***Logit Model***.

Step 5. Iteration process. The step 3 to step 4 will be repeated at every time step.

3.5 Network structure

3.5.1 Subzones Division

In the dynamic assignment, the geometry model for the road network of Tjörn community is built on the basis of the map published by Trafikverket. Considering the population statistics which can be seen in table 15 (Statistics Sweden, 2009), the geometry model simplifies Tjörn Kommun into 7 zones, and the geometry boundary of the network is defined in a 10*10 km frame, as figure 39.

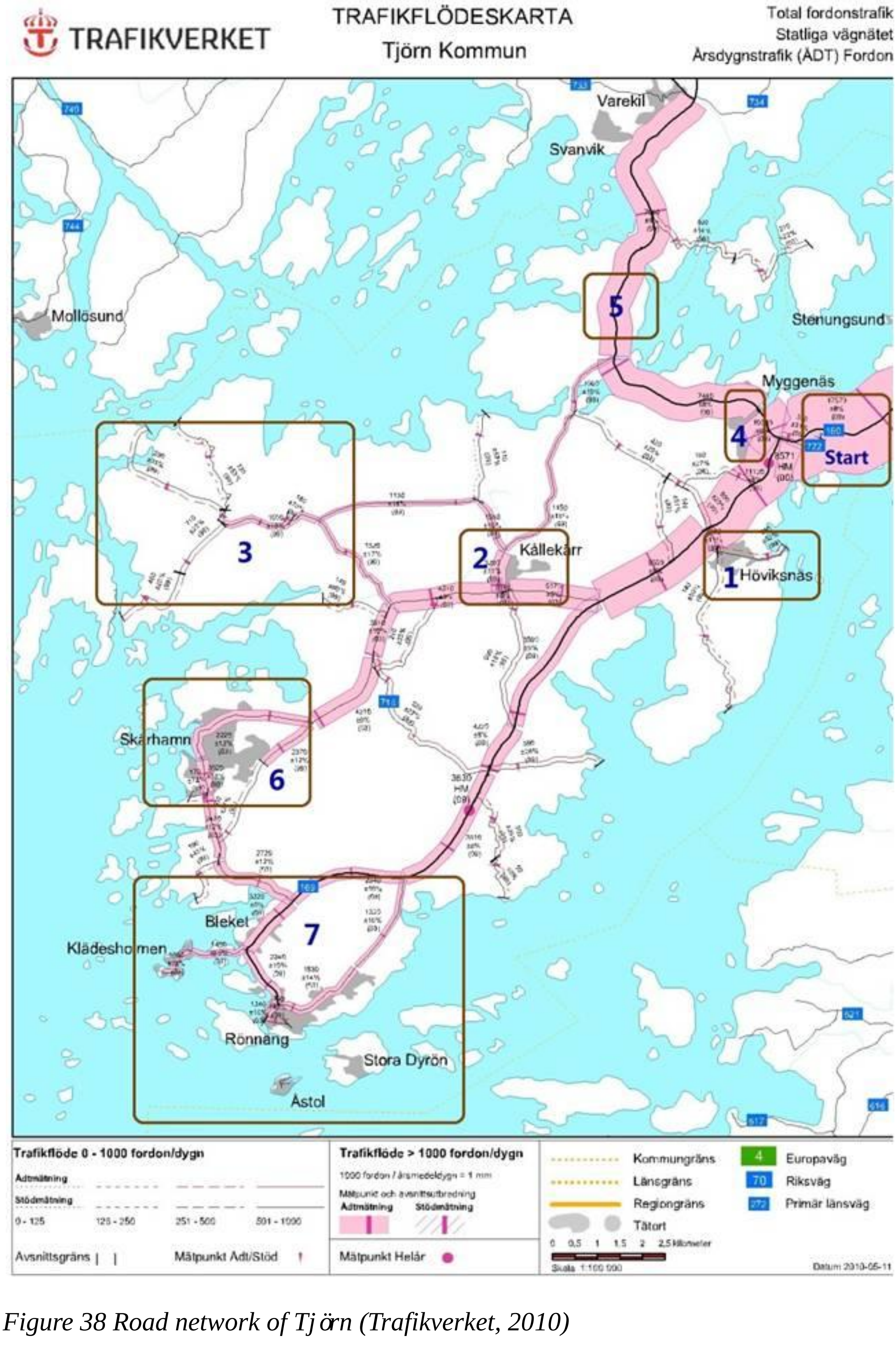


Figure 38 Road network of Tjörn (Trafikverket, 2010)

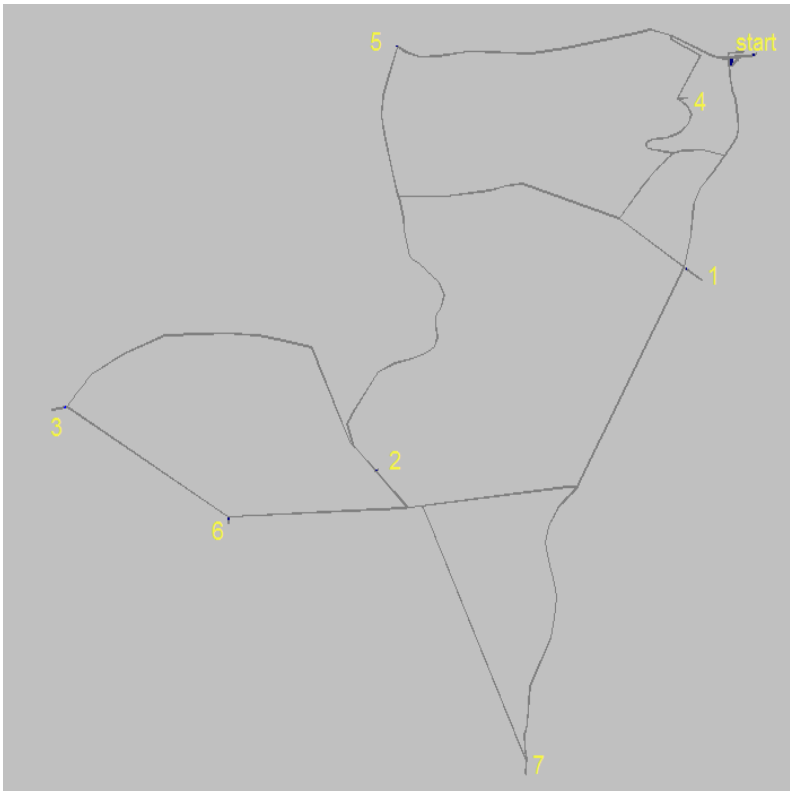


Figure 39 Geometry boundary of network

Table 15 Population statistics in Tjörn

Zone	1	2	3	4	5	6
Name	Höviksnäs	Kålekärr	Kyrkesund	Myggenäs	Orust	Skärhamn
Residents	480	863	5000	389	7654	10129
Percentage	0.02	0.03	0.18	0.01	0.28	0.37
Zone	7*					
Name	StoraDyrön	Åstol	Bleket	Klädesholmen	Rönnäng	TOTAL
Residents	215	850	915	474	225	27194
Percentage	0.01	0.03	0.03	0.02	0.01	1.00

**Stora Dyrön, Åstol, Bleket, Klädesholmen and Rönnäng are altogether regarded as zone 7*

3.5.2 Traffic distribution

For the simulation of dynamic assignment, the traffic volume is specified by *origin-destination matrices (O-D matrices)* which contain information of information for a certain traffic composition in a certain time interval.

The vehicles from Stenungsund are distributed to 7 zones. The distribution method is *Gravity Assumption* (Slinn et al, 2005). Since the region is small, the *distance* is not viewed as the effective parameter, therefore the traffic generated at Stenungsund are distributed into each 7 zones only based on the population proportion of each destination. The OD matrices can be seen in Appendix 5.

Because the traffic volume generated in 7 zones and toward Myggnäs intersection are not to be estimated, the traffic flow from western V160 and V169 is still statically. It means the trip distribution of these vehicle are manual and don't obey the rules of dynamic route search and choice.

Table 16 Distribution of traffic flow from Stenungsund (vehicle/hour)

Zone	1	2	3	4	5	6	7	Total
Percentage	0.02	0.03	0.18	0.01	0.28	0.37	0.1	1.0
Traffic volume 2010	21	38	222	17	340	450	119	1209
Traffic volume 2030	24	43	249	19	381	504	133	1358

3.6 Route search

It is hard to know the set of n best routes for each Origin-Destination-pair by algorithm. Hence this problem has to be solved by searching the best route for each O-D-pair step by step, during each iteration cycle in dynamic assignment. In this process, traffic situation and travel times would change after each iteration cycle. When the convergence criteria is fulfilled, and different best routes might be found.

3.7 Calibrate Supplement Price

Supplement price is placed on south branch of V169. The burden of this price is carried on the vehicles that passing through this specific section. This cost can stand for both real cost or conception cost. Real cost includes the toll cash, congestion fee etc; and conception cost can be viewed as an evaluation made by drivers or an equivalent price, for example a driver don't want to driving through congestion road section as if it cost his money. In this experiment, this weight of this value is calibrated by the difference between real traffic flow distribution (static model 2010) and ideal traffic flow distribution (dynamic model 2010) before it used as criterion in 2030 model. **The result of the measurement is ΔP=0.32KR/vehicle**.

3.8 Route choice

Assume that not only everybody uses the best route but that less attractive routes are also used by a minor part of the drivers. When a set of routes and their general cost are known, the *Logit* model is used to handle route choice (PTV, 2009).

$$p(R_j) = \frac{U_j^k}{\sum_i U_i^k} = \frac{e^{k\log U_j}}{\sum_i e^{k\log U_i}} = \frac{e^{-k\log C_j}}{\sum_i e^{-k\log C_i}}$$

$$U_j = \frac{1}{C_j}$$

Where,

U_j= utility of route j

C_j = general cost of route j

$P(R_j)$= probability of route j to be chosen

K= sensitivity of the model

The sensitivity k determines how much influence the difference in utility have, while the relative difference in utility determines the distribution. The very low sensitivity factor would lead to rather equal distribution among the routes, and the higher factor forces more drivers choose best route.

3.9 Iterated process and convergence criteria

The iteration process is lasting until a stable situation is achieved, which is called convergence. If the change of travel time on paths is lower than 15% compared to its travel time in previous run and the absolute difference of old and new volume on edges is less than 15 vehicles, the convergence is fulfilled.

3.10 Result analysis

3.10.1 **Trip distribution**

The trip distribution during half of peak hour (16:15-- 16:45) from Stenungsund includes straightaway and left-turning in dynamic assignment. The first quarter and last quarter are excluded because the traffic flow distribution is still unstable.

It is shown that, while the route search and choice are based on general cost which is relative with travel time, more vehicles would choose to go straightaway comparing with scenario 1. For scenario 3, the straightaway vehicles apparently take larger part than static model for scenario 3 which also follow the traffic distribution of 2010.

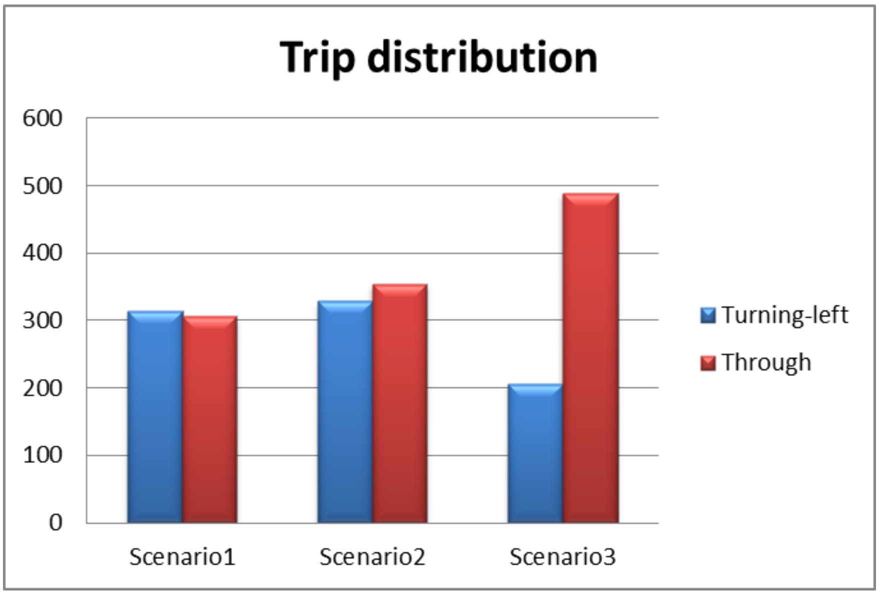


Figure 40 Trip distribution in dynamic model

Table 17 Trip distribution in dynamic model compared with static model

	Scenario 1	Scenario 2	Scenario 3
	straight:left	straight:left	straight:left
Static	102:100	102:100	102:100
Dynamic	97:100	107:100	42:100

3.10.1.1 Impact of Bus terminal

Interpretation of supplement price

This phenomenon implies, for scenario 3, the cost vehicle spent through the left-turn bay is higher, therefore more vehicles will avoid to go this way and choose driving straightway instead. Compared Scenario 2 with Scenario 3, the only change is the new bus terminal. Hence, it indicates that the bus terminal changes the travel cost of left-turning route.

Table 18 Supplement price

Supplement price	Scenario 2	Scenario 3
Value	0.32	0.32+adding supplement price
Driver's Evaluation	OK	Too high
Influencing factors to supplement price	➢ Model adjustment ➢ Road sign ➢ Congestion aversion	➢ Model adjustment ➢ Road sign ➢ Congestion aversion ➢ Bus terminal

Observe the influencing factors to the supplement price. For scenario 1 and 2, the factors generally include the adjustment of model limit, the road sign, and driver's congestion aversion. For Scenario 3, bus terminal is added which will influence the new supplement price from following aspects:

1. More travel time and delay time are supposed to be consumed by bus terminal, which is regarded as internality change.
2. The configuration of intersection become more complicated and the travel time will be longer for personal car after the new bus terminal finished, therefore the drivers' congestion aversion increase, which is regarded as externality change.

Actually, the new supplement price in scenario 3, 0.32+ adding supplement prices, is too high to drivers so they choose cheaper route to arrive at destination. This explains why the number of driver choosing straightway in dynamic scenario3 is obviously increased.

It also can be seen that, this adding supplement price includes both internalities which don't change the trip distribution and externalities which change the distribution caused by bus terminal. **In other words, part of the adding price reflects the internality.** Therefore, in order to measure how bus terminal impact the trip distribution, it not suitable to compare Dynamic Scenario 2 with Dynamic Scenario3. Instead, we are going to adjust the supplement price of Dynamic Scenario 3 until the traffic distribution is the same as Static Scenario 3.

The value of impact, marginal cost and sensitivity

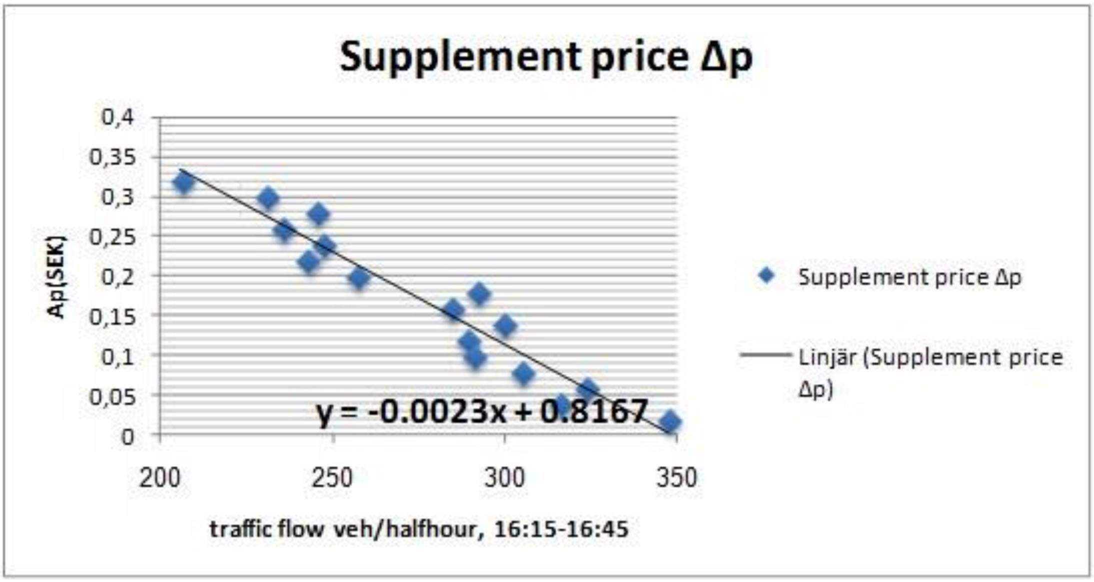


Figure 41 Supplement price and left-turning traffic flow

More vehicles are going to choose to pass through left-turn lane while the supplement price in Scenario 3 is decreased, and the relative data are collected in figure 41. The price is decreased as a 0.02SEK per step. When the price turns down to 0.02SEK, the dynamic scenario 3 shares the same trip distribution (1:1) with static model.

Therefore, the impact of the bus terminal is calibrated as about **0.3 SEK** per vehicle in peak hours. Furthermore, if an accordingly trend line is added, therefore the marginal cost for vehicles is approximately equal to **0.0046 SEK** and the sensitivity of the bus terminal can be expressed as the term of *Elastic*:

$$E=-\frac{d(\Delta P)/_{\Delta P}}{dQ/_{Q}}$$

And the result shows the elasticity is equal to 1.88. The elasticity is more than 1, which shows the traffic distribution and the drivers' alternative are **very sensitive** and the bus terminal might not cause so much congestion.

3.10.2 **Travel time**

It reveals that the travel time route of Stenungsund-Tjörn has shorter travel time in scenario 3. But in all of three dynamic approaches, the travel time is apparently increased. The possible reason is that the vehicles from the western V160 and V169 road are assigned statically.

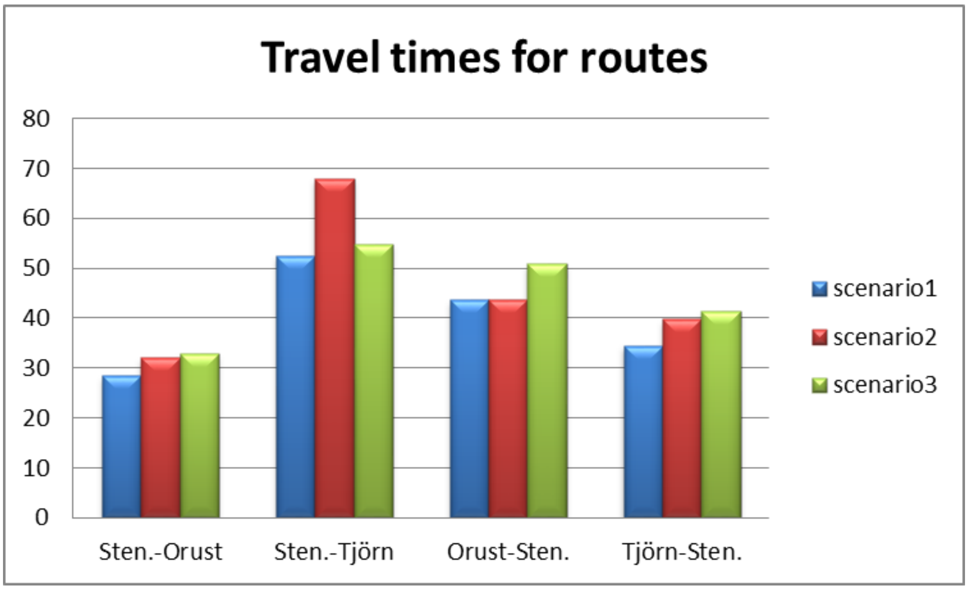


Figure 42 Travel times for different routes produced by dynamic model

Table 149 Travel times and Saving times by scenario 3

	Scenario 1	Scenario 2	Scenario 3	Saving
Sten.- Orust	28.5s	32.1s	32.9s	-0.8s
Sten.-Tjörn	52.5s	68s	54.9s	13.1s
Orust- Sten.	43,6s	43.8s	50.8s	-7s
Tjörn- Sten.	34.5s	39.8s	41.3s	-1.5s
Total	159.1s	183.7s	179.9s	3.8s
Static Total	191.1s	213.1s	206s	7.1s

3.10.3 **Delay time**

More delay time is produced for every route in scenario 2 than in scenario 1. However, the delay times of three routes is reduced in scenario 3.

For all of routes, the delay time in the dynamic model is evidently less than in static model.

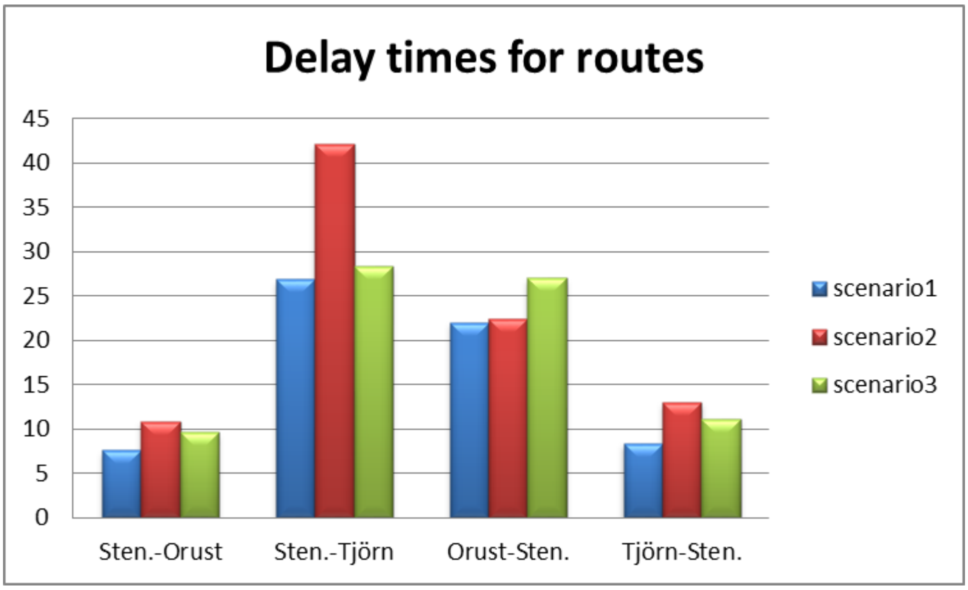


Figure 43 Delay times for different routes produced by dynamic model

Table 20 Delay times and Saving time by scenario 3

	Scenario 1	Scenario 2	Scenario 3	Saving
Sten.- Orust	7.6s	10.9s	9.6s	1.3s
Sten.- Tjörn	26.9s	42.2s	24.8s	17.4s
Orust.- Sten.	22s	22.4s	27.0s	-4.6s
Tjörn - Sten.	8.4s	13.0s	11.2s	1.8s
Total	64.9s	88.5s	72.7s	15.8s
StaticTotal	96.1s	116.7s	101.6s	15.1s

3.10.4 **Queue**

In the table 21, it shows the difference among the three scenarios. The traffic volume assigned dynamically gives a shorter queue length when the bus terminal existed. The road section with signal lane will not be blocked anymore.

Table 21 Average and maximum queue lengths

	Through lane(point 2)		Left- turn lane(point 3)		Times of queue formed at point 1
	AVG.	MAX.	AVG.	MAX.	
Scenario 1	1.6	26.8	28.3	209	2
Scenario 2	2.3	32.0	67.8	314	9
Scenario 3	3.0	59.9	16.5	112	0

3.10.5 **Degree of saturation**

The degree of saturation for left-turn lane of eastern V160 is decreased from 0.86 to 0.54 and through lane increased from 0.31 to 0.42 because trip distribution is changed in scenario 3 as mentioned above.

Table 22 Degree of saturation for dynamic assignment

Approach	160 west			160-east			169-north	169-south	
Movement	RT	T	L	RT	T	L	RTL	R	TL
Scenario1	0.37	0.37	0.02	0.27	0.27	**0.78**	0.11	0.38	0.48
Scenario2	0.42	0.42	0.02	0.31	0.31	**0.86**	0.12	0.43	0.54
Scenario3	0.42	0.42	0.02	0.42	0.42	**0.54**	0.12	0.51	0.54

3.10.6 **Delay at intersection**

Scenario 1 15.1 s

Scenario 2 19.5 s

Scenario 3 14.8 s

For the dynamic assignment, the Level of Service of this intersection is LOS B. The level is better than Static Scenario 3.

3.11 Recommendation

3.11.1 **Upgrade the Sundby intersection**

Consider more traffic flow might pass through the Sundby intersection, the Sundby intersection need to be upgraded to deal with this. For example, traffic signal system is one option on that intersection.

3.11.2 **A revised road sign**

A combined directional sign can be used instead of the current one, the destination Skärhamn is better to be marked at both left-turning and straight away direction. Hence the travellers can have more flexibility and accessibility from Myggenäs Korsväg to Skärhamn.

3.11.3 **Questionnaires**

The main delimitation of this trial is the insufficiency of the data. Even the inaccuracy of traffic network is complemented by Dynamic Scenario1; the value of time for travellers is controversy. The value of the time often has profound effects on traffic flows, travel times and anticipated revenues (Börjesson et al, 2007). Therefore, we recommend carrying out an in-depth survey such as questionnaires to investigate the travellers' attitude about this new construction in order to evaluate the time value. The questionnaire is approximately includes 3 questions:

1. Do you think the bus terminal will lead to more congestion?
2. How do you consider the differences between route Myggenäs-Sundby-Skärhamn and Myggenäs-Vallhamnkryset-Skärhamn?
3. Will you prefer going to Skärhamn via Sundby if the left-turn lane occurs congestion?

3.12 Conclusion and discussion

3.12.1 **The endless work to mirror the reality by simulation**

In this project, three iterative programs are applied in order to approach to the current situation and future situation. However, the real world is very complicated and develops all the time therefore the simulation model can't mirror the reality exactly. The function of these three programs will basically remain the same even the parameters of the programs would have been change depend on each specific situation. Thereby the way one can use the creation produced by this thesis accompanied with proper parameters and continuously data calibration.

3.12.2 **The gap between the empirical and rational route choice**

There would have been external debate for the alternative between the empirical methodology and rational methodology, since the time of ancient Greek, when Aristotle criticism against Plato. Even more, in the late 17th century through 18th, British philosophers such as John Lock, George Berkley and David Hume try to demonstrate and develop the methodology of empiricism and at the same time, continental philosophers such as Réne Descartes, Baruch Spinoza and Von Leibniz, who argue that the world is dominated by reason and wisdom. This famous debate is so-called the debate between and British Empiricism and Continental Rationalism (Zalta et al, 2008).

This debate extends to the discussion whether drivers make their decision depend upon experience or cost. In this project, two groups of results are got from the static and dynamic models respectively. Following the theory of rational expectation, the alternative between these two groups of models depends on how much the information is widely known for drivers, that is, if the correct information is wider realized by drivers, the dynamic model is preferable (Sargent, 2008).

3.12.3 **The continuous framework for the model optimization**

A lasting OD survey is necessary to improve the accuracy of this project through optimizing the data, parameters continuously even the situation that not mentioned in this paper occurs. Several kinds of survey frameworks for obtaining the schedule of travellers, households can be taken here, which stated in the book *"Traffic and mobility"* published by Springer.

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5 Appendixes

5.1 Appendix 1

The traffic flow was recorded every 15 mins during the evening peak hour (16:00-17:00). The locations of counter devices are depicted as figure 22. So the traffic volumes from each approach and traffic distribution are both obtained. The average numbers are input in “Vehicle Input” and “Routing Decision” of VISSIM model.

Approach	Direction	Time	12/01	12/02	12/03	12/04	12/07	12/08	12/09	Average
A	A	0	284	289	281	304	269	300	284	287
		15	299	292	325	298	323	312	368	317
		30	314	288	295	336	301	297	355	312
		45	335	270	300	310	291	302	241	293
	A-B	0	121	121	133	160	152	169	155	144
		15	136	134	163	176	190	181	167	164
		30	107	128	114	175	183	163	213	155
		45	161	96	120	161	162	158	131	141
	A-C	0	163	168	148	144	117	131	129	143
		15	163	158	162	122	133	131	201	153
		30	207	160	181	161	118	134	142	158
		45	174	174	180	149	129	144	110	151

B	B	0	104	98	98	110	106	99	117	105
		15	121	121	119	129	111	115	145	123
		30	107	83	109	77	106	104	110	99
		45	77	102	81	79	73	104	107	89
	B-C	0	25	18	4	22	26	24	35	22
		15	12	13	14	29	29	24	30	22
		30	23	17	13	20	30	26	21	21
		45	10	27	7	14	16	30	25	18
	B-A	0	79	80	94	90	93	78	94	87
		15	109	108	105	98	78	90	110	100
		30	84	66	96	67	82	93	90	83
		45	67	75	74	67	52	75	95	72
C	C	0	77	67	72	81	68	67	100	76
		15	82	80	72	72	76	89	90	80
		30	68	87	67	69	72	83	87	76
		45	53	60	75	75	60	74	79	68

	C-A	0	54	45	52	59	43	54	61	53
		15	52	58	50	46	55	67	64	56
		30	46	67	47	45	53	52	66	54
		45	40	34	53	51	37	46	49	44
	C-B	0	23	22	20	22	25	13	39	23
		15	30	22	22	26	21	22	26	24
		30	22	20	20	24	19	31	21	22
		45	13	26	22	24	23	28	30	24

5.2 Appendix 2

*.pua file is one of important files for completing the real time signal control program. It contains the information about interstages, in which the phases are defined and intergreen times are determination as well when the phase change occurs.

```
$SIGNAL_GROUPS
$
K1      1
K2      2
K3      3
K4      4
K5      5
K6      6
K7      7
F1      8
F2      9
F3      10
F4      11

$STAGES
Stage     Signal group
$
Stage_1         K1 K5 F1 F2
red              K2 K3 K4 K6 K7 F3 F4
Stage_2         K1 K2 K3
red                  K4 K5 K6 K7 F1 F2 F3 F4
Stage_3      K3 K4 K7 F3 F4
red             K1 K2 K5 K6 F1 F2
Stage_4      K5 K6 F1 F2
red             K1 K2 K3 K4 K7 F3 F4

$STARTING_STAGE
$
Stage_1

$INTERSTAGE
INTERSTAGE_number :     1
length [s]     :     8
from stage     :     1
to stage     :     2
```

$
K2 2 127
K3 4 127
K5 -127 0
F1 -127 0
F2 -127 0

$INTERSTAGE
INTERSTAGE_number : 2
length [s] : 8
from stage : 1
to stage : 3
$
K4 5 127
K3 4 127
K7 5 127
K1 -127 0
K5 -127 0
F1 -127 0
F2 -127 0
F3 8 127
F4 8 127

$INTERSTAGE
INTERSTAGE_number : 3
length [s] : 8
from stage : 1
to stage : 4
$
K6 1 127
K1 -127 0

$INTERSTAGE
INTERSTAGE_number : 4
length [s] : 8
from stage : 2
to stage : 3
$
K1 -127 0

K2 -127 0

K4 4 127

K7 5 127

F3 8 127

F4 8 127

$INTERSTAGE

INTERSTAGE_number : 5

length [s] : 8

from stage : 2

to stage : 4

$

K1 -127 0

K2 -127 0

K3 -127 0

K5 4 127

K6 1 127

F1 7 127

F2 7 127

$INTERSTAGE

INTERSTAGE_number : 6

length [s] : 8

from stage : 2

to stage : 1

$

K2 -127 0

K3 -127 0

K5 4 127

F1 7 127

F2 7 127

$INTERSTAGE

INTERSTAGE_number : 7

length [s] : 9

from stage : 3

to stage : 4

$

K4 -127 0

K3 -127 0
K6 9 127
K5 9 127
K7 -127 0
F3 -127 0
F4 -127 0
F1 8 127
F2 8 127

$INTERSTAGE
INTERSTAGE_number : 8
length [s] : 9
from stage : 3
to stage : 1
$
K1 5 127
K5 9 127
F1 8 127
F2 8 127
K3 -127 0
K4 -127 0
K7 -127 0
F3 -127 0
F4 -127 0

$INTERSTAGE
INTERSTAGE_number : 9
length [s] : 8
from stage : 3
to stage : 2
$
K4 -127 0
K1 5 127
K2 5 127
K7 -127 0
F3 -127 0
F4 -127 0

$INTERSTAGE

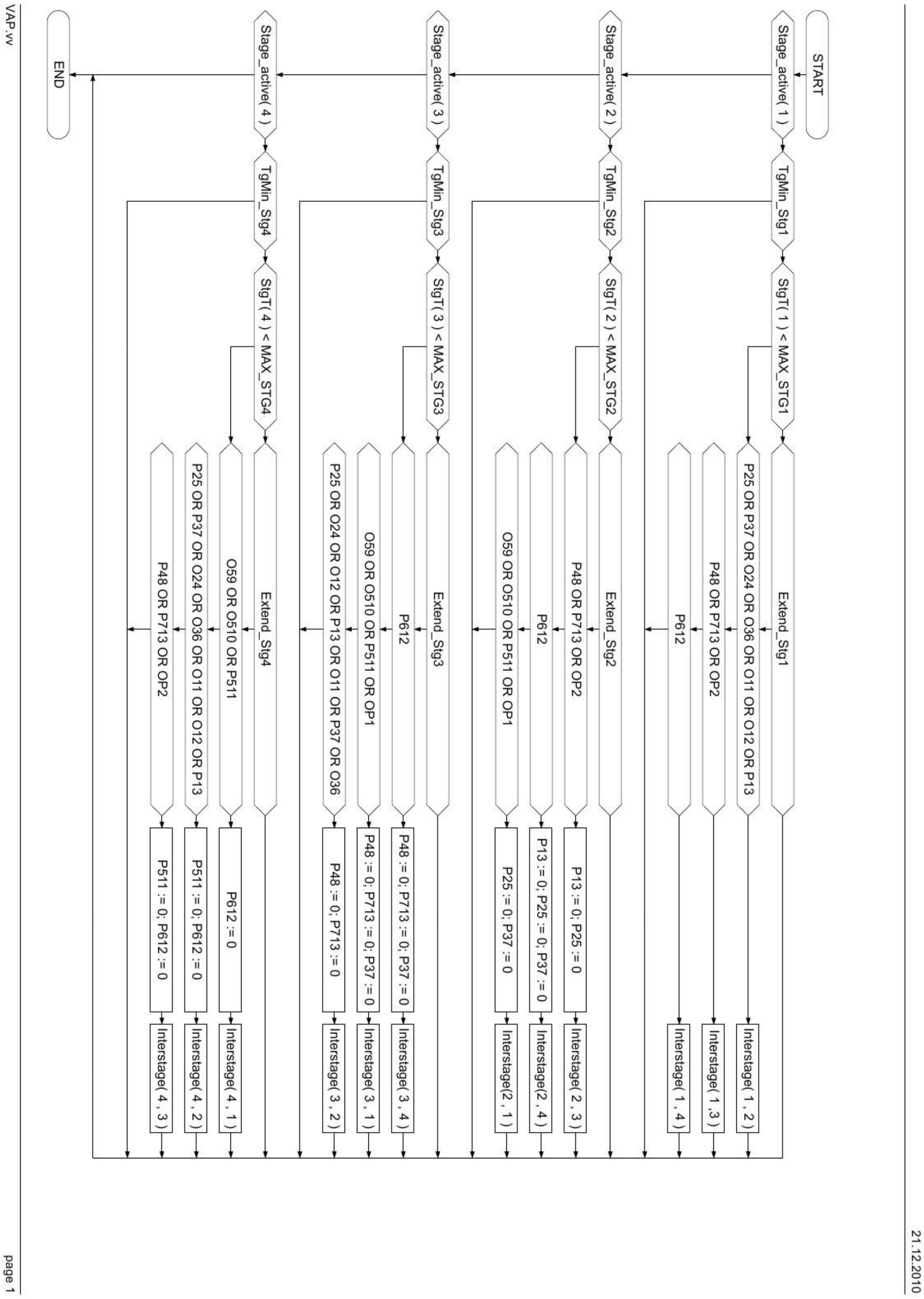
INTERSTAGE_number : 10
length [s] : 8
from stage : 4
to stage : 1
$
K6 -127 0
K1 5 127

$INTERSTAGE
INTERSTAGE_number : 11
length [s] : 8
from stage : 4
to stage : 2
$
K6 -127 0
K5 -127 0
K1 5 127
K2 2 127
K3 4 127
F1 -127 0
F2 -127 0

$INTERSTAGE
INTERSTAGE_number : 12
length [s] : 8
from stage : 4
to stage : 3
$
K6 -127 0
K5 -127 0
K4 8 127
K7 4 127
K3 4 127
F1 -127 0
F2 -127 0
F3 8 127
F4 8 127
$END

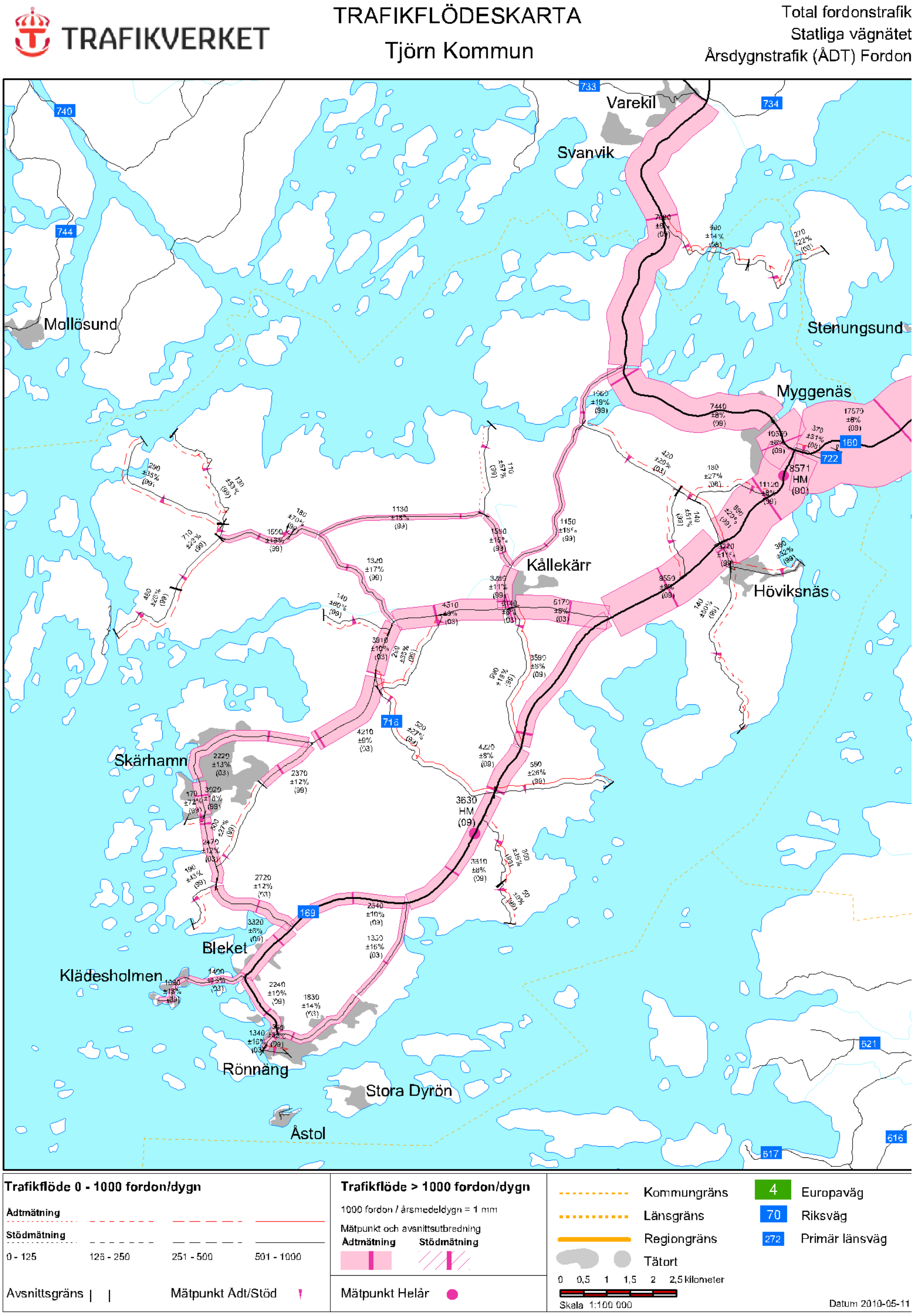
5.3 Appendix 3

*.pua file is one of important files for completing the real time signal control program. It contains the information about interstages, in which the phases are defined and intergreen times are determination as well when the phase change occurs.



Expressions	Contents
TgMin_Stg1	(Tg(K1) >= Tgmin(K1)) & (Tg(K5) >= Tgmin(K5)) & (Tg(F1) >= Tgmin(F1)) & (Tg(F2) >= Tgmin(F2))
P25	Presence(DK25) OR P25
P37	Presence(DK37) OR P37
O24	Occupancy (DK24) > 0
O11	Occupancy (DK11) > 0
OP1	Occupancy (Pe1) > 0
OP2	Occupancy (Pe2) > 0
O36	Occupancy (DK36) > 0
Extend_Stg1	(Headway(DK511) <= MAX_GAP) OR (Headway(DK510) <= MAX_GAP) OR (Headway(DK59) <= MAX_GAP)
TgMin_Stg2	(Tg(K2) >= Tgmin(K2)) & (Tg(K3) >= Tgmin(K3)) & (Tg(K1) >= Tgmin(K1))
Extend_Stg2	(Headway(DK13) <= MAX_GAP) OR (Headway(DK12) <= MAX_GAP) OR (Headway(DK11) <= MAX_GAP) OR (Headway(DK24) <= MAX_GAP) OR (Headway(DK25) <= MAX_GAP) OR (Headway(DK36) <= MAX_GAP) OR (Headway(DK37) <= MAX_GAP)
P48	Presence(DK48) OR P48
P713	Presence(DK713) OR P713
TgMin_Stg3	(Tg(K4) >= Tgmin(K4)) & (Tg(K3) >= Tgmin(K3)) & (Tg(K7) >= Tgmin(K7)) & (Tg(F3) >= Tgmin(F3)) & (Tg(F4) >= Tgmin(F4))
Extend_Stg3	(Headway(DK48) <= MAX_GAP) OR (Headway(DK713) <= MAX_GAP)
O59	Occupancy(DK59) > 0
O510	Occupancy(DK510) > 0
P612	Presence(DK612) OR P612
P511	Presence(DK511) OR P511
TgMin_Stg4	(Tg(K5) >= Tgmin(K5)) & (Tg(K6) >= Tgmin(K6)) & (Tg(F1) >= Tgmin(F1)) & (Tg(F2) >= Tgmin(F2))
Extend_Stg4	(Headway(DK612) <= MAX_GAP)
O12	Occupancy(DK12) > 0
P13	Presence(DK13) OR P13

5.4 Appendix 4



5.5 Appendix 5

OD matrix is imported to dynamic assignment model as vehicle input. It defines the traffic volume between the origin and destination within certain interval. The different vehicle type needs to be defined separately.

The private car in 2010:

*time interval in hour 0.0 0.15 *scaling factor 1 *Number of zones： 8 *zones： 43 45 47 49 51 53 55 57 *number of trips between zones 0 5 4 9 50 102 27 77 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	*time interval in hour 0.15 0.30 *scaling factor 1 *Number of zones： 8 *zones： 43 45 47 49 51 53 55 57 *number of trips between zones 0 5 4 9 54 110 29 83 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
*time interval in hour 0.30 0.45 *scaling factor 1 *Number of zones： 8 *zones： 43 45 47 49 51 53 55 57 *number of trips between zones 0 5 4 9 54 110 29 83 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	*time interval in hour 0.45 0.60 *scaling factor 1 *Number of zones： 8 *zones： 43 45 47 49 51 53 55 57 *number of trips between zones 0 5 4 9 50 102 27 77 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0

The HGV in 2010

*time interval in hour 0.0 0.15 *scaling factor 1 *Number of zones： 8 *zones： 43 45 47 49 51 53 55 57 *number of trips between zones 0 0 0 1 3 7 2 5 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	*time interval in hour 0.15 0.30 *scaling factor 1 *Number of zones： 8 *zones： 43 45 47 49 51 53 55 57 *number of trips between zones 0 0 0 1 3 7 2 5 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
*time interval in hour 0.30 0.45 *scaling factor 1 *Number of zones： 8 *zones： 43 45 47 49 51 53 55 57 *number of trips between zones 0 0 0 1 3 7 2 5 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	*time interval in hour 0.45 0.60 *scaling factor 1 *Number of zones： 8 *zones： 43 45 47 49 51 53 55 57 *number of trips between zones 0 0 0 1 3 7 2 5 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0

The private car in 2030

*time interval in hour 0.0 0.15 *scaling factor 1 *Number of zones： 8 *zones： 43 45 47 49 51 53 55 57 *number of trips between zones 0 5 4 9 55 111 29 84 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	*time interval in hour 0.15 0.30 *scaling factor 1 *Number of zones： 8 *zones： 43 45 47 49 51 53 55 57 *number of trips between zones 0 6 5 10 59 120 32 91 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
*time interval in hour 0.30 0.45 *scaling factor 1 *Number of zones： 8 *zones： 43 45 47 49 51 53 55 57 *number of trips between zones 0 6 5 10 59 120 32 91 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	*time interval in hour 0.45 0.60 *scaling factor 1 *Number of zones： 8 *zones： 43 45 47 49 51 53 55 57 *number of trips between zones 0 5 4 9 55 111 29 84 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0

The HGV in 2030:

*time interval in hour 0.0 0.15 *scaling factor 1 *Number of zones： 8 *zones： 43 45 47 49 51 53 55 57 *number of trips between zones 0 0 0 1 5 10 3 8 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	*time interval in hour 0.15 0.30 *scaling factor 1 *Number of zones： 8 *zones： 43 45 47 49 51 53 55 57 *number of trips between zones 0 1 0 1 5 11 3 8 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
*time interval in hour 0.30 0.45 *scaling factor 1 *Number of zones： 8 *zones： 43 45 47 49 51 53 55 57 *number of trips between zones 0 1 0 1 5 11 3 8 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	*time interval in hour 0.45 0.60 *scaling factor 1 *Number of zones： 8 *zones： 43 45 47 49 51 53 55 57 *number of trips between zones 0 0 0 1 5 10 3 8 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0

Zones	43	45	47	49	51	53	55	57
Name	Stenungsund	Höviksnäs	Myggenäs	Kållekär	kyrkesund	Skärhamn	*Composite zone	Orust

**Stora Dyrön, Åstol, Bleket, Klädesholmen and Rönnäng are altogether regarded as zone 55*