CHALMERS

Pedestrians in microscopic traffic simulation

Comparison between software Viswalk and Legion for Aimsun

Master of Science Thesis in the Master's Programme Infrastructure and Environmental Engineering

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Department of Civil and Environmental Engineering
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ABSTRACT

Pedestrians make up an important group in the transport system, but their role in traffic planning is often indefinite. Microscopic traffic simulation is a recognised tool for traffic planning and analysis. Software has been developed to handle both the behaviour of pedestrians and all characteristics of vehicular traffic, trying to simulate their complex interaction. The aim of this study is to analyse the utility and possibilities for integration of pedestrians in microscopic traffic simulation. The study includes an examination and comparison of two software programs – Viswalk and Legion for Aimsun – with the additional purpose of defining a decision support tool for choice of software in different situations.

The study is conducted in four main phases. The first phase is an overview of pedestrian planning with consideration to pedestrian characteristics and requested measurements. It is found that a software examination should regard model construction, pedestrian behaviour and performance measurements. The second phase is an examination of software Viswalk and Legion for Aimsun, with regards to these aspects. In this phase, it is found that definition of pedestrian types, the predefinitions for pedestrian crossings and features for modelling pedestrians as PT passengers differ between the software. To complement these findings, simulations are performed in the third phase of the study, where the aspects ease of use, modification possibilities, pedestrian behaviour and performance measurements are evaluated. For the fourth and final phase, the analysis is conducted and major Strengths, Weaknesses, Opportunities and Threats found in each software program are evaluated and compiled in a SWOT analysis. The analysis results in a tool for analysing the possibilities to perform a pedestrian traffic simulation of a potential situation.

The major differences between the two examined software programs are that Viswalk is more transparent and provide more modification possibilities whereas Legion for Aimsun is easier to use and gives a better visualisation with default settings. For each situation, the utility of a simulation and the possibilities provided by available software, determine whether a pedestrian traffic simulation should be conducted or not, and in which software. As long as simulations are critically assessed, there is great utility and many possibilities for integration of pedestrians in microscopic traffic simulations. Pedestrians are gaining more focus in traffic planning and deserve greater recognition in microscopic traffic simulations. These two improvements would enhance each other.

Key words: pedestrians, pedestrian simulation, microscopic traffic simulation, simulation software, Viswalk, Legion for Aimsun, SWOT analysis

Preface

This Master's Thesis has been carried out from January to May 2013. The purpose of the thesis was formed in dialogue with Kristina Schmidt, Transportation Analyst, and Tobias Thorsson, Associate Director, WSP Analysis & Strategy. These two became supervisors of this thesis and have contributed with ideas and knowledge through the whole process.

Furthermore, the thesis has been supervised by Professor Gunnar Lannér, Chalmers University of Technology. The software developers PTV and TSS have made this study possible, by providing software licenses. Additionally, they have given support on software issues, which has been very helpful. We would like to thank everyone who has supported this study through interviews and by providing information materials, and the entire staff at WSP Analysis & Strategy in Göteborg, who have encouraged us through our work. Finally, Sebastian Hasselblom, WSP, and Fredrik Johansson, LiU, are highly appreciated for their guidance on microscopic traffic simulation and pedestrian simulation, respectively.

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Gothenburg, May 2013

Stina Alexandersson
Emmi Johansson

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Abbreviations

Legion for Aimsun	LfA
Level Of Service	LOS
Origin Destination	OD
Pedestrian	ped
PTV Viswalk	Viswalk
Public Transport	PT
Strengths, Weaknesses, Opportunities, Threats	SWOT
Vehicle	veh

1 Introduction

Pedestrians make up an important group in the transport system. Walking is positive for the individual health and well-being, gives vivid streets and has no negative impact on the environment (Johansson, et al., 2011). Despite the well-known positive aspects of walking, there are many difficulties in planning for pedestrians and their role in the traffic planning is often indefinite.

Microscopic traffic simulation is used for traffic planning and analysis. This enables analysis of complex traffic systems, with interaction between different components and variation over time (Xiao, Ambadipudi, Hourdakis, & Michalopoulos, 2005). Two of the major software programs for this are VISSIM and Aimsun. Increasingly, pedestrians are integrated in microscopic traffic simulation, with their characteristic behaviour and complex interaction with vehicles (Suh, et al., 2013). Two software programs handling this issue are PTV Viswalk and Legion for Aimsun (PTV, 2012 & TSS, 2012). These are add-ons to VISSIM and Aimsun respectively.

By integrating pedestrians in traffic simulations, optimisation of the traffic network with regards to both vehicles and pedestrians should be possible and the risk of overlooking one of them when planning for the other should be reduced. This study is an examination of how these two significantly different groups in the transportation system can be handled together in simulation, by examination of software Viswalk and Legion for Aimsun.

1.1 Aim

The aim of this study is to analyse the utility and possibilities for integration of pedestrians in microscopic traffic simulation. The study includes an examination and comparison of two software programs – Viswalk and Legion for Aimsun – with the additional purpose of defining a decision support tool for choice of software in different situations.

1.2 Scope

The focus of this study is on *pedestrian* model construction, behaviour and performance measurements. The pedestrian interaction with other modes of transport is examined through simulation; hence vehicular traffic is modelled as well. However, the software comparison is only regarding the implementation of pedestrian elements and the *interaction* between pedestrians and motorized modes of transport. In order to construct a model of an existing intersection, input data for traffic demand, infrastructural design and operational data is required. Such data is gathered and processed in this study, but no further analysis is conducted of collection of input data. The opportunity of calibrating models is evaluated by examination of what modification possibilities the software offers, but not by collection or analysis of verification data.

The software programs are compared and examined based on these licenses:

- *Legion for Aimsun* – with licenses: Aimsun Standard Edition 7.0.4 and Legion for Aimsun (Lite Edition)

- *PTV Viswalk* – with license: VISSIM 5.40-08 with pedestrian specific modules PTV Viswalk (2000 pedestrians) and Area Based Measurements

In other licences provided for this software, other features might be available or missing. What may or may not be available in other licenses is not discussed. The only exception is for the performance measurements available in Legion for Aimsun, where the supplementary software Legion Analyser is briefly discussed.

This study examines and compares the software by literature review and also modelling and simulation. However, it does not include evaluation of the software support or manuals.

1.3 Method

This study has been conducted in 4 phases.

Phase 1. Overview of pedestrian planning by interviews and literature study with regards to:

- pedestrian characteristics
- requested pedestrian measurements

⇒ with the purpose to identify interesting aspects of a software examination.

Phase 2. Examination of software Viswalk & Legion for Aimsun by literature study and software exploring, with regards to:

- model construction
- pedestrian behaviour
- performance measurements

⇒ with the purpose to identify similarities and differences and in order to select interesting situations to study in Phase 3, through modelling and simulation.

Phase 3. Examination of pedestrians in microscopic traffic simulation, by simulation study of an existing intersection, in each of the software, with regards to:

- a general network
- interaction with vehicles
- interaction with public transport

⇒ with the purpose to evaluate ease of use, modification possibilities, pedestrian behaviour and performance measurements.

Phase 4. The analysis of the entire study, Phase 1-3, results in SWOT analyses, for each of the software, with regards to:

- Strengths
- Weaknesses
- Opportunities
- Threats

⇒ with the purpose to provide a decision support tool for analysing the possibilities to perform a pedestrian traffic simulation of a potential situation.

In the report, **Phase 1** is found in Chapter 2, **Phase 2** in Chapter 3-5, **Phase 3** in Chapter 6-9 and finally, **Phase 4** in Chapter 10.

2 Pedestrians in Traffic Simulation

The first Phase of this study derives a background on microscopic simulation, characteristics of pedestrians as mode of transport and requested measurements of simulations.

Microscopic traffic simulations are extensively used for traffic analysis and design (Barceló, 2010). An advantage with simulations is the possibility to examine how traffic varies over time and to get an overview of complex traffic systems. In microscopic simulations, each vehicle is individually simulated and represented; with independent behaviour. Traffic simulations enable testing of different traffic demand, inclusion of randomness, numerical measurements as well as visualisations of traffic situations (Xiao, et al., 2005).

Pedestrian simulations are used for analysing pedestrian flows, for example at airports and railway stations (Dallmeyer, Lattner, & Timm, 2012). Software for this kind of studies is often focusing on pedestrian density and evacuation issues.

As a combination of these two types of simulations, software for simulating realistic pedestrians integrated in traffic systems has been developed (Suh, et al., 2013). The software handles both the behaviour of pedestrians and all characteristics of vehicular traffic, trying to simulate their complex interaction. Two such software programs are Viswalk and Legion for Aimsun.

2.1 Pedestrian characteristics

Pedestrians differ from other modes of transport in several ways. Pedestrians are a heterogeneous group and their traffic characteristics, for example speed and gap acceptance, are affected by factors such as purpose with the trip, age, physical strength etc. (Johansson, et al., 2011) .Their movements are not restricted to assigned infrastructures; they tend to take the shortest path. In additions to this, pedestrians are more unpredictable than vehicular traffic and they often disregard rules. For example, at a signalised crossing, pedestrians tend to practice a gap-seeking behaviour rather than obey the signals (Suh, et al., 2013).

When designing for pedestrians, the aspects of accessibility, safety and attractiveness are important (Johansson, et al., 2011). The status of pedestrians in urban planning and design has been low for many years but it is improving. There is a lack of data about walking as a mode of transport. This makes it difficult to calibrate simulations of pedestrians in traffic (Lind, 2013). Furthermore, there is a lack of guidelines for pedestrian planning and difficulties to show effects of improvements for pedestrians (Johansson, et al., 2011).

2.2 Requested measurements

For an analysis to be useful, the requested and the derived results must agree. One requested measurement regarding pedestrians is density maps (Pestell, 2013). Density maps graphically display the pedestrian density over an area, e.g. by a colour scale. The scale can represent standards for level of service.

Level of Service, LOS, is a concept for analysing convenience for travellers, developed in the Highway Capacity Manual in 1965 (Spring, 2000). It consists of six ranges, from A which is the most convenient situation, to F which is the most inconvenient situation. Industry standards of LOS for pedestrians have been developed, giving specifications on the ranges A to F. An acknowledged LOS standard for pedestrians is developed by Fruin, defining levels of density for the ranges (Fruin, 1971). Different values are provided for different pedestrian areas, such as walkways, stairways and queues, since pedestrians expect, accept and require different levels of density on different areas. LOS A for a walkway corresponds to free flow, where pedestrians walk unimpeded and pass each other smoothly. LOS F corresponds to a situation where the density is critical and pedestrians frequently have to stop because they interrupt each other. There are several LOS standards, and they can regard pedestrian density, delay and/or speed.

As mentioned, density maps are requested results of pedestrian analyses. This together with 2D visualisation of pedestrians is two of the most useful ways to present pedestrian situations, according to Pestell (2013). These visual presentations can be derived from microscopic simulations. In general, visualisation is a major advantage of simulation. According to Park & Schneeberger, "the importance of visualization when using microscopic simulation models cannot be overemphasized" (2003, p. 190). A video recording from a simulation is a powerful tool for communication; it enables communication with non-technicians, it is understandable, does not require any industry terms and holds more information than a single number. But for communication, the simulation must be trustworthy; recognisable and reasonable visualisation is required to achieve a video for communication purposes.

Considering the characteristics of pedestrians and requested measurements for pedestrians as mode of transport, it is concluded that the examination and comparison of simulation software in Phase 2 should regard model construction, pedestrian behaviour and performance measurements. If these aspects are examined, understanding would be derived on the ability to handle pedestrians and their characteristics in microscopic traffic simulations, and the usefulness of such simulations.

3 Viswalk

The first chapter in Phase 2 examines the software Viswalk. VISSIM is a software program for microscopic traffic simulation developed by the German company Planung Transport Verkehr AG, PTV in short. With an add-on for pedestrian simulation, the software is referred to as PTV Viswalk by the distributors (Rickborn, 2013). In the continuation of this report, this software is referred to as Viswalk. The possibility to simulate pedestrians with a more realistic behaviour and the opportunity to derive performance measurements for pedestrians were developed in 2007 (PTV, 2008). The software has, for example, been used to simulate pilgrimage in Mecca.

The software can vary depending on the licence, with different add-on modules. In this study the following licence is used (Don, 2013):

- Program: PTV Vissim 5.40-08
- Modules: 3D Visualization, Managed Lanes, Unlimited link types, COM Interface, User Interface PuT, Area based measurements, PTV Viswalk (2000 Pedestrians), Multi-Storey

The pedestrian add-on Viswalk is optional in a VISSIM licence. Without the add-on, a simulation can include a maximum of 30 pedestrians at the same time, and a selection of features and predefinitions are not available (PTV, 2012). A Viswalk license can also be provided as a standalone product, which does not include any vehicle features.

Model construction for pedestrians is conducted in a certain pedestrian edit mode and one of the main differences to other modes of transport is that pedestrians move on areas rather than links. The available pedestrian features for construction of a model in Viswalk are described in Section 3.1. The movement of a pedestrian is the sum of attractive and repulsive forces (PTV, 2012). The forces come from the defined destination and from other pedestrians, obstacles and attractions. The pedestrian behaviour in Viswalk is described in Section 3.2. In order to obtain an understanding of the assessment possibilities Viswalk offers, pedestrian performance measurements, both visual and numerical, are examined in Section 3.3.

3.1 Pedestrian model construction

All pedestrian model construction in Viswalk is performed in *Pedestrian traffic mode* which is activated through the *Pedestrian Edit Mode* icon. The other mode that exists in the software is the *Vehicle traffic mode*. The features in the pedestrian traffic mode are: *areas, obstacles, stairs, pedestrian inputs* and *routes* (PTV, 2012). Performance measurements are the *travel time* feature and *measurement areas* feature. A few features are correspondent in the two different modes, such as links, priority rules, signal heads and detectors. Analogue to vehicle modelling, the necessary inputs are; traffic demand data, infrastructural design and operational data such as traffic regulations.

Pedestrian types, pedestrian classes, walking behaviour and *area behaviour types* can be modified, similar to how vehicle attributes are modelled (PTV, 2013). The pedestrian types are predefined whilst the others are optional and are created by the user. There are two predefined pedestrian types, man and woman. The user can create a new pedestrian type or edit the default values, e.g. maximum acceleration, behaviour parameter file and also the appearance of the pedestrian.

A *pedestrian composition* is predefined in the software, with an equal ratio of men and women (PTV, 2013). It is in the pedestrian composition a *desired speed distribution* is defined. The pedestrian composition and the desired speed distributions can be edited by the user analogously as for vehicles and furthermore, several different compositions can be created.

Walkable areas, *pedestrian areas* and non-walkable areas, *obstacles* can be imported from CAD files (PTV, 2012). However, only closed polygons can be imported, not other shapes of obstacles e.g. fences drawn as lines. These areas can also be drawn manually. For each pedestrian area, *pedestrian behaviour type*, *dwell time*, *queuing* and *public transport usage* can be defined. In order to create pedestrian movement via *Pedestrian OD matrix* the areas are defined as origins and/or destinations. Overlapping areas correspond to free movement between the areas. *Ramps*, such as stairs or escalators are used to connect pedestrian areas at different levels. Pedestrians can only move on the designated areas and ramps, hence those areas are created on all walkable locations. If there is a location on the area where pedestrians do not or cannot move, an obstacle can be created on top of the pedestrian area. Construction of several smaller areas rather than one large area is recommended in order to minimize the computational effort (Beutin, 2013).

The construction feature that allows interaction between pedestrians and other modes of transport is *pedestrian links* (PTV, 2012). For other modes of transport, the link is created as a one directional link with the possibility of several lanes, widths and turns. Creation of pedestrian links is conducted similar to other links, and then the option *use as pedestrian area* is chosen. Viswalk creates a second link with the opposite direction but the same coordinates in order to allow pedestrians to cross in both directions. Compared to vehicle links, pedestrian links cannot be curved or contain pedestrian input.

The interaction pedestrian/vehicle, is modelled by links and controlled by the same regulation features as for interaction vehicle/vehicle (PTV, 2012). The options are *signal control, conflict areas, detectors* and *priority rules* and they are handled analogously for pedestrian/vehicle interaction as for vehicle/vehicle interaction. However, note that since the pedestrian link is actually two counter links, this creates two conflict areas and caution has to be taken when placing traffic signals. It is recommended to use the feature conflict areas rather than priority rules at non-signalised intersections. The conflict area is created automatically on all spots where conflicts can occur, hence where two links are traversed. The user has to define which regulation the conflict area should have. If left undefined, notice will not be given between the traffic on the links. For pedestrian/vehicle interaction, priority can be given either to the vehicles or the pedestrians. This differs from the interaction vehicle/vehicle, where the option yield-yield also is available which gives priority to the vehicle that arrives first to the conflict area.

There are two methods to define pedestrians and their movements; by the two features *pedestrian inputs* and *pedestrian routes* or by the feature *pedestrian OD matrix* (PTV, 2012). The first option is analogue to creation for vehicles. The two methods are explained separately, but both methods can be used in the same simulation.

Firstly, *pedestrian inputs* are created, defining number of pedestrians per hour and which *pedestrian composition* to be used, for each of the origins. Analogue to vehicle input, the flow can vary for different time steps. Then the *routes* are created, from the origin area to the different destination areas, an example of such is presented in Figure 1 (PTV, 2013). How the pedestrian input is distributed from the origin to the different destinations is defined as a static percentage for the routes with the same origin. Hence the number of pedestrians using a route depends on the pedestrian input and this ratio.

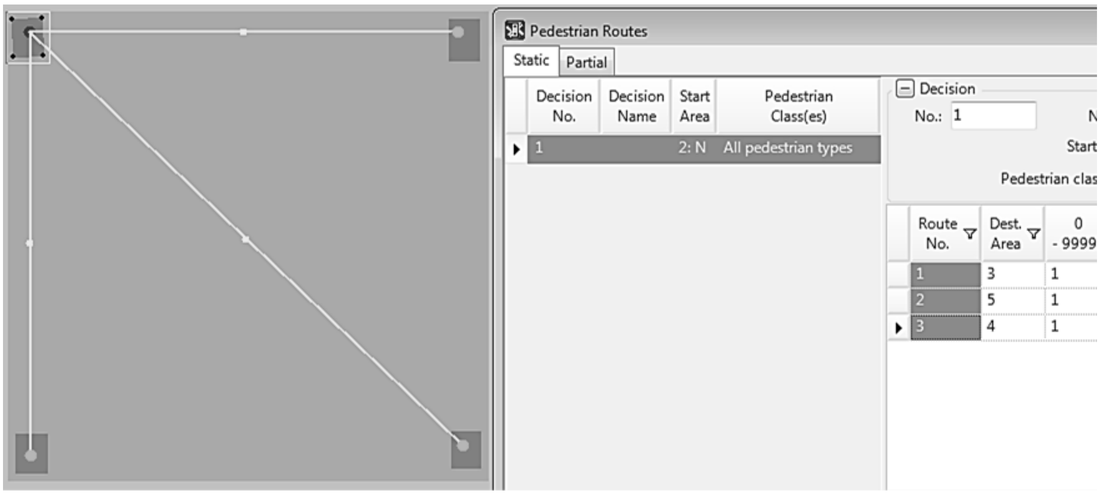


Figure 1. Viswalk model with one pedestrian input, equally distributed on 3 routes

From the chosen origins and destinations the pedestrians' actual path is calculated by the software. If a pedestrian route contains more than the two fixed points of origin and destination, or if the user wants to determine routes more specifically, *intermediate points* or *partial routes* can be used (PTV, 2012). Intermediate points are used to force pedestrians to pass a certain point during the route. Partial routes are defined on sections where several static routes occur. Here, pedestrians are re-distributed on the partial routes and after completion of these, they continue on their original static route. Partial routes can be used in order to simulate for example a visit to the ATM. The user can define how the pedestrians will be distributed among the partial routes, see Section 3.2.1 for explanation of route choice models.

The other option for defining pedestrian inputs is *OD matrix*. This is considered the faster option; however this precludes the use of intermediate points and partial routes (PTV, 2012). When the pedestrian areas are created, the user can choose to define it as an origin and/or a destination. This way the OD-matrix is created automatically with origins represented in rows and destinations in columns. If applicable, the user can add origins and destinations to the matrix manually instead. When the OD-matrix is created, the user enters the pedestrian flow in each cell, from each origin to each destination, in pedestrians per hour. An example is presented in Figure 2 (PTV, 2013).

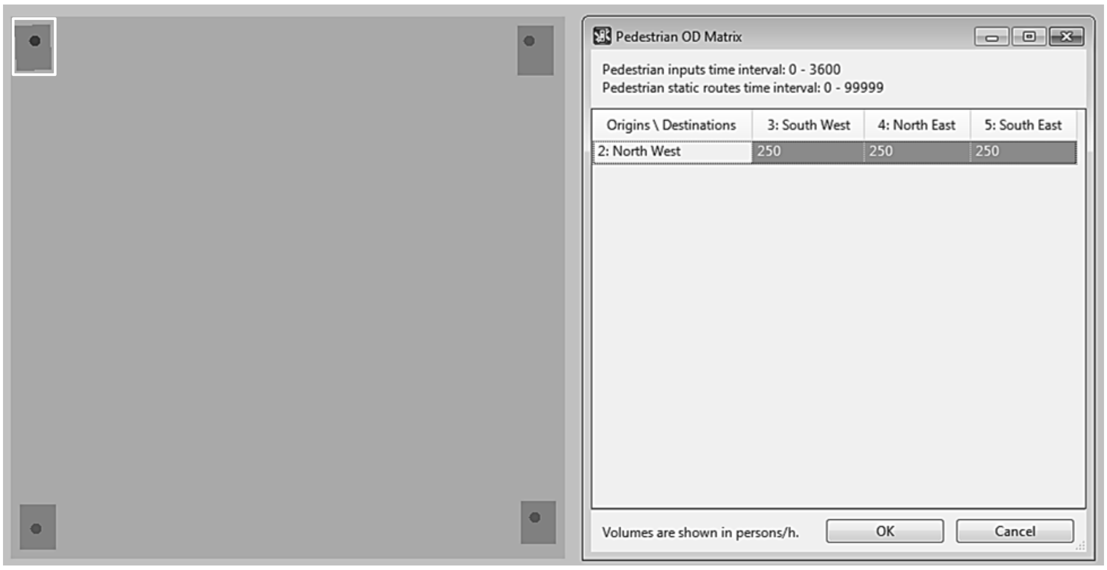


Figure 2. OD-matrix in Viswalk, which corresponds to the 3 routes in Figure 1

For both methods, the number of pedestrians is added as absolute or stochastic values in pedestrians per hour. The pedestrians arrive randomly, both in time and space, with the predefined composition and within the origin area (PTV, 2012). As soon as the pedestrians reach their destination area they disappear.

3.1.1 Pedestrians as PT passengers

In order to model pedestrians as PT passengers several settings has to be applied for different construction elements, e.g. *PT stop*, *PT line* and *pedestrian areas*. A detailed description of construction and settings to be applied for each construction element is presented in Appendix I.

Several pedestrian areas have to be created in order to model pedestrians' use of public transport. A *platform edge* has to be created in order to have passengers alighting PT vehicles and are used as origin area when creating their following routes (PTV, 2012). If no route is created from the platform edge, the passengers will disappear as soon as they alight. Note that an OD-matrix cannot be used for distribution of alighting passengers; the only option available is the *pedestrian route* feature. However, *pedestrian input* is not necessary since it is the alighting passengers that correspond to the pedestrian flow from the platform edge. In the *PT Stop Data* window for each line and each stop, the user defines the percentage and composition of pedestrians alighting a PT vehicle. Hence, the alighting percentage for each line at a *PT stop* is consistent, while the occupancy on each vehicle can vary. Occupancy of all the PT vehicles has to be set in order to have alighting passengers. A platform edge can be created either by the option *generate platform edge* when the PT stop is created, or by drawing a pedestrian area and ticking the option *public transport usage* and then *platform edge*.

Waiting area is the other option for *public transport usage* of pedestrian areas (PTV, 2012). These are created in order to have passengers boarding PT vehicles. The waiting areas are set as destination areas for routes or in an OD-matrix. The number of pedestrians arriving to the waiting area and boarding the PT vehicles is thus defined in the pedestrian input or the OD-matrix. Pedestrians arriving at the waiting area wait until a PT vehicle arrives and by default, aboard the first vehicle that arrives. The user can allocate a share of boarding pedestrians to each of the PT lines at a stop. This is set in the *boarding data* window of a stop. The waiting areas are created by drawing a pedestrian area, ticking public transport usage and then define it as waiting area. The size and shape of the area determines the location where the pedestrians will wait.

The distribution of passengers among the doors of a PT vehicle is chosen by the user, both for alighting and boarding (PTV, 2012). The properties and number of doors are set by the user in the *Geometry* window for vehicles. This is also where it can be set that certain doors should be used solely for boarding or alighting. If a waiting passenger cannot board the vehicle, as a consequence of not enough dwell time or full occupancy of the vehicle, it will move back to the waiting area and wait for the next vehicle to arrive.

The *dwell time* of PT vehicles can be modelled as a function of the pedestrians. By default, the vehicle departs three seconds after the last passenger have boarded (PTV, 2012). The options are: set a *boarding and alighting time per passenger*, set a *minimum dwell time distribution*, set *a slack time factor,* add an *off-set departure time* and tick the option *late boarding possible*. All options can be used and in that case, the greatest dwell time will be determining.

3.2 Pedestrian behaviour

The pedestrian behaviour in Viswalk is based on a Social Force Model, which is a continuous model with base in Newtonian mechanics (Johansson A. F., 2009). The model considers repulsive, friction, attractive and driving forces and all these result in one force driving the pedestrian. The social force model for pedestrian dynamics used in Viswalk is developed by D. Helbing and P. Molnár (Helbing & Molnár, 1995). The model has been examined in several studies since it was developed, and Parisi, Gillman & Moldovan (2009, p. 3601) summarize the opinions on this model by describing it as “a famous continuous model for describing pedestrian dynamics that qualitatively reproduces many self-organizing phenomena like lane formation”. The major factors influencing the motion of a pedestrian are shown in Table 1 (Helbing & Molnár, 1995).

Table 1. Factors considered in the Social Force Model in Viswalk

Factor	Effect	Description
Desired direction	Direction	Peds take the shortest path to their destination
Desired speed	Acceleration	Free flow speed. Varies between pedestrians
Relaxation time	Acceleration	Within which time peds try to reach their desired speed
Other pedestrians	Repulsive effect	Peds avoid getting close to strangers. They have their private spheres
Obstacles	Repulsive effect	Peds avoid buildings, fences etc. The closer they get the more attention they pay
Attractions	Attractive effect	Peds are attracted by friends, window displays etc
Angle of sight	Weighting of factors	Things in front of pedestrians affect their motion a lot more than things behind them
Fluctuation	Random variations	Some randomness is included, e.g. for the choice between two equal options

The implementation of the social force model in Viswalk has required definition of these parameters; see Appendix II for predefinitions and explanations of pedestrian parameters in Viswalk. Pedestrian parameters in Viswalk are organized in *parameters by pedestrian type*, which can have different values for different pedestrian types, and *global parameters*, which are the same for all pedestrians within the same simulation (PTV, 2012). All of these are found in a behaviour parameter file. The default values are calibrated to represent "a moderate conservative average of an adult not mobility impaired group" (Müller, 2013).

Yet, the user has the possibility to adjust these parameters and define new *pedestrian types*, with different characteristics. Examples of parameters by pedestrian type are relaxation time, which determines aggressiveness, and impact of other pedestrians, by values for the force strength, range and impact of relative velocity between pedestrians. A *Pedestrian Type* in Viswalk is defined partly by a behaviour parameter file, but also by options for shape and colour (PTV, 2012). A *Pedestrian Composition* is then defined by choosing one or more pedestrian types, and defining desired speed and ratio for each chosen type. The desired speed is set by selecting a speed distribution, either a pre-defined or user-defined. It is the pedestrian composition that is used as input for a route or an OD-matrix. The feature *Area-based Walking Behaviour* together with definition of *Walking Behaviour* enables variation of walking behaviour and speed among pedestrian groups, areas and time intervals.

3.2.1 Route choice

The global parameters previously mentioned impact the route choice (PTV, 2012). Viswalk parameters for *dynamic potential*, aiming at making pedestrians find the path with the shortest travel time, are calibrated by several studies. One of the most recent calibration efforts includes pedestrians within a telepresence system, where the participants get the feeling of being within a virtual environment and their movements are tracked in detail (Kretz, Hengst, & Roca, 2011).

Pedestrians in Viswalk search for the quickest path to their assigned destination, intermediate or final (PTV, 2012). By default, a method with static route choice is used, when the shortest path for each OD-pair is calculated and then used for all pedestrians assigned to this OD-pair during the simulation. Optionally, a dynamic potential can be implemented for selected routes, making each pedestrian recalculate their quickest path in each time step, considering other pedestrians in the system. The user defines to what extent these calculations should affect the route choice, and the length of a time step. These calculations have high demands of computing capacity.

When using inputs and routes for definition of pedestrian flows, *intermediate points* can be created (PTV, 2012). These are handled as midway destinations; the path from origin to intermediate point and the path from the intermediate point to the final destination are calculated separately.

In addition to the global route choice method, *Partial Routes* can be defined within a model and the user chooses which route choice method should be applied for specific routes (PTV, 2012). If the route choice is set to be static, the user defines fixed ratios for the alternative routes. If the route choice method *Travel Time* is chosen, pedestrians are distributed according to the travel times for pedestrians who have already completed these routes. Hence, the first pedestrians are distributed equally and thereafter, their travel times are used for distribution of the following pedestrians. The user can define details on these travel time evaluations and to what extent they should be decisive. Partial routes can also have the application *Service point selection*, which implies that pedestrians make decisions on whether to go to or pass by a service point, based on current queue at the service point.

To conclude, there are several options and modification possibilities for pedestrian behaviour and route choice within a Viswalk simulation. Parameters for interaction with other pedestrians and speed distributions can be modified by the user, but default settings are also available. The default pedestrian route choice considers the shortest path, but other options are available, such as continuously calculating the quickest path considering other pedestrians or by evaluating the performance of previous pedestrians with the same origin and destination.

3.3 Pedestrian performance measurements

This section describes which pedestrian performance measurements that can be obtained from Viswalk; what evaluation possibilities the software provides, both in visual and numerical outputs.

3.3.1 Visualisation

By default, the pedestrians in 2D view are coloured in several different colours (PTV, 2013). The optional *user-defined dynamic colours* give the pedestrian a colour that depends on which value they have on a certain parameter. The parameters available for individual pedestrians are speed and acceleration. The default colour scale can be modified by the user.

Another performance measurement that can be displayed in colour in 2D view is *Level of Service*, LOS. This is an aggregated value for pedestrians, with the available parameters of speed and density (PTV, 2012). The user chooses if the measurement should be area based, e.g. walkways, stairways, or grid based, cell size and how many nearby cells they should regard. The update frequency is defined, and it is chosen if the values should be average for the interval, average cumulative or worst of interval average. There are multiple pre-defined options available based on acknowledged investigations by scientists such as Fruin (1971). Table 2 presents all possible maps in Viswalk (PTV, 2013).

Table 2. Visual evaluation options in Viswalk

Definition	**Measurement**	**Name**
Predefined	Density [ped/m^2]	Fruin (walkways, stairways or queuing)
		Weidmann (walkways)
		HBS (walkways or queuing)
		HCM (walkways or queuing)
		Pushkarev-Zupan (walkways)
		Polus (walkways)
		Tanaboriboon-Guyana (walkways)
	Speed [km/h]	Teknomo
User defined	Speed [km/h]	User-defined: Speed
	Density [ped/m^2]	User-defined: Density

Figure 3, presents an example of colour scale, in ped/m^2, for Fruin walkways, the grey area represents obstacles (PTV, 2013).

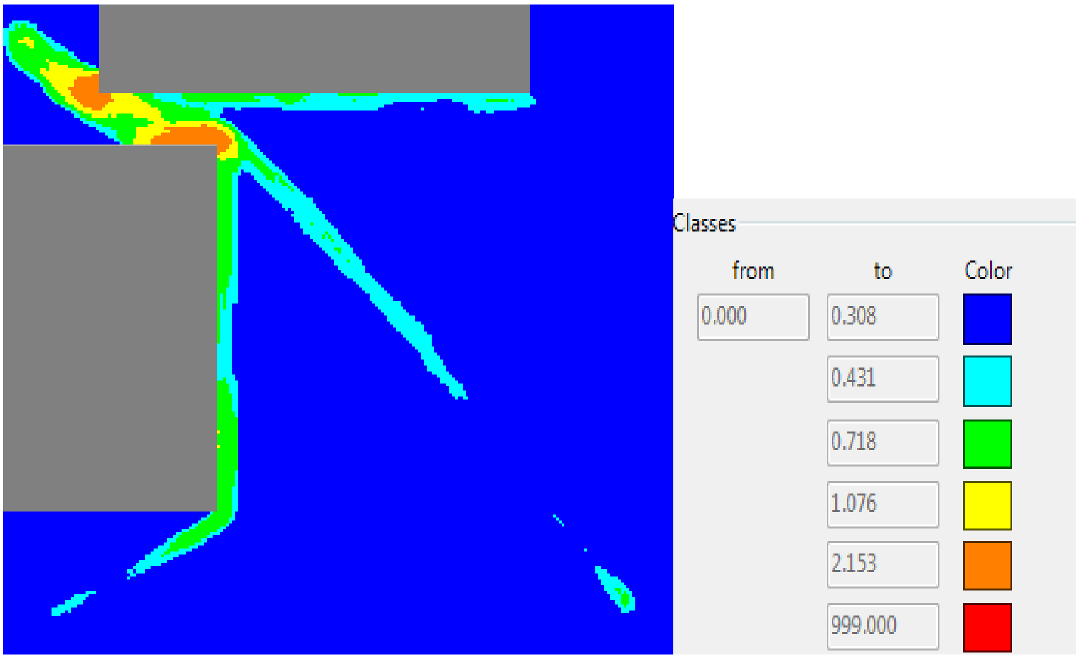


Figure 3. A density map of LOS: Fruin (walkways) in Viswalk

Output in 3D visualisation is available both in regular 3D view and from a pedestrian perspective; hence a view from the chosen pedestrian's eyes (PTV, 2012).

3.3.2 Numerical outputs

Storage of numerical outputs is optional with the selection of files or database (PTV, 2012). These options are not pedestrian specific; outputs for other modes of transport can also be stored in either files or databases. This study examines how evaluation can be conducted using files. A file is created during the simulation run, for each evaluation type defined by the user.

There are several options available in Viswalk to evaluate a model. Different outputs for pedestrians can be obtained, such as travel time, delay and mean distance travelled. For pedestrian evaluation there are different features; *area measurements, pedestrian record, pedestrian queue* and *travel time* (PTV, 2012). Refer to Appendix III for all possible outputs and for which feature they are available.

Travel time: Measures travel time between origins and destinations. Since the origins and destinations are set to pedestrian areas, this is how it is measured; when the pedestrian enters the origin area travel time measurements start and as soon as they reach their destination area the measurements stop. User can define the evaluation time during which measurements shall be conducted.

Area measurements: The location and size of a measurement area is user-defined and provides information about pedestrians within the measurement area. The user also defines which outputs from the area that should be collected from a list of numerous outputs.

Pedestrian record is an evaluation feature that records data per time step and is obtained per pedestrian. User can define both for which pedestrian types and time steps record should be retrieved. Analogue to vehicle outputs, the option of retrieving this pedestrian specific information during simulation is available. By double clicking on a pedestrian, a new window with pedestrian information will open.

Simulation in Viswalk is based on input files and random seeds. A random seed is a fixed profile of the traffic arriving (PTV, 2012). Simulations with the same input file and the same random seed produce identical results. By changing the random seed, the traffic will arrive differently; hence the stochastic variation of the input flow is simulated, which can impact the result. In order to retrieve a more statistically certain result, it is possible to do a *multirun* simulation with different random seeds and calculate the arithmetic mean. For multirun option the user defines initial random seed and number of simulation runs. Separate output files are obtained for each simulation run.

4 Legion for Aimsun

This chapter in Phase 2 examines the software Legion for Aimsun. Legion Limited is a company founded in 1997, in the United Kingdom, which provides software for microscopic pedestrian simulation (Legion Limited, 2013). After a few years of research and development, the company distributed the Legion software in 2003. Legion software has been used for simulation of several major events, such as the Olympic Games. In addition to their principal product, Legion SpaceWorks, they also provide a software program, in collaboration with the company TSS, called Legion for Aimsun (Legion Product Support, 2013).

Legion for Aimsun integrates a pedestrian microscopic simulation software, Legion, with a traffic microscopic software, Aimsun. There are three licence options for Legion for Aimsun; Base, Lite and Extra (Trulock, 2013). Base license is included in the standard Aimsun software and the others, which contain more features and can handle larger numbers of pedestrians per hour, are optional extras.

Aimsun is a traffic simulation software provided by TSS, Transport Simulation Systems (TSS, 1997-2013). TSS started out with microscopic traffic simulation in the end of the 1980's. It has now expanded and includes macroscopic and mesoscopic traffic simulation in addition to microscopic.

The license used in this study is *Aimsun Standard Edition 7.0.4* with a Legion license *Legion for Aimsun (Lite Edition).*

This chapter describes Legion for Aimsun with regards to pedestrian model construction; the available pedestrian features for construction of a model are examined in Section 4.1. The behaviour of pedestrians simulated in Legion for Aimsun is described in Section 4.2. Lastly, the assessment possibilities of a Legion for Aimsun model are described in Section 4.3.

4.1 Pedestrian model construction

This chapter describes the different construction features found in Legion for Aimsun. A model is structured in different project folders, e.g. infrastructure and demand data, and can also be handled in different layers. For pedestrian construction, a separate *Legion project folder* and *Legion layer* is created. Features used for pedestrian construction is within the Legion structure: *pedestrian area*, *obstacles* as *polygon* and *polyline*, *decision node*, *pedestrian entrance* and *exit*, *level change object* and *service point* (TSS, 2012). The feature *pedestrian crossing*, which models the interaction between pedestrians (Legion) and other modes of transport (Aimsun) is however found within the Aimsun structure. Required inputs for pedestrian simulation in Legion for Aimsun are traffic demand, infrastructural design and operational data such as traffic regulations.

Firstly, a *pedestrian type* is created; the user can choose *entity profile*, *speed profile* and *luggage size* for the pedestrian type by choosing between predefined options, see Section 4.2 for further details. In addition to pedestrian profiles, 2D display and 3D display of the pedestrians can be chosen and modified, for example height and colour of clothing (TSS, 2013). The project folder Legion is automatically generated when a pedestrian type is created.

A walkable area for pedestrians is created with the construction feature called *pedestrian area* (TSS, 2012). These areas cannot overlap or be connected, which means that pedestrians cannot walk from one area to another. Pedestrians can move freely within the whole area. In order to prevent them from walking on the vehicle road network or other elements they should avoid, *obstacles* are created. Obstacles can be created in four different ways; using layers, objects, CAD files and manually. From CAD files, both polygons and lines can be imported as obstacles. The construction feature *level change object* can create paths to cross over or under roads.

The construction feature that provides interaction between pedestrians and other modes of transport is called *pedestrian crossing*. These are created within a *pedestrian area* and have to be placed adjacent to a node. A *node* is either an intersection between *sections* (roads) or a *split section*; hence it is still possible to create a node wherever a pedestrian crossing should be placed. The pedestrian crossing feature automatically gives pedestrians priority. It is not suitable for other usage than as a zebra crossing – for example as an informal crossing where pedestrians cross without priority – since priority to pedestrians is given by default and cannot be modified. Yet, pedestrian crossings can be added to *traffic signal groups* to regulate vehicle/pedestrian interactions at signalised intersections. However, in order to have pedestrians obey the signals, the crossing has to be part of the pedestrians' *O/D route*, described in the following paragraph. The signals do not affect the pedestrians, unless the pedestrians are designated to the crossing by an OD route; without OD route, they will cross the road despite red signal, and the vehicle will stop despite green signal, hence the pedestrians still get priority.

Pedestrian centroids are used to define pedestrian origin and destination points (TSS, 2012). The centroids can be either *pedestrian exit* or *pedestrian entrance*. A *pedestrian O/D matrix* is the feature where the number of trips between origins and destinations are defined in pedestrians per hour. After creation of pedestrian entrances and exits, the structure of the pedestrian OD-matrix is obtained and the user can add the pedestrian demand, in pedestrians per hour, between all origins and destinations. The pedestrian matrix is handled analogue to the other vehicle matrices. Figure 4 below presents an example of a model with pedestrian entrances, exits and corresponding OD-matrix.

Figure 4. Pedestrian entrances and exits with corresponding OD-matrix in LfA

If the user wants to define which path within the pedestrian area the pedestrian choses between these origins and destinations, the feature *pedestrian O/D routes* can be created in addition to the OD-matrix. The routes are defined between an entrance centroid and an exit centroid including different points of interest; the user could for example determine that a route should include a *pedestrian crossing*, a *decision node*, a *level change object* or a *service point*. Hence a pedestrian route is not a fixed path but rather a series of fixed points that pedestrians walk between within the pedestrian area, for further route choice behaviour see Section 4.2.1. If no routes are added to the OD-matrix, the pedestrians' paths will be determined solely by the route choice model in the software. The user defines what percentage of the total number of pedestrians per hour, previously defined in the OD- matrix, will follow each of the routes with the same OD-pair.

A *decision node* is an area where pedestrian rethink their path between the fixed points, according to the manual "they are very useful for defining realistic pedestrian paths and movements" (TSS, 2012, p. 96). Within a decision node, there is a *focal point* which the pedestrian focus towards. This point can be moved around within the decision node or outside to create a *focal segment*. A focal segment is a line instead of a point, thus it gives a broader focus and prevents pedestrians from entering the decision node identically. A *service point* is an area where pedestrians can stay and wait for a while, before continuing their route. This tool can be used to model for example shops or information signs.

A variation of pedestrians could be modelled by creating several pedestrian types and handle these in different matrices. One original matrix can be split and then different pedestrian types can be chosen for the split matrices. Several matrices can also be used in order to have different pedestrian flow at different time intervals.

After construction, the pedestrian model and the traffic model needs to be integrated before a combined simulation can be achieved. Firstly the Legion for Aimsun simulator is activated in the *Dynamic Scenario* with specific settings. Matrices for all modes of transport, including the pedestrian OD-matrix or matrices, are added to a *Traffic demand*.

4.1.1 Pedestrian as PT passengers

To integrate public transport and pedestrians, several settings have to be applied. These settings are defined for different model elements, such as *PT stop, PT line, time table* and *O/D matrix*. For a detailed listing of required definitions, for each interface, refer to Appendix I.

When constructing a *public transport stop* the possible parameters to define concerning pedestrians are; *wait for pedestrians to board*, from which *road side* to board and *boarding/alighting time per pedestrian* (TSS, 2012).

The boarding and alighting time is used to calculate the total vehicle stop time, the dwell time of the PT vehicles (TSS, 2012). Additionally, a *dwell time distribution* can be defined for each stop of each *PT line,* and this distribution is also considered in the calculation of the dwell time. *Pedestrian exit* and *entrance* are created at the public transport stop in order to allow pedestrians routes to and from the PT stop. The length of the *PT stop* is defined by the user and affects where people are waiting. The amount of people boarding and alighting a public transport vehicle is defined in the *time table*, for each *public transport line*. The actual numbers of people that board respectively alight also depend on how many people are waiting at the stop when the vehicle arrives respectively how many people are on the vehicle initially. The maximum capacity of the vehicles is defined under *vehicle type*, either as a length multiplying factor or as a total number of people. *Door characteristics* are also defined for the vehicle type, including distance to vehicle front and regulations of boarding and alighting. According to the manual, "the amount of pedestrians to board or alight is distributed equally between all exit/entrance doors" (TSS, 2012, p.109).

When the exits and entrances at the public transport stops are created, they also appear in the *pedestrian O/D matrix*. The amount of people walking to the stop exits is defined in the matrix. This amount should correspond to the number of pedestrians boarding the PT vehicles, defined previously in the *PT line time table* (TSS, 2012). The trips from the entrances at PT stops are defined in a separate *ratio O/D matrix*. In this matrix, the proportional amounts are defined as percentages to each network exit, instead of amounts in pedestrians per hour. This is because the actual amount of pedestrians is the number of alighting passengers, which is defined in the *PT line time table*. The method for defining routes can also be applied for public transport users.

4.2 Pedestrian behaviour

The pedestrian simulation in Legion is a multi-agent system, called auto-navigation by the software developer (Legion SpaceWorks, 2012). This kind of model treats every pedestrian as an autonomous agent with a set of rules controlling its movements, giving the agents artificial intelligence (Johansson A. F., 2009). The concept in Legion is that each pedestrian evaluates all feasible options searching for the route with minimum effort (Legion SpaceWorks, 2012). This is done firstly on macro level; searching for the shortest path to the destination. This navigation on macro level determines the route choice. Secondly, the pedestrian evaluates its possibilities on micro level, optimizing the next step. This means that a main path is found on macro level and then modified on micro level.

The effort, which the pedestrians try to minimise, includes three factors (Legion SpaceWorks, 2012):

- *frustration* – when congestion forces you to slow down
- *inconvenience* – when you have to dissuade from the shortest path
- *discomfort* – when your personal sphere is intruded

Pedestrians gather information from their surroundings, perception zone, and use this to decide their next step. This decision includes:

- avoiding obstacles
- personal preferences, such as personal sphere and desired speed
- avoiding collisions
- identifying other pedestrians as "friends or foes," to define how to interact with them
- learning along the way, buildup of memories
- possibility to adjust preferences and characteristics

When creating a *Pedestrian type*, the user chooses *entity profile*, *speed profile* and *luggage size* (TSS, 2012). The pedestrian characteristics are imbedded in the entity profile. The profiles to choose among are predefined by Legion. In Table 3, the alternatives for definition of a pedestrian type in Legion for Aimsun are presented, the default values are grey (TSS, 2013).

Because of commercial sensitivity, Legion does not present details on the parameters for the entity and speed profiles (Legion Product Support, 2013). Thus, the options for the user in defining pedestrian behaviour are limited to the pre-defined entity and speed profiles, and information about these profiles is not available. The behaviour is calibrated by comparing simulation with videos of real situations (Berrou, Beecham, Quaglia, Kagarlis, & Gerodimos, 2007). The video recording has been performed in different parts of the world and of different pedestrian situations, resulting in the predefined entity and speed profiles.

Table 3. Options for defining a pedestrian type in LfA

Entity Profile				
Asian	Chinese	North American	Southern European	UK
Speed Profile				
Chinese commuters	Chinese weekend passengers	Asian commuters	Asian weekend passengers	Runners
Stadium users	UK commuters	Tourists	Southern European commuters	North American commuters
Luggage Size				
None	Small	Medium	Big	Any

4.2.1 Route choice

As mentioned, the route choice model of Legion for Aimsun is imbedded in the auto-navigation, in the primarily navigation on macro-level (Legion SpaceWorks, 2012). The route choice model cannot be modified by the user.

To specify pedestrians' routes through a network, the user can construct *decision nodes* and include these in *O/D routes* (TSS, 2012). These are intermediate destinations for the pedestrians; the pedestrians navigate towards the decision node. The user can define whither the pedestrians shall focus, by moving the *focal point* of the decision node, or make a *focal segment* to give a broader focus. When reaching the decision node, the pedestrian navigates anew to find their path to their final destination.

To conclude on pedestrian behaviour in Legion for Aimsun, there are predefined profiles for pedestrian characteristics and speed. The options are limited and information on underlying parameters is not available. Thus, the decision on which profile to use in a simulation is solely based on what the profiles are named. The route choice model used in simulations cannot be modified by the user and as for pedestrian characteristics; information on parameters and algorithms is not available.

4.3 Pedestrian performance measurements

This section describes what pedestrian performance measurements that can be obtained from Legion for Aimsun. This gives an overview of which assessment possibilities the software provides, both in visual examination and output values.

4.3.1 Visualisation

A general advantage of microscopic simulation is the visual result. This result is both the visualisation when running the simulation and the outputs that can be presented visually in maps or video recording. The visual examination of the simulation run is available in both 2D and 3D view. However, it is not possible to present outputs visually in the Legion for Aimsun license examined (TSS, 2013).

Legion Analyser is the application that analyses simulation results for Legion SpaceWorks. A Legion SpaceWorks model integrated with an Aimsun model can be analysed in the Legion Analyser (Legion Product Support, 2013) . The Legion for Aimsun license used in this study does not contain the Legion Analyser application. Therefore, the application has not been explored and evaluated in this study. The information regarding Legion Analyser in this section is provided by Legion for the software *Legion SpaceWorks* and it should be highlighted, that it is not examined if this could be achieved for a Legion for Aimsun model.

In order to get an overview of what could be done with the application, here are some examples provided by Legion: “Track individual Entities and visualise their walking path over time, visualise key metrics in the form of maps and run detailed analyses, and display the results as time series, stacked bars or histograms” (Legion SpaceWorks, 2012, p. 4). According to Legion, the user can define a combination of outputs to examine and the key measurements are “safety, efficiency, capacity and level of service” (Legion SpaceWorks, 2012, p. 5). In addition to the graphical and numerical outputs, maps can also be obtained presenting colour scales based on for example Fruin’s Level of Service and the US Highway Capacity Manual, amongst other industry standards. Figure 5 displays a density map of a Legion SpaceWorks model.

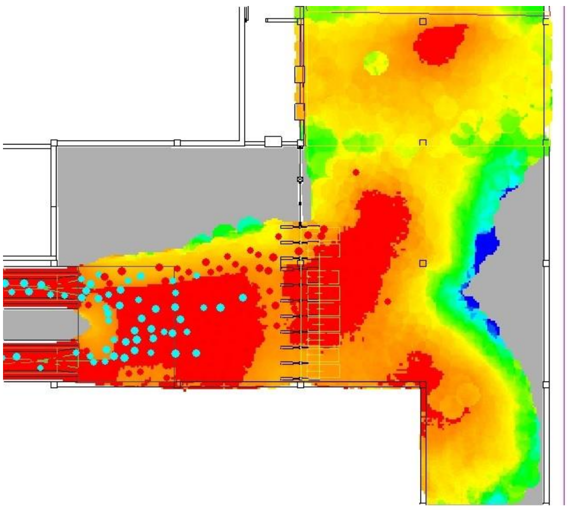


Figure 5. A density map of a Legion SpaceWorks model (Legion Limited, 2012, p. 306)

The scale can also be user defined and the colours can represent measurements of: "time, density, speed, dissatisfaction, frustration, discomfort and inconvenience" (Legion SpaceWorks, 2012, p. 5). Note that this study does not evaluate how these tools for analysis work; strengths and weaknesses are not accounted for.

4.3.2 Numerical outputs

Legion for Aimsun provides several pedestrian performance measurements from a simulation, e.g. flow, speed and travel time. For the pedestrian evaluation, available selections for measurement are; the *entire system*, *pedestrian crossings* and *OD-pairs*. Refer to Appendix III for all possible outputs and for which selection they are derived. Note that these are the outputs available in Legion for Aimsun; additional numerical outputs might be available in previously mentioned Legion Analyser.

When a simulation is completed, a network summary is displayed automatically. This contains a selection of the pedestrian outputs. It is also possible to get individual information for a specific pedestrian, by double clicking on a pedestrian during simulation (TSS, 2013). An example is provided in Appendix III.

For a full output summary, the user is referred to a database. A table for each of the possible measurement selections are stored in the database; entire network (table MISYSLEGION), pedestrian crossing (MICROSSLEGION) and OD-pairs (MIODPAIRLEGION) (TSS, 2012). The user can define for which time interval the outputs should be presented, in addition to results for the full simulation time.

The results for the *entire network* are presented as mean values for all pedestrians in the network. The results in the *pedestrian crossing* table are obtained for each of the crossings. The *OD-pair* table contains results presented per OD-pair. This contains the OD-pairs for each of the entrance and exit in the system, except for the entrances at PT stops. Hence, the pedestrians who enter the system as alighting PT passengers are not included in the table.

In order to run a simulation, a *Dynamic Scenario* is created for the model. Within the scenario, the user chooses which traffic demand to simulate (TSS, 2012). Several traffic demands, control plans and PT plans can be created for the same model, and then simulated in different scenarios. For the scenario, at least one *Experiment* is defined. In the experiment, several *Replications*, with different random seeds, can be conducted. Results from numerous replications can be automatically gathered and the mean and deviation of outputs from all replications are presented in one database.

5 Comparison of Viswalk and Legion for Aimsun

This chapter compares the software programs and presents the results of Phase 2 by summarizing Chapter 3 and 4. Main similarities and differences with regards to model construction, behaviour and performance measurements are displayed in tables.

5.1 Pedestrian model construction

Table 4 below displays the comparison of construction features for pedestrians. The comparison is made with regards to modelling the *geometrics*, the *traffic demand* as well as the specific features for *interaction with vehicles* and with *public transport*. Note that Appendix I provide the full description of how pedestrians are constructed as PT passengers for each of the software.

Table 4. Comparison of pedestrian model construction

		Viswalk	Legion for Aimsun
Geometrics	Similarity	• Pedestrian areas • Obstacles • Ramps • Objects can be imported from CAD-files	• Pedestrian area • Obstacles • Level change object • Objects can be imported from CAD-files
	Difference	• Several ped areas are created. When overlapping, the peds move between • Other infrastructure, such as roads, are avoided by creating numerous of ped areas around them • Only polygons can be imported from CAD-files, as areas or obstacles	• One ped area is created over the whole area where peds move • Several obstacles are created in order to have peds avoid other infrastructure, such as roads • All shapes can be imported from CAD-files, as obstacles
Traffic demand	Simil.	• Pedestrian types • OD-matrix • Intermediate points to steer ped paths	• Pedestrian types • OD-matrix • Decision nodes to steer ped paths
	Difference	• Ped areas are used as origins and destinations • Ped types and attributes can be used as default or be modified by user • Traffic demand is created in the features OD-matrix *and/or* with the features ped input and routes • Creation of a route path: Drag intermediate points on the routes to desired locations or create partial routes • Ped composition can be created by selecting percentage of created ped types	• Origins and destinations are constructed as ped entrance and exit • Ped types and attributes can only be chosen from predefined entity and speed profiles • Traffic demand is created in the feature OD-matrix. Via the OD-matrix, routes can be used to define specific paths • Creation of a route path: Create points of interest; decision nodes, service points. Create routes that include these points • In order to have different ped types, multiple OD-matrices are necessary

Interaction with vehicles	Simil.	• A separate feature models interaction; pedestrian link	• A separate feature models interaction; pedestrian crossing
	Difference	• Traffic regulation is not pre-defined • Priority can be given to either peds or vehicles • Signalised crossing is constructed analogue to a vehicle/vehicle-signalised crossing	• Traffic regulation is pre-defined: priority to peds • On non-signalised crossings the default priority given to peds cannot be modified • On signalised crossings, peds have to be defined to walk on the crossing in order to follow the traffic signals. Hence free route choice is not available for signalised crossings
Interaction with PT	Similarity	• Boarding passengers only board if the vehicle is not full • Requires inputs on several different elements; PT stops, PT lines, routes/OD-matrices. • Dwell time can be defined both as a time distribution and as a required time per passenger • Alighting passengers routes start on the platform edge, as a ratio of alighting peds as ped input	• Boarding passengers only board if the vehicle is not full • Requires inputs on several different elements; PT stops, PT lines and OD-matrices • Dwell time can be defined both as a time distribution and as a required time per passenger • A new ratio OD-matrix is created, where the ratio for alighting peds on different routes are defined
	Difference	• To define passengers' routes, ped areas are created for all PT stops; platform edge and waiting areas • Peds wait to board on the user-defined waiting area • The number of alighting passengers is decided by occupancy on each PT **vehicle** and the alighting percentage of the PT stop • All peds who have a route that ends on a waiting area board PT. Data can be added as a ratio for the different PT lines at the stop, in order to different amount of peds on the PT lines • User can define alighting and boarding distribution on the doors • Dwell time can be calculated from four factors, the greatest is determining	• To define passengers' routes, PT exits and entrances are created for all PT stops • Peds wait to board on automatic created waiting area • The number of alighting passengers is defined by mean and deviation for the PT **line**. Occupancy has to be greater in order for them to alight • The number of boarding passengers is defined by mean and deviation for each PT line. Also, add peds in the OD-matrix with the ped exit at the PT stop as destination. These two settings have to correspond • Boarding/alighting passengers are equally distributed on the doors • Dwell time can be calculated from two factors

5.2 Pedestrian behaviour

Table 5 displays the major similarities and differences between the software programs when comparing the pedestrian behaviour in simulations and the possibilities for the user to modify this behaviour. The comparison is made with regards to pedestrian *behaviour parameters*, *route choice* and *speed*.

Table 5. Comparison of pedestrian behaviour

		Viswalk	Legion for Aimsun
Behaviour parameters	Similarity	• Predefined behaviour model: Social force model • Pedestrians keep distance to obstacles and other pedestrians • Several pedestrian types can be simulated together	• Predefined behaviour model: Multi-agent model • Pedestrians keep distance to obstacles and other pedestrians • Several pedestrian types can be simulated together
	Difference	• User can modify behaviour parameters • User can make conscious modifications. Yet, it requires knowledge on the social force model • Transparent algorithms and parameters, all information available	• User can choose entity profile, but is limited to the available profiles • Decisions on which profile to use is solely based on what the profiles are named • Commercial sensitive algorithms and parameters, not distributed information
Route choice	Similarity	• Pedestrians automatically find their path through the model, from origin to destination • Intermediate points can be constructed to steer pedestrians	• Pedestrians automatically find their path through the model, from origin to destination • Decision nodes can be used to steer pedestrians
	Difference	• User can choose between static (shortest path) and dynamic (influenced by other pedestrians) route choice • User can modify the parameters on which route choice is based • For one OD-pair, partial routes can be defined and how pedestrians choose between different routes can be based on for example travel time • No definition on where the pedestrians should focus	• One predefined route choice • Information on underlying parameters and algorithms is not available • For one OD-pair, several OD-routes can be defined. The share of pedestrians to follow them must be set by the user • Focal points or segments can be used to define pedestrians' focus
Speed	Simil.	• Distribution of desired speed; the speed varies between pedestrians	• Distribution of desired speed; the speed varies between pedestrians
	Difference	• User can define speed distributions • User can make conscious modifications • Possible to let the speed differ between different areas	• User can choose speed profile, but is limited to the available profiles • User does not know what different speed profiles imply • A pedestrian type has the same speed profile through the whole simulation

5.3 Pedestrian performance measurements

Table 6 below displays the major similarities and differences when comparing the available pedestrian performance measurements, with regards to *visualisation*, *numerical outputs* and *statistical certainty*. Also, refer to Appendix III for a full summary of possible numerical outputs. Visual examination that requires Legion Analyser and might not be applicable to Legion for Aimsun models are commented with “Legion Analyser required”.

Table 6. Comparison of pedestrian performance measurements

		Viswalk	**Legion for Aimsun**
Visualisation	Similarity	• Density and speed maps • Colour scales based on industry standards, e.g. Fruin’s LOS, or user defined • Visual features can be imported or created, e.g. backgrounds	• Density and speed maps. Legion Analyser required • Colour scales based on industry standards, e.g. Fruin’s LOS or user defined. Legion Analyser required • Visual features can be imported or created, e.g. backgrounds
	Difference	• Several options, predefined and user defined, for aggregated and individual values of speed, acceleration or density • No visual features are created automatically, such as road marks & signs	• Cannot be tested since Legion Analyser is required • Several visual features are created automatically, such as road marks & give way signs
Numerical outputs	Similarity	• Output obtained for all pedestrians between an origin and destination • Click on a pedestrian during simulation to obtain individual pedestrian specific information	• Output obtained for all pedestrians between an origin and destination • Click on a pedestrian during simulation to obtain individual pedestrian specific information
	Difference	• Output obtained for user defined measurement area • In order to obtain outputs for a crossing, a user defined measurement area has to be created • Can obtain data for each pedestrian • Many output options, such as mean, minimum and maximum • All PT passengers are included in the pedestrian outputs	• Output obtained for the entire network • Output obtained for a crossing • Cannot obtain data for each pedestrian in database • Might have further analysing possibilities in the Legion Analyser • Alighting passengers are not included in the OD-output
Stat. certainty	Simil.	• Uses random seeds to get variation • Multiruns available	• Uses random seeds to get variation • Replications available
	Differ.	• During multirun, the outputs are obtained in numerous separate files	• Automatically created average for all replications

This Phase 2 is the base for identification of what is of certain interest to make comparative simulations of, and also what is not possible to compare in simulations. Some major differences in available features for model construction, how the pedestrian behaviour is defined and what possibilities for assessment there are, are identified through Table 4, Table 5 and Table 6 and used to determine the approach of the simulation study.

Concerning model construction, it is found that how areas versus obstacles are used, how pedestrian types are defined, the predefinitions for pedestrian crossings and features for modelling pedestrians as PT passengers differ between the software programs. These differences motivate simulation of a *general network*, where the usage of areas and definition of pedestrian types can be examined. They also motivate detailed studies of *interaction with vehicles*, by simulations of pedestrian crossings, and *interaction with public transport*, by simulation of PT with alighting and boarding passengers.

For the pedestrian behaviour, a major difference is that Viswalk offers possibilities to choose and change route choice model, whereas the route choice in Legion for Aimsun is predefined and is not possible for the user to modify. This prevents a comparison of how modifications of the route choice affect a simulation and therefore, only the default route choice is compared in simulation.

Regarding performance measurements, the licences used in this study differ significantly in availability of visually presented performance, such as density maps. Therefore, a comparison of these possibilities cannot be conducted by simulation. Yet, the visualisation of a running simulation and a selection of numerical outputs can be studied in both software programs and thus compared. Both pedestrian and vehicle measurements are of interest, to evaluate their impact on each other.

The simulation studies are performed in Phase 3 and ease of construction, observations of pedestrian behaviour and performance is examined in the two software programs. For comparison purposes, the default settings and predefinitions provided by the software are examined, but also the possibilities for the user to modify a model of pedestrians in interaction with other modes of transport.

6 Simulation Study: General Network

The first chapter of Phase 3 is a simulation study of a general network modelled in both Viswalk and Legion for Aimsun. The models represent an existing intersection with several modes of transport and large flows of pedestrians. An existing intersection is chosen in order for a visual examination to be comparable to field studies. Refer to Appendix IV for details on traffic demand, infrastructural design and traffic regulations used as input data in the models. The models are evaluated with regards to:

- Ease of construction
- Pedestrian behaviour
- Visual and numerical performance measurements

Also, the possibilities to modify the models are evaluated.

In order to make an accurate comparison, a base model is firstly constructed for each of the software and examined with regards to the above listed aspects. The base models are then modified and changes in behaviour and performance are observed. The following is examined:

- Base model with default pedestrian characteristics
- Changes in pedestrian characteristics
- Route choice with default route choice method

In this chapter, the method and findings for these evaluations of a general network are presented. The first section considers the examination in Viswalk and the second section considers Legion for Aimsun. This is followed by a comparison of the two software programs.

6.1 Viswalk

The Viswalk base model of a general network is constructed with available features and default pedestrian settings.

In order to change the pedestrian characteristics, a new pedestrian parameters file is defined. The purpose is to increase the distance that confronting pedestrians keep to each other and to smoothen their passing behaviour. For this the parameters *grid size* and *VD* are increased, refer to Appendix II for explanation of these parameters.

The default route choice method for pedestrians is examined by modelling: intermediate points on routes, obstacles, narrow pedestrian link, crowded pedestrian link, conflict area with priority for pedestrians, conflict area with priority for vehicles and finally such a conflict area with high saturation of vehicular traffic. The tests of route choice are performed with parallel possible routes and by observing changes in route choice when the measures mentioned above are applied to the base model. Since the route choice methods are numerous in Viswalk but not in Legion for Aimsun, only the default method is examined. Please note that other route choice methods are available in Viswalk.

6.1.1 Ease of construction

When constructing walkable areas and links, a noticeable difficulty is to make these overlap sufficiently. The model is sensitive to infrastructural design and pedestrians may get stuck or disappear in crevices of the walkable area.

Altering pedestrian characteristics by changing values in the default pedestrian parameter file is tricky, and knowledge in the social force model and its implementation in Viswalk are required. Yet, the modification possibilities are immense and with the right skills, a user can modify the parameters in detail to get preferred pedestrian behaviour.

All features used in the study of route choice are easily constructed. But once again, the user has to be aware of the sensitivity to infrastructural design; small changes in pedestrian areas or pedestrian links may cause large changes in route choice.

6.1.2 Observations of pedestrian behaviour

Observations of the default simulated pedestrian behaviour are that they find the shortest path across walkable areas and avoid obstacles in a reasonable way. The speed differs among pedestrians and overtaking is observed. They walk one by one, not in groups. Another comment is that a pedestrian may walk straight against another pedestrian and make a sharp turn when they reach each other.

When the pedestrian characteristics are changed, a clear difference in the behaviour is observed visually. The desired changes are fulfilled; pedestrians walking against each other keep greater distance and make smoother avoidance when passing.

For the route choice, a homogenous behaviour for all pedestrians with the same origin and destination is observed. This is in compliance with the default static route choice method, calculating the shortest path for each OD-pair and then applying this through the whole simulation. Intermediate points on routes work as expected; pedestrians pass the defined point, thus the feature enables the user to specify pedestrians' paths. Furthermore, it is observed that crowding a pedestrian passage does not affect the route choice, also in compliance with this static route choice method. Yet, it is found that the width of a passage and the appearance of obstacles do affect the route choice. In contrary, conflicts with vehicles do not have any effect, neither with priority for pedestrians nor for vehicles. The route choice is not affected even if the vehicle road is highly saturated.

6.1.3 Examination of performance

From visual examination of a general network in Viswalk, it is observed that no traffic regulation objects, such as road marks, are automatically displayed, see Figure 6.

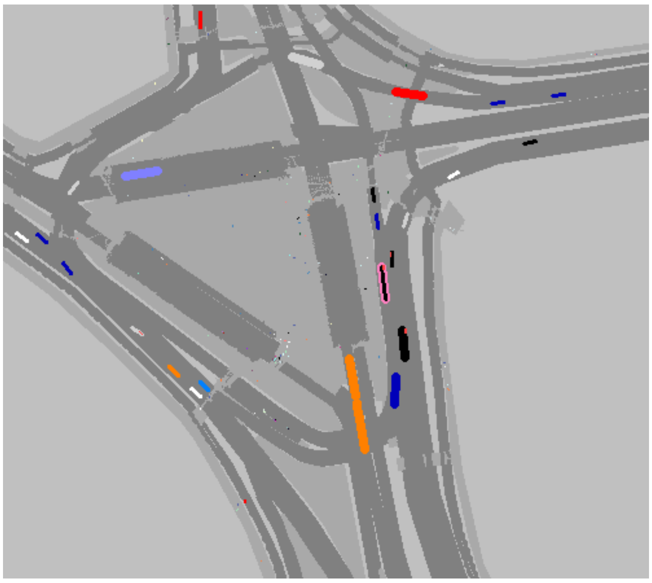


Figure 6. Viswalk general network model in 2D view

However, there are several options for the user to modify the view. For example, the network can be hidden and an imported map can be used as background. Other options are: adding lane marking and import pictures as sky and background for 3D view, and objects can be hidden or displayed in different colours. There are also many modification possibilities of how pedestrians are displayed. The default visualisation of a simulation might not be appropriate for display in all situations. Figure 7 presents a 3D view of the general network model.

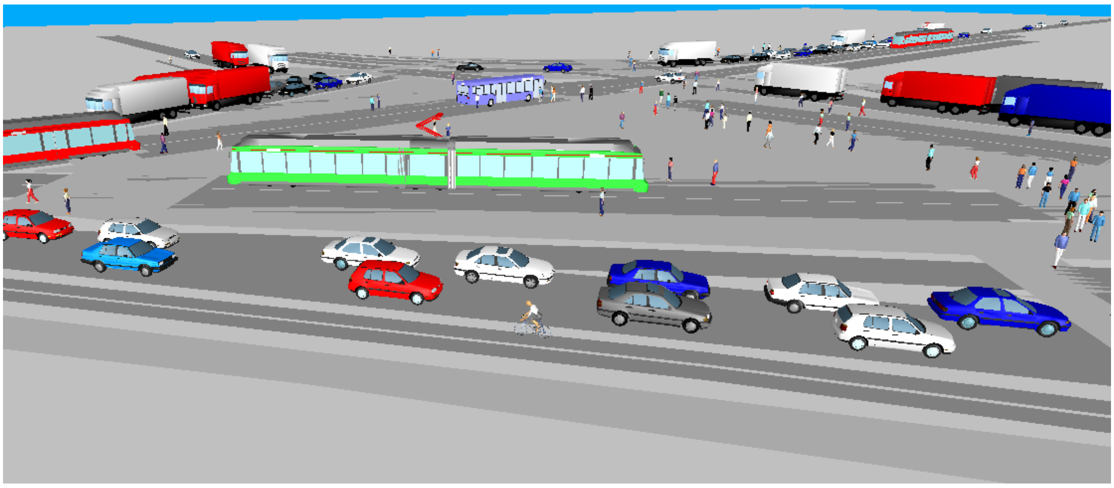


Figure 7. Viswalk general network model in 3D view

The numerical outputs derived from the base model are reasonable compared to the inputs. The examination of effects on performance, from changing pedestrian characteristics is made as a comparison between the base model and the modified model, where pedestrian parameters are changed. The selected numerical outputs to study are: travel time and speed for pedestrians as well as travel time and delay for vehicles. The outputs are derived from a section with a pedestrian crossing where vehicles give priority to pedestrians; hence the pedestrians cause a delay for the vehicles.

In Figure 8, the performance of the model with default pedestrian behaviour is compared to a model where the behaviour is changed by doubling the parameters *grid size* and *VD*. The diagram shows the ratio between the outputs from the different simulations. It is clear that, despite the distinct difference observed in visual examination, the effects on the chosen numerical outputs are inconsiderable. This is represented by the similarity in size between the block for default behaviour (*default*) and the block for changed behaviour (*x2*) in each bar.

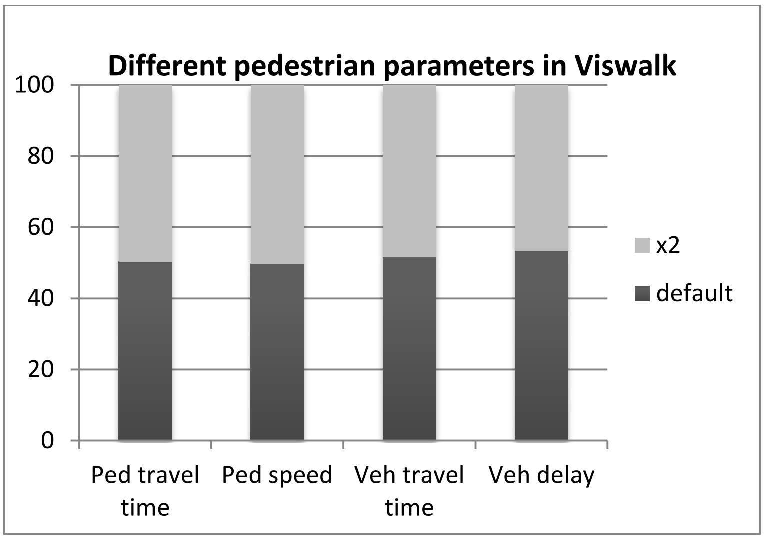


Figure 8. Proportional outputs for different pedestrian parameters in Viswalk

For the studies of route choice, no numerical outputs are derived since the purpose of the study is to examine whether certain measures affect the route choice or not which is examined visually. It can be concluded that the default route choice method performs as expected, with no consider to other pedestrians nor vehicular traffic. If another route choice method was applied, with dynamic potential, the results would probably be different.

Statistical certainty of numerical outputs is handled by using the feature multirun, which renders several simulations of a model, with different random seeds. This is easy to use and simulations with increased traffic demand can be conducted without much effort, by choosing a percentage; hence a sensitivity analysis is easy to conduct. Outputs are derived from each simulation run and are compiled by the user.

6.2 Legion for Aimsun

The Legion for Aimsun base model of a general network is constructed with available features and default pedestrian settings.

In order to test changes in pedestrian behaviour, new pedestrian types are defined, by choosing entity profiles and speed profiles other than the default option. The tested profiles are [entity: Chinese, speed: Chinese Commuter] and [entity: Southern European, speed: Tourists].

The route choice method for pedestrians is examined by modelling: decision nodes on OD-routes, obstacles, narrow pedestrian crossing, crowded pedestrian crossing, pedestrian crossing with priority for pedestrians and finally such a crossing with high saturation of vehicular traffic. A crossing where pedestrians give way to vehicles cannot be examined with regard to route choice, since the only possibility for changing regulation of a pedestrian crossing is by signalising. Then the crossing has to be part of an OD-route in order to have pedestrians obey the signals, hence the automatic route choice is precluded.

6.2.1 Ease of construction

When constructing the walkable area, one large pedestrian area is made over the whole intersection. Note that it is not possible to connect pedestrian areas with each other. Thereafter, the vehicle network is defined as pedestrian obstacles. This requires little effort since the option generate pedestrian obstacle is available.

Changing pedestrian characteristics is not demanding; just make a new pedestrian type and choose profiles for entity and speed. Yet, there is no possibility to examine what the options imply; decisions are based solely on the name of the profiles, e.g. Asian or Tourist.

All features used in the study of route choice are easily constructed. Yet, the options are limited since there is no possibility to apply automatic route choice for a pedestrian crossing with any other traffic regulations than the default.

6.2.2 Observations of pedestrian behaviour

In the simulation of a general network in LfA, it is observed that pedestrians find the shortest path across areas, overtake each other because they walk at different speed and avoid obstacles reasonably. An exception is when obstacles form an invert cone; then pedestrians sometimes walk in there and get stuck. The spread over walkable areas is reasonable; they keep distance to each other and to obstacles, but do not walk in groups.

When altering the pedestrian type, difference in pedestrian behaviour can be observed visually, especially difference in speed.

When testing the route choice, it is observed that not all pedestrians assigned to the same OD-pair choose the same path through the network. Decision nodes work as expected; pedestrians firstly navigates towards the node and thereafter towards their final destination, thus the feature enables the user to specify pedestrians' paths. It is also observed that narrow passages and obstacles affect the route choice, whereas no affects are observed from crowding, pedestrian crossings or increase of vehicular traffic.

6.2.3 Examination of performance

A visual examination of the general network model in Legion for Aimsun is performed when default view settings are used. Several visual elements are automatically created, such as road marks, give way signs and traffic signals. In 3D view, there is automatically a sky and backgrounds can be imported. Figure 9 displays the general network model in 2D and 3D view. The visualisation is appealing in both 2D and 3D and there are several options for modifications of the view, including the visualisation of pedestrians.

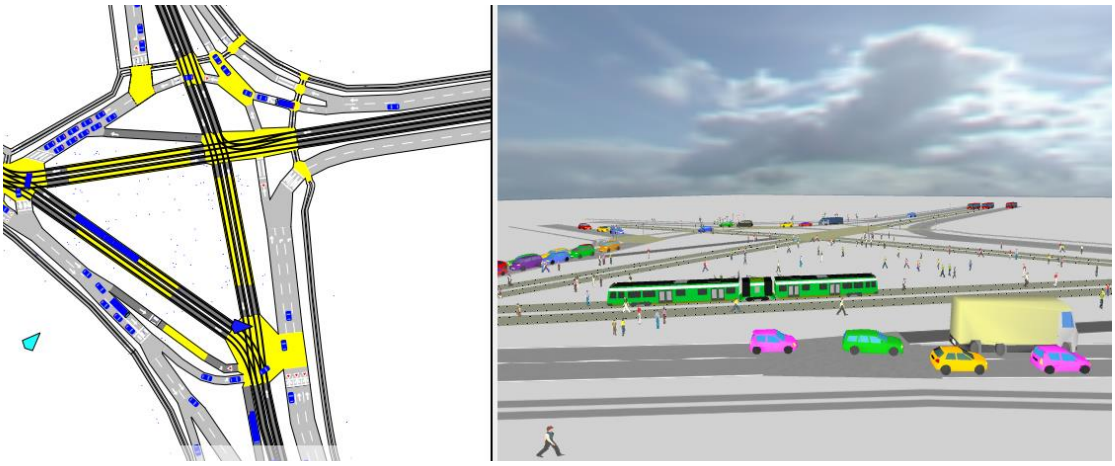


Figure 9. General network model in LfA, in 2D & 3D view

The numerical outputs derived from the base model are reasonable compared to the inputs. Changing pedestrian type has considerable effects on the numerical outputs of pedestrian travel time and speed as well as vehicular travel time and delay. Figure 10 shows the proportions between outputs from the model with default pedestrians [entity: UK, speed: UK Commuters] (*UK Commuter*) and from a model with pedestrians defined by [entity: Southern European, speed: Tourists] (*Tourist*). As shown in the diagram, the mean speed is higher for UK Commuters, meanwhile the delay for vehicles is considerably smaller. Changing the pedestrian type has significant impact on performance for both pedestrians and vehicles, but there is a lack of information on what the different Entity Types and Speed Profiles imply. The differences are possible to identify in both visual and numerical examination, hence such examinations can to some extent be helpful for finding the characteristics of the pedestrian profiles in LfA.

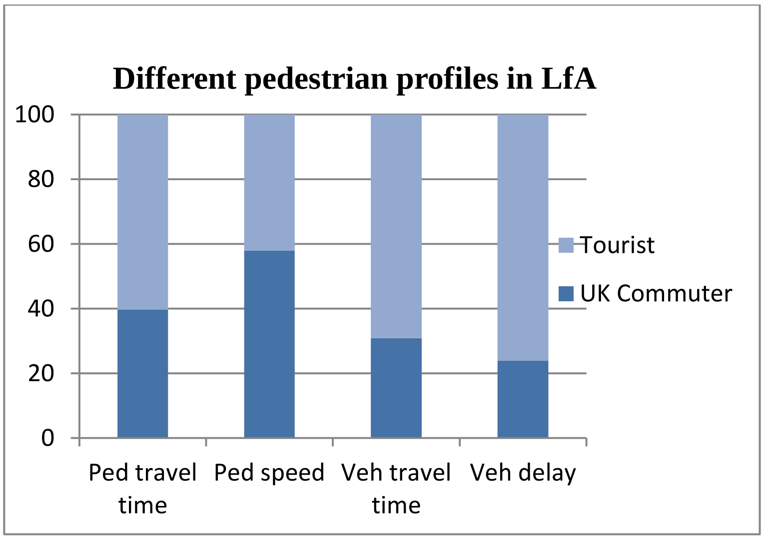


Figure 10. Proportional outputs for different pedestrian profiles in LfA

For the studies of route choice, a comparison against expected behaviour is difficult to perform, since the information on the route choice model is scarce. Yet, it can be concluded that within this examination, no effect on routs choice is observed for changes in traffic demand but for infrastructural changes, such as implementing obstacles and decreasing the width of a passage.

Statistical certainty of numerical outputs is handled by making several replications of a model, with different random seeds, and using the feature create average. The results are then compiled automatically, and an average for all replications is derived. The traffic demand can easily be multiplied by a chosen factor, by using a specific feature for this in the OD-matrices, to conduct a sensitivity analysis.

6.3 Comparison

The general impression is that the visualisation with default view settings is more appealing in Legion for Aimsun than in Viswalk, but in both software programs there are several possibilities to modify both 2D and 3D view. Pedestrians are satisfactory visualised in both software and their shape, size and colours can easily be modified in the 3D view.

The tests on changing pedestrian behaviour resulted in visually observed changes in Viswalk, but no or inconsiderable effect on the selected numerical outputs. The test in LfA gave both visually observable effects and considerable effects on numerical outputs for both pedestrians and vehicles. The difference in results can of course be due to the difference in changes made on pedestrian behaviour. The reason for this is that the possibilities in altering pedestrian behaviour differ between the software programs. It is easier to perform changes in behaviour in Legion for Aimsun, but the options are limited and choices are made without insight into the underlying parameters. In Viswalk, changing pedestrian behaviour by modifying parameters requires knowledge on the social force model, but gives unlimited modification possibilities.

The default route choice appears to work similarly in the two software programs, but in Legion for Aimsun it is observed that pedestrians with the same OD-pair can choose different paths, which is not the case in Viswalk. In Viswalk there are possibilities for altering the route choice model and such possibilities are not found in LfA. Additionally, the information on route choice model is more extensive for Viswalk than for Legion for Aimsun.

7 Simulation Study: Interaction with Vehicles

In order to examine the possibilities for simulating pedestrians in interaction with vehicles, a part of the already modelled intersection is chosen for in-depth study. This investigation area contains a pedestrian crossing over a vehicle road.

The crossing is examined in both Viswalk and Legion for Aimsun, with regards to ease of construction, pedestrian behaviour and performance measurements. Modification possibilities are also regarded. The models are adjusted in order to test different situations. The following situations are tested:

- Non-signalised pedestrian crossing
- Signalised pedestrian crossing
- Shared space, i.e. a common area for pedestrians and vehicles

To compare performance in the two software programs, outputs on pedestrian travel time and speed are derived, as well as vehicle travel time and delay. A visual examination is also performed.

7.1 Viswalk

Firstly, the Viswalk model of a non-signalised pedestrian crossing is examined. This model contains a pedestrian link across a vehicle link, and a conflict area giving the pedestrians priority. The front gap and rear gap for the conflict area is increased, to make the model more reasonable. Default pedestrian settings are used, but since the pedestrian speed differs significantly between the two software programs, an additional simulation is made with a new speed distribution in Viswalk in order to support a comparison between the performances of the software programs. This distribution is defined with the minimum and maximum speed for the speed profile UK commuter in Legion for Aimsun. Note that this information is not available in the manuals, but is the only underlying parameters that have been provided by Legion upon request.

Thereafter the model with default pedestrian behaviour is modified by signalising the crossing, using signal heads on both the pedestrian link and the vehicle link. Finally, two different ways of modifying the non-signalised pedestrian crossing into a shared space are tested. The first way is to broaden the pedestrian link and keep the priority for pedestrians on the conflict area. The second way is to construct several adjacent pedestrian links and let every second conflict area give priority for pedestrians, and the rest priority for vehicles. The tested methods are own inventions, since there is no specific feature for shared space.

7.1.1 Ease of construction

A non-signalised pedestrian crossing is constructed without much effort. It is also not demanding to modify, the priority in the conflict area can be altered and location and width of the crossing can be changed. The feature reduced speed areas can be used in order to make vehicles slow down before the crossing. The default front gap and rear gap defined for the conflict area are easily modified, in order to make pedestrians and vehicles keep greater distance to each other.

Signalising of a pedestrian crossing is not a complicated process either, but the user must be aware of the direction of the pedestrian link on which a signal head is placed. Two links of opposite direction are automatically created for each pedestrian link and the correct link must be used for the signal heads in order to have the signalising work properly. The signal head is also the stop line, hence the user can define at what distance to the road pedestrians shall wait at red signal.

When modelling a shared space, there are no predefinitions or available features for this. Hence, one of the difficulties is to find an appropriate method.

7.1.2 Observations of pedestrian behaviour

Observations show that the priority regulations of a non-signalised crossing are obeyed by both pedestrians and vehicles. By default, the margins are very small but as mentioned above, this is improved by modifications of the conflict area parameters. Pedestrians do not walk outside the pedestrian crossing and they do not slow down before the crossing.

Before a signalised crossing, pedestrians slow down and stop at red light. Pedestrians waiting at red light form a cluster, standing next to each other, see Figure 11. In 3D view, the waiting pedestrians are stomping. Everyone obeys the signal control.

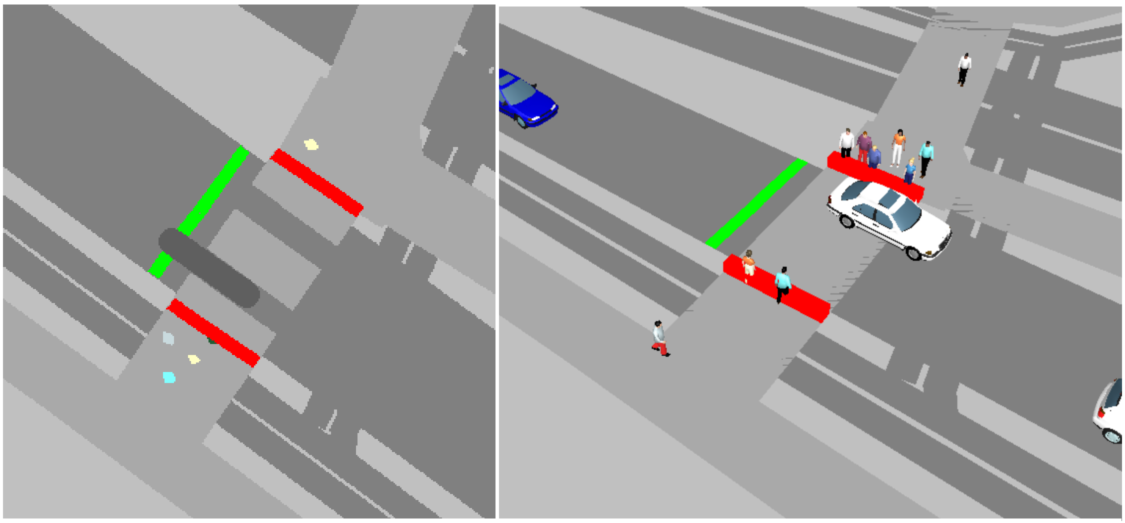


Figure 11. Viswalk model of pedestrians at a signalised intersection

When testing shared space, none of the methods renders satisfying behaviour. Pedestrians do not interact with vehicles in the desired way. With the extended pedestrian link, pedestrians walk unaffected by vehicles and vehicles stop far away, at the start of the link, and there are never pedestrians and vehicles within the area at the same time. With several adjacent links, pedestrians and vehicles find themselves at the area simultaneously, but the movements are choppy.

7.1.3 Examination of performance

The visual examination of both non-signalised and signalised crossing shows good results; the interaction between vehicles and pedestrians is clearly visualised in both 2D and 3D view, see Figure 12.

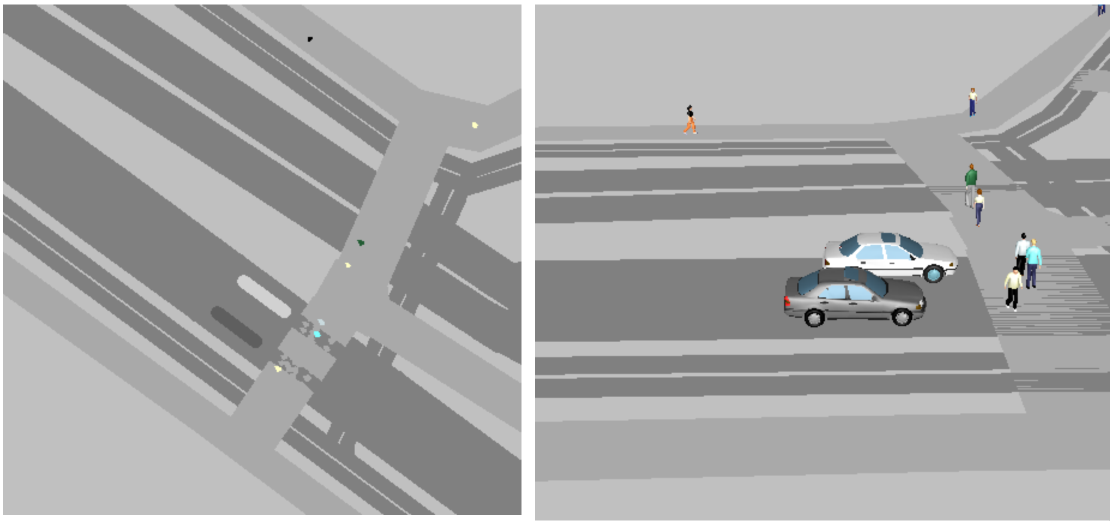


Figure 12. Interaction at a non-signalised crossing in Viswalk, in 2D & 3D view

Numerical outputs of travel time and speed for pedestrians, and travel time and delay for vehicles are derived. Figure 13 shows the proportions of these outputs, compared between a non-signalised and signalised crossing. With the used signal cycle, the pedestrian performance is similar in the two simulations. Yet, the vehicles get a larger delay and consequently a longer travel time when the crossing is signalised. This implies that the signal cycle is not optimized for the vehicular traffic demand. Numerical performance measurements can be helpful in finding effects from a signalising, for both pedestrians and vehicles.

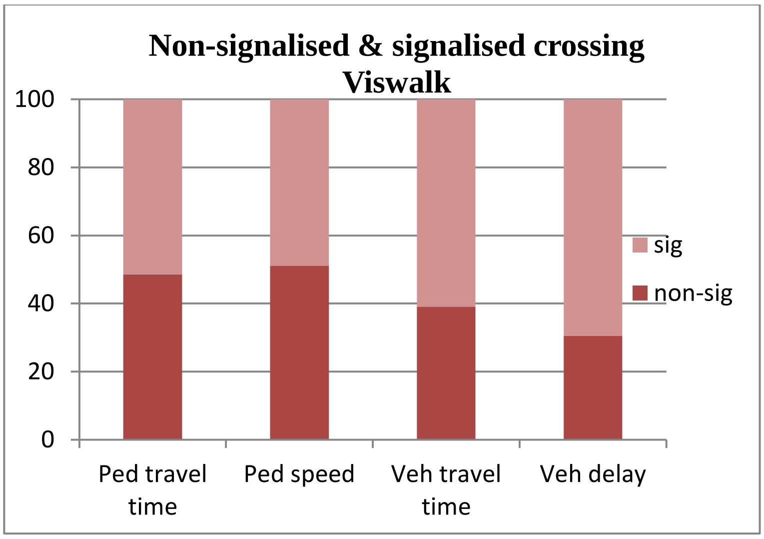


Figure 13. Proportional outputs: non-signalised & signalised ped crossing in Viswalk

The visual examination of shared space is not satisfactory, the behaviour of pedestrians as well as the vehicles are not as desired. Due to these observations, no numerical outputs are derived from the shared space model.

7.2 Legion for Aimsun

Firstly, the Legion for Aimsun model of a non-signalised crossing is examined. The feature pedestrian crossing is used and no additional settings are done. Thereafter, the crossing is signalised and all pedestrians using the crossing are assigned to OD-routes including the crossing. This must be done in order to have pedestrians detect the signals. Finally, a test of modelling shared space is performed, by modelling a vehicle section across a pedestrian area. This is according to a suggestion from TSS Support Team (TSS Support, 2013). There is no specific feature for modelling shared space.

7.2.1 Ease of construction

A non-signalised pedestrian crossing is easily created on a vehicle road. Automatically, priority is given to pedestrians on the crossing. If another regulation is desired, the crossing must be controlled by signals and detectors; hence effort is required to modify the predefined priority.

Signalising of a pedestrian crossing is a comprehensible process. In order to make the pedestrians react to the signals, they have to be assigned to an OD-route including this crossing. In a model with many OD-pairs for pedestrians, effort is required for making OD-routes for each OD-pair using the signalised crossing. It also renders limitations in appliance of free route choice since the share of pedestrians following an OD-route must be defined by the user.

It is not difficult to construct a shared space model according to the chosen method, but there are no predefinitions or available features for modelling a shared space. Hence, one of the difficulties is to decide upon how to construct the model in order to get the most reasonable simulation.

7.2.2 Observations of pedestrian behaviour

At a non-signalised pedestrian crossing, the interaction between pedestrians and cars is reasonable in the sense that cars reduce their speed and stop when a pedestrian is approaching a non-signalised crossing, and wait until the crossing is empty. The pedestrians do not hesitate to enter the crossing; they do not slow down. Everyone obey the regulations and none of the pedestrians walk outside the pedestrian crossing.

At a signalised crossing, pedestrians stop and wait in a reasonable way at red signal. They keep distance to each other and to the road, see Figure 14. Everyone obeys the signals.

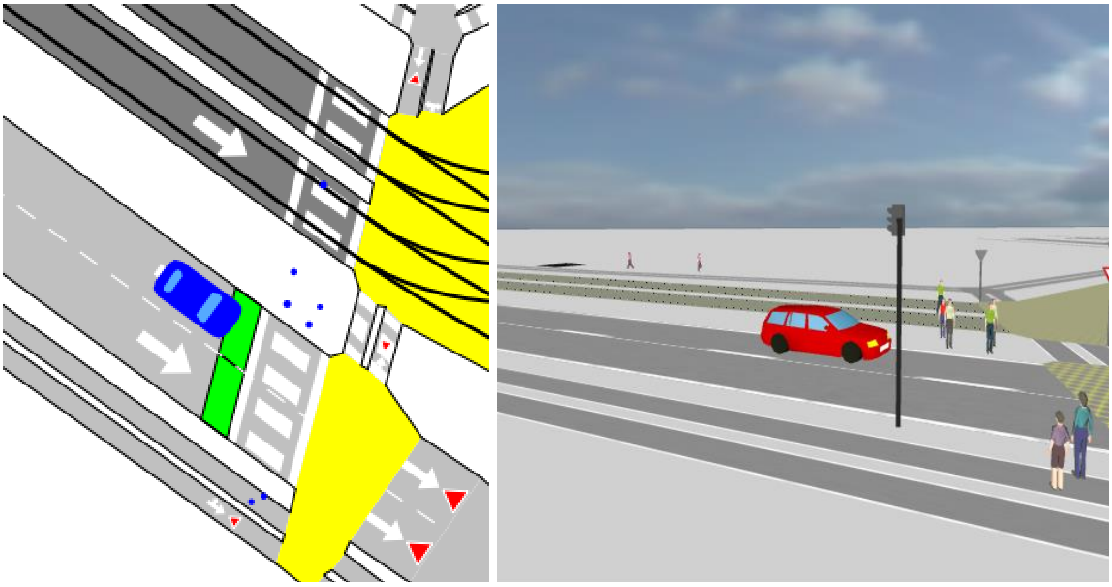


Figure 14. LfA model of pedestrians at a signalised intersection

Regarding the shared space model, the behaviour is not satisfying since pedestrians do not interact with vehicles as they should. According to TSS Support "Legion pedestrians and Aimsun vehicles only interact i.e. notice each other, on pedestrian crossings, and unfortunately this kind of [shared space] models cannot be properly handled by Aimsun" (TSS Support, 2013).

7.2.3 Examination of performance

A visual examination shows good results for both non-signalised and signalised pedestrian crossings; the interaction between pedestrians and vehicles is reasonably visualised in both 2D and 3D view, see Figure 15.

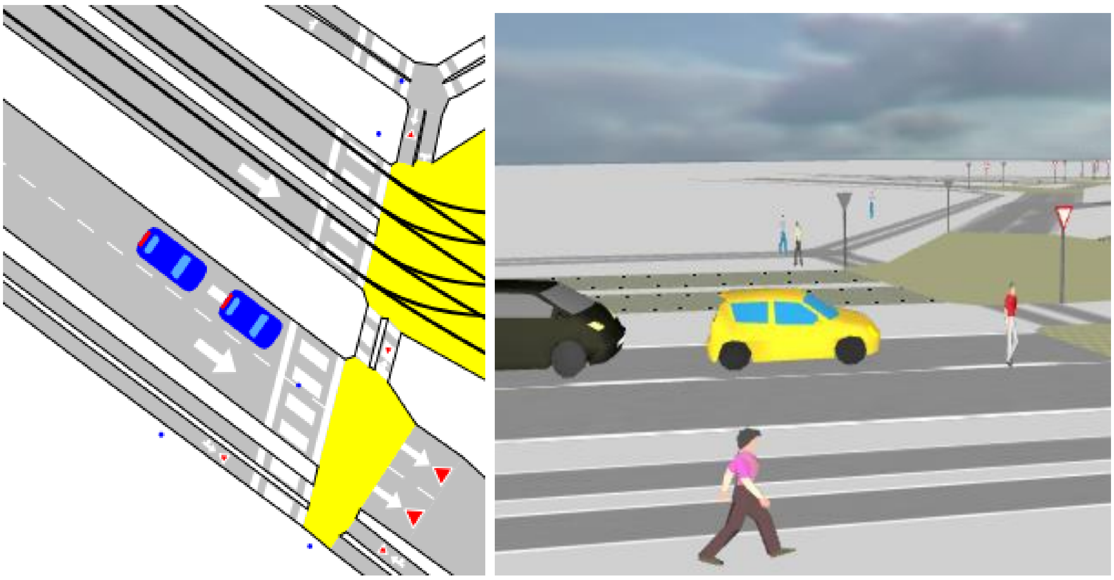


Figure 15. Interaction at a non-signalised crossing in LfA, in 2D & 3D view

Numerical outputs of travel time and speed for pedestrians as well as travel time and delay for vehicles, are compared between the simulation with non-signalised and signalised crossing. The proportional results are found in Figure 16. With the used signal cycle, pedestrian performance is not considerable affected by signalising. Yet, the travel time and the delay are increased for vehicles when the crossing is signalised.

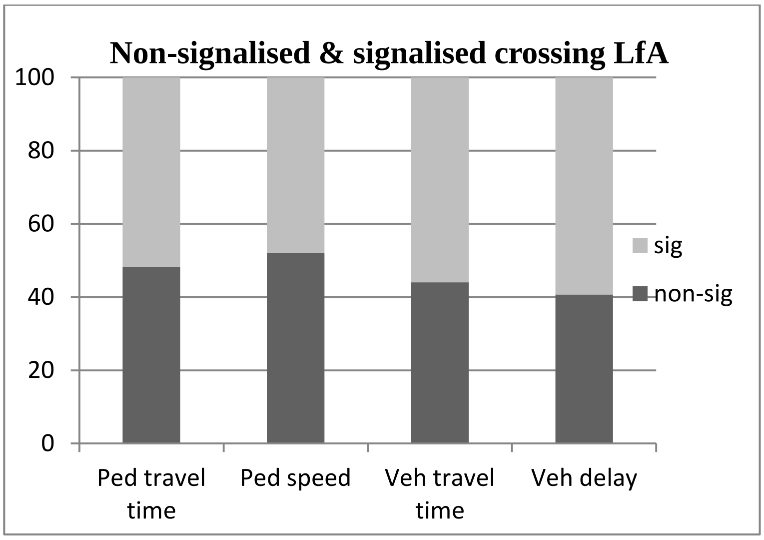


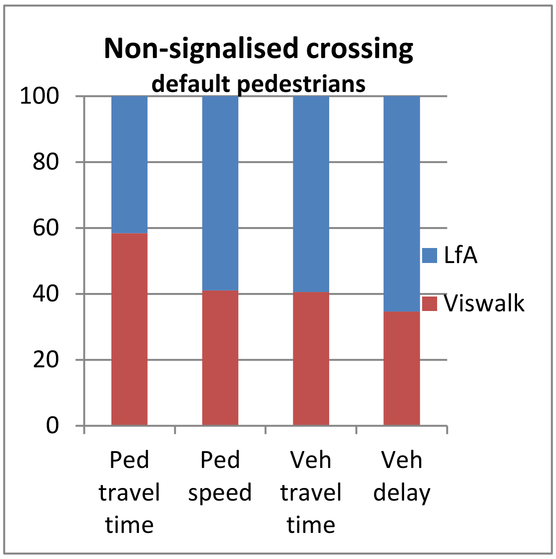
Figure 16. Proportional outputs: non-signalised & signalised ped crossing in LfA

The visual examination of shared space shows that the model is not satisfactory, the behaviour of pedestrians as well as the vehicles are not as desired. Due to these observations, no numerical outputs are derived from the shared space model.

7.3 Comparison

Modelling a non-signalised pedestrian crossing is equally demanding in both software programs. Also, the pedestrian behaviour is equal; in none of the software the pedestrians slow down before the crossing hence it looks like the pedestrians have full confidence in that the vehicles will stop before the crossing and let the pedestrians pass. Yet, there are more modification possibilities in Viswalk.

Figure 17 displays the results for a non-signalised crossing with default pedestrian speed in the diagram to the left and in the diagram to the right, the speed is harmonized by increasing the pedestrian speed in Viswalk. It is clear that the speed is still higher in LfA than in Viswalk. This may be due to differences in defined speed distributions, caused by lack of knowledge in how the speed is distributed within the group of pedestrians in LfA.



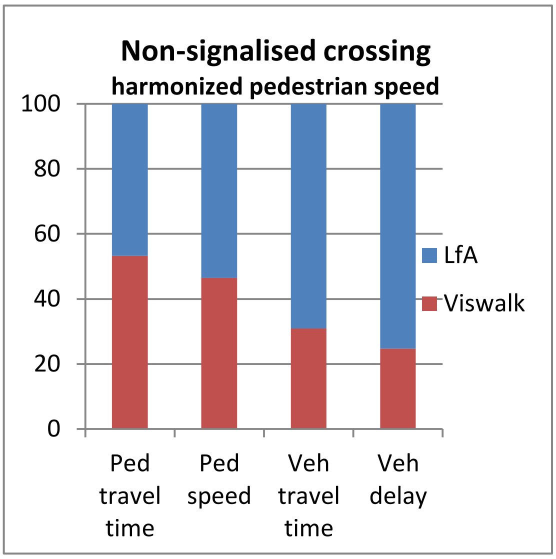
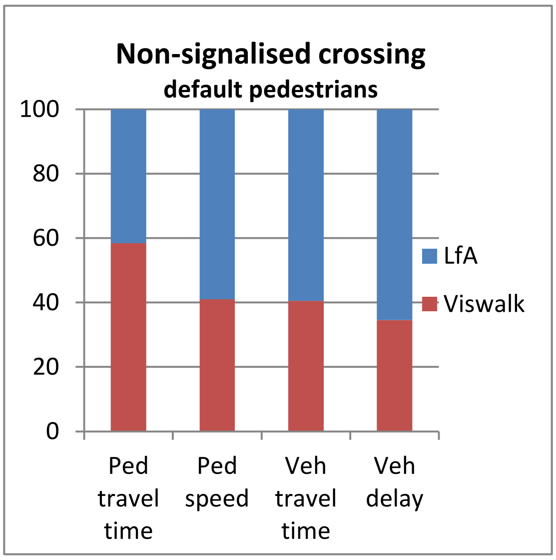


Figure 17. Proportional outputs: non-signalised ped crossing, in Viswalk & LfA

Naturally, the travel time is decreased for Viswalk pedestrians when their speed is increased. For vehicle outputs, the difference in delay and travel time has increased. It seems that pedestrians in LfA have stronger impact on vehicle performance and it is not because they are faster. Contrariwise, the vehicle delay is decreased when the pedestrian speed is increased. The larger vehicle delay in Legion for Aimsun could be because vehicles keep larger distance to pedestrians and decelerate more before the crossing. This could be modified in Viswalk by constructing reduced speed areas for cars before the crossing and by increasing front and rear gap.

Changing priority – giving the vehicles priority when pedestrians cross the road – is considerably easier in Viswalk. In Legion for Aimsun, a crossing with priority for vehicles must be simulated with signals and detectors and in addition to the difficulties in model construction, signalising prevents free route choice in the simulation.



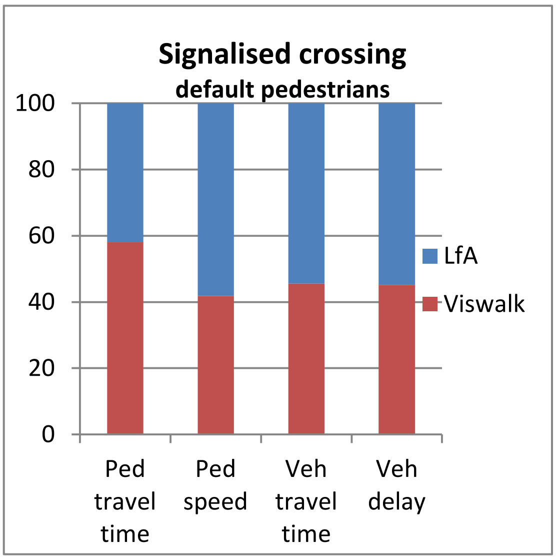


Figure 18. Proportional outputs: non-signalised & signalised ped crossing, in Viswalk & LfA

When it comes to signalised crossing, the largest difference in construction is that OD-routes are needed in LfA which requires more effort and renders limitations. The visual examination shows reasonable behaviour. Figure 18 shows the proportional numerical outputs from non-signalised and signalised crossing, compared between Viswalk and Legion for Aimsun. The ratios between pedestrian performances are very similar, thus the pedestrians seems to be equally affected of the signalising in the software.

Considering the vehicle outputs, the difference in performance between the software is decreased by signalising of the crossing. The vehicle performance is almost the same in Viswalk as in Legion for Aimsun for a signalised pedestrian crossing. This is probably because the driving is controlled by the equally defined signal phases, and travel time and delay are not depending on the interaction with pedestrians but on the traffic lights.

A shared space cannot be satisfying simulated in neither of the software. This may cause difficulties if the user wants to simulate for example a square.

8 Simulation Study: Interaction with Public Transport

In order to examine the possibilities for simulation of pedestrians in interaction with public transport, two opposing public transport stops in the general network are chosen for in-depth study. These PT stops are used by buses and trams, with different amounts of alighting and boarding passengers. Pedestrians cross the tram tracks to get to and from the PT stops, and then they give way to trams and buses. The PT stops are examined in both Viswalk and Legion for Aimsun, with regards to ease of construction, pedestrian behaviour and performance measurements. Modification possibilities are also regarded. Different details of the models are thoroughly examined:

- Alighting
- Waiting and boarding
- Dwell time

When studying alighting, the possibilities to simulate pedestrians crossing the tram tracks and give way to trams are also considered. To compare performance, outputs on pedestrian speed, number of pedestrians alighting, vehicle travel time and vehicle dwell time at PT stop are derived. Also, visual examinations are performed and compared.

8.1 Viswalk

When the PT stops are created, the alternative of automatic creation of platform edges is used. A platform edge is required to allow alighting. Waiting areas assigned to the PT stops are drawn by the user, where the user finds it reasonable to wait for PT. An OD-matrix is used for pedestrians who intend to board PT, and routes are used for the pedestrians alighting PT. Timetables, doors and number of passengers alighting and boarding are set using the available features for PT. The priority for vehicles, when pedestrians cross the tram tracks, is defined using conflict areas. Dwell time is set with a minimum dwell time distribution, defined as mean and deviation, and with values for required time per passenger to board or alight. The option late boarding possible is chosen for the PT stops.

8.1.1 Ease of construction

In Viswalk, it is not demanding to create a platform edge, but the user should be aware of that this edge does not follow if the location of the PT stop or the link is changed. If any adjustments of the location of the link are done, the platform edge must be manually synced; otherwise it will not work properly. The software is very sensitive to crevices in the walkable area. It is recommended to create the platform while creating the PT stop. Viswalk offers the opportunity to adjust the departures and the numbers of alighting in detail for each vehicle. Alighting passengers are handled in several interfaces; hence the process may seem confusing. After alight, the pedestrians must have a route to follow, otherwise they are removed from the simulation. The number of alighting passengers and pedestrians walking from the PT stop will always agree, since they are handled by pedestrian routes, with the alighting passengers as pedestrian input. The priority for trams, before pedestrians crossing the tram tracks, is defined analogue to priority for pedestrians.

The waiting area can have any shape, the user define it analogously to other pedestrian areas. This means that the user has the possibility to determine where pedestrians shall be waiting. It also means that a complete PT stop for alighting and boarding consists of overlapping pedestrian areas; with a base area, platform edge and waiting area. These are not correlated to each other or to the vehicular PT stop and if any geometrical adjustments are done, all elements must be adjusted manually to agree and work properly again. The definition of waiting pedestrians, by assigning a waiting area as the destination for a number of pedestrians, is easy and consistent with the general management of pedestrian traffic demand. The number of pedestrians walking to the PT stop and the number of pedestrians boarding PT automatically agree, since the boarding is defined by proportions for each PT line, derived from the total number of pedestrians at the waiting area.

Dwell time can be managed in several ways, which may be confusing for the user. Yet, the alternatives are optional; the definition can be very easy and meanwhile, there are many possibilities for adjustments available. All dwell time definitions are compatible; the maximum gets determining.

8.1.2 Observations of pedestrian behaviour

Observation of alighting passengers shows that they alight according to defined distribution on doors and follow their assigned route after alight. The interaction with trams on the tram track works reasonably; pedestrians give way to trams but if a pedestrian is already on the track, a stopped vehicle may wait to depart until the track is clear.

Waiting pedestrians spread reasonably over the defined waiting area, see Figure 19. A comment is that if the waiting area gets crowded, pedestrians act strangely trying to get in to the area. Therefore, the user must define a sufficiently large waiting area, but still within a reasonable distance from the PT stop in order to get good waiting behaviour. The strange behaviour could also be avoided by using dynamic potential for the pedestrians' route choice, but be aware of the computational effort required. The boarding behaviour is reasonable. Waiting pedestrians approach the doors as the bus or tram arrives to the PT stop but let alighting passengers go first, and then they board.

The dwell time seems to fit the number of alighting and boarding. An exception is if the waiting area is large, thus some of the pedestrians wait far away from the PT stop. Then a vehicle may leave before everyone has got on even if the user has chosen to allow late boarding, since the doors close after three seconds without any boarding or alighting. This can be prevented by adjustments of the waiting area or definition of longer minimum dwell time.

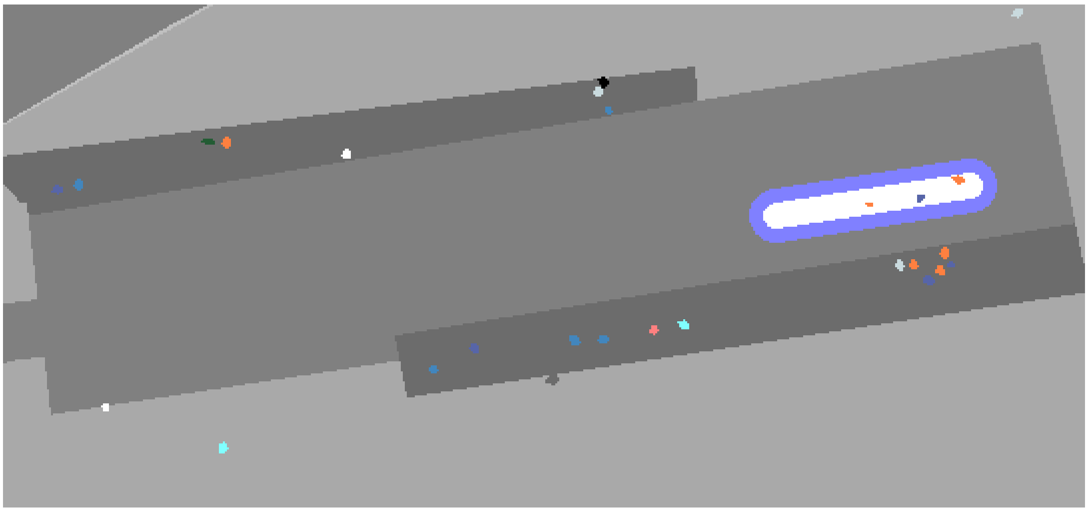


Figure 19. Peds waiting at PT stop, at dark grey user-defined waiting areas, in Viswalk

8.1.3 Examination of performance

Considering the number of alighting passengers, the defined and the actually simulated amount agree. The visualisation of alighting passengers is good.

Waiting and boarding is also well visualised, see Figure 20. It is clear who is boarding and who is alighting.

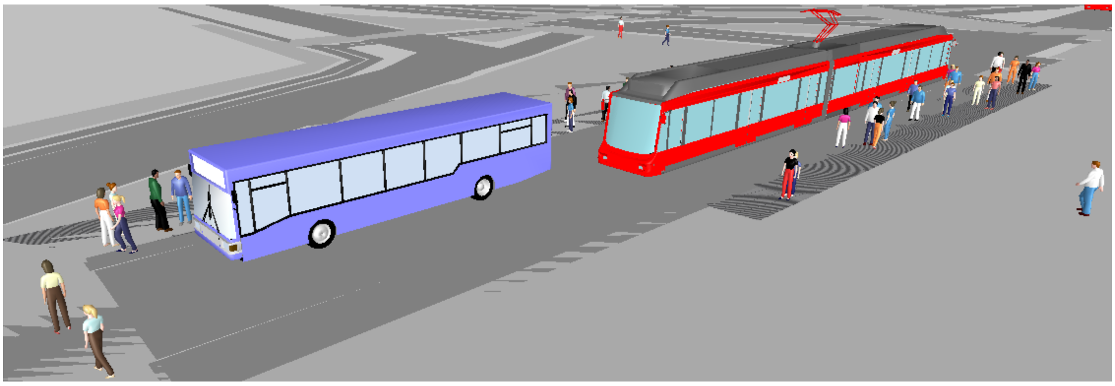


Figure 20. Pedestrians waiting at a PT stop in 3D view in Viswalk

The mean dwell time gets slightly longer than the defined minimum dwell time. It can depend on the deviation of defined minimum dwell time distribution or that the number of alighting and boarding passengers requires longer time than the minimum dwell time. It is understandable how the dwell time is calculated by the software; there are different optional dwell time settings and during simulation, the factor rendering the longest dwell time is determining.

8.2 Legion for Aimsun

When the PT model is constructed in Legion for Aimsun, the available features for PT are used. A new vehicle type is created to represent trams. This is defined with the highest possible resemblance to the trams used in the Viswalk simulation. Alighting passengers are assigned to OD-routes, since this is required to give priority to trams when pedestrians cross the tram tracks. Pedestrian crossings are made on the tram tracks, and signalised. These signals are actuated by detectors, giving trams green light when they arrive and giving pedestrians red light meanwhile the trams pass. Waiting passengers are defined via an OD-matrix, by assigning flows to the pedestrian exits at the PT stops. These flows are set to match the number of boarding, defined via PT timetables. The dwell time is set accordingly to the Viswalk model; with a dwell time distribution defined with mean and deviation in timetables and with a required time per passenger, for boarding and alighting.

8.2.1 Ease of construction

In Legion for Aimsun, it is comprehensible to model PT and its passengers. It is noticeable, that the user cannot modify the number of alighting per vehicle, only per PT line. A difficulty in the tested construction is modelling a pedestrian crossing over a tram track where pedestrians ought to give way; it requires effort and knowledge on signal control and precludes the option of applying free route choice.

For waiting pedestrians, no area has to be assigned. This facilitates modelling but also limits the modification possibilities. Yet, the area where pedestrians wait can be adjusted by changing the length of the PT stop or by adding obstacles. One interesting aspect is that, in order to let pedestrians board, the user has to both define an OD-matrix with pedestrians having the PT stop as destination and define number of boarding people for the specific PT line at the specific stop. If the number of pedestrians getting to the PT stop exceeds the number of boarding PT passengers, there will be a surplus of pedestrians. If the number of pedestrians getting to the PT stop is less than the defined number of boarding passengers, too few will board. For the alighting passengers, no such contradictions can occur in the model since they are handled by a proportional OD-matrix.

Mean and deviation of dwell time is easily defined for each line and stop. Additionally, there are default values of the time required per alighting and boarding passenger and these can be modified for each PT stop.

8.2.2 Observations of pedestrian behaviour

From observations, it seems that pedestrians alight and board at the same time. The detector controlled crossings, representing pedestrians giving way to trams, works but need detailed and time consuming adjustments of the signal phases to imitate priority for trams. Otherwise, pedestrians may wait unreasonably long to cross the track after a vehicle has passed, for example.

Pedestrians in the simulation automatically choose to wait within a rectangular area in the vicinity of the PT stop, with reasonable distance to each other and to the vehicular road, see Figure 21.

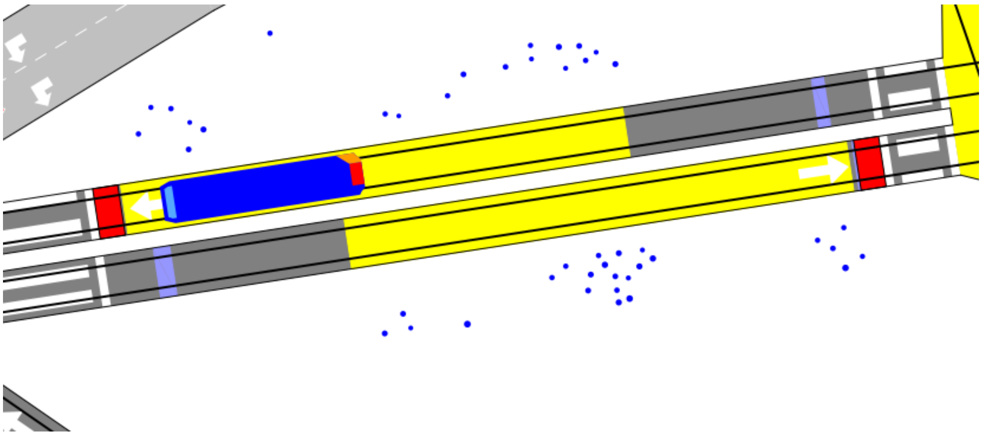


Figure 21. Peds waiting at a PT stop in LfA, waiting location based on PT stop

The visually observed dwell time is short and some passengers seem to board after departure, as if they board while the vehicle is running. This can probably be patched by adjustments of the defined dwell time.

8.2.3 Examination of performance

The number of alighting passengers agrees with the defined amount.

The boarding and alighting is not well visualised in the simulation, neither in 2D nor 3D view. It is not possible to fully distinguish who is boarding, alighting or just walking around at the PT stop. However, waiting pedestrians are well visualised, see Figure 22. Note that signals and detectors must be created in order to give PT vehicles priority.

Figure 22. Pedestrians waiting at a PT stop in 3D view in LfA

The dwell time gets slightly longer than the defined mean dwell time. This seems reasonable with the used dwell time settings – mean and deviation for the PT line and required time per passenger – but it is unclear how the software actually calculates the dwell time during a simulation; it is not stated which of the two definitions of dwell time that gets determining or how they affect each other.

8.3 Comparison

In ease of construction and modification possibilities, the software differ. An advantage of Legion for Aimsun is that it does not require as much effort to model pedestrians in interaction with PT; the process is comprehensible. Yet, the difficulty of simulating pedestrians giving way to vehicles is a disadvantage of the software. The strength of Viswalk is the modification possibilities. Examples of this are the user-definition of waiting area and the possibility to define number of alighting passengers per vehicle.

Visual examinations of the simulations show that the major visual difference regards the boarding and alighting. In Viswalk, the visualisation is clear and reasonable whereas it is unclear in Legion for Aimsun.

As shown in Figure 23, the numerical outputs derived from the models are similar, for both pedestrians and vehicles. The pedestrian speed, number of pedestrians alighting and the vehicle travel time gets slightly larger values in Viswalk, and the vehicle dwell time gets slightly larger in Legion for Aimsun. Yet, the differences are small and the performances of the simulations in each of the software are considered equal regarding these numerical outputs. Hence, the two software programs seem to handle pedestrians as PT passengers correspondingly.

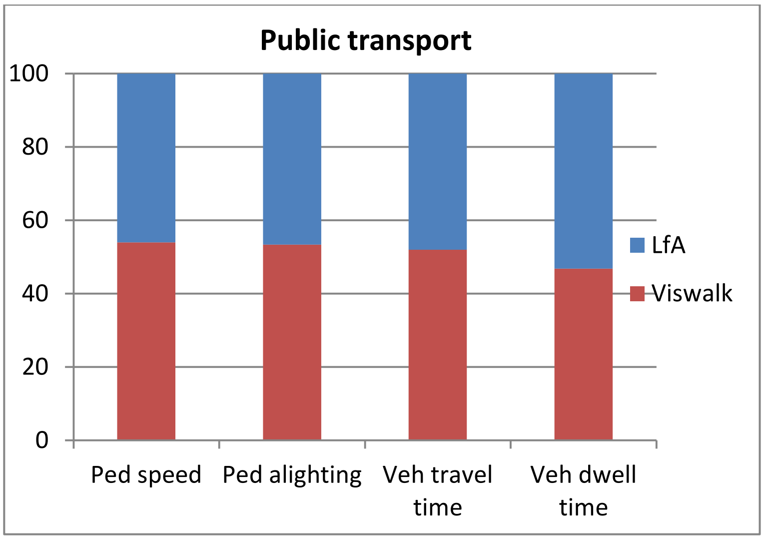


Figure 23. Proportional outputs of interaction with PT in Viswalk & LfA

9 Simulation Study: Comparison

In this chapter, the results from Phase 3 are summarized. Firstly, the findings on ease of construction are presented. Secondly, the pedestrian behaviour observed in simulations is commented and lastly, the findings on performance measurements are evaluated. The results are presented in tables, with a four step grading and one example of what each grade is based on. The chosen example represents the most significant aspect on which the grade is based.

9.1 Ease of construction

The ease of construction is summarized for *geometrics* (modelling infrastructure), *traffic demand* (defining traffic flows), *interaction with vehicles* (constructing pedestrians crossing) and *interaction with public transport* (making all settings needed to simulate pedestrians as PT passengers), see Table 7.

Construction refers to model construction by use of available features. Very Easy construction means that a fairly low level of application knowledge is required to build a simple model. The scale continues with Easy, Fairly Difficult and Difficult, which means that it is demanding to find out how to model this object or it is a complicated process.

Modification refers to the possibilities to modify an object. Very Good modification possibilities mean that there are several options for adjusting and refining the model, and the user has the possibility to make conscious changes. Scarce possibilities imply the opposite, where there are no or very limited options or when information on underlying parameters is not available.

Table 7. Comparison of ease of construction

Model construction		Viswalk	Legion for Aimsun
Geometrics	Construction	Easy. Sensitive to design details & multiple areas	Very Easy. Vehicle roads are made obstacles. Peds may get stuck in corners
	Modification	Very Good. Coordinates in error message may help finding crevices	Very Good. Obstacles can be generated from existing objects, CAD-files or drawn manually
Traffic demand	Construction	Easy. The correlation between OD-matrix and routes is undistinguished	Very Easy. The correlation between OD -matrix and OD - routes is clear
	Modification	Very Good. Possible to use either routes, OD-matrix or both	Very Good. Can use OD-matrix alone or in combination with OD-routes
Interaction with vehicles	Construction	Very Easy. Priority is defined by the user	Very Easy. Peds are given priority
	Modification	Very Good. Priority is easily changed and either mode of transport can get priority	Scarce. Changing priority is problematic and excludes free route choice
Public transport	Construction	Fairly Difficult. Several construction elements requires several settings and inputs	Easy. Requires several settings but the construction is logical
	Modification	Good. Can modify in detail, e.g. alighting per PT vehicle	Fairly Scarce. Cannot modify in detail, e.g. alighting per PT vehicle

One aspect worth highlighting is the limitations on pedestrian crossings in Legion for Aimsun. When signalising a crossing, the free route choice cannot be applied and it is difficult to let pedestrians give way to vehicles. When simulating an informal pedestrian crossing, i.e. a spot where pedestrians choose to cross the road without regulations, it could be useful to model a pedestrian crossing where vehicles have priority. This is much less demanding in Viswalk.

To conclude on model construction, Legion for Aimsun is easier to use if only predefined features are desired but Viswalk offers more modification possibilities.

9.2 Observations of pedestrian behaviour

The findings on pedestrian behaviour are summarized for *behaviour parameters* (how pedestrians interact with other pedestrians and their nearest environment), *route choice* (how pedestrians find their way through the model) and *speed*, see Table 8. *Default* considers how reasonable the simulated pedestrians behave with default settings. *Modification* considers the modification possibilities of pedestrian behaviour; if, how demanding it is and to what extent the behaviour can be modified.

Table 8. Comparison of observations of pedestrian behaviour

Pedestrian behaviour		**Viswalk**	**Legion for Aimsun**
Behaviour parameters	Default	Good. Reasonable stopping and waiting behaviour however, walk straight against each other and then make a sharp turn	Very Good. Reasonable walking, stopping and waiting behaviour
	Modification	Very Good. All parameters can be changed but it requires knowledge on the social force model	Scarce. It is easy to change entity profile however, descriptions of the entity profiles are not available
Route choice	Default	Good. All peds with the same OD-pair choose the same path. Obstacles and narrow passages influence, but not traffic situation or crossings	Very Good. Can choose slightly different paths. Obstacles and narrow passages influence, but not traffic situation or crossings
	Modification	Very Good. Can be modified by infrastructural changes, intermediate points, partial routes for which the user chooses route choice method and by dynamic potential	Fairly Scarce. Can be modified by infrastructural changes and OD-routes but the route choice method, the parameters of auto-navigation on macro level, cannot be changed nor examined
Speed	Default	Very Good. Predefined speed distribution & speed variation is observed	Very Good. Predefined speed distribution & speed variation is observed
	Modification	Very Good. The user can choose between different speed distributions or define new distributions	Scarce. It is easy to change speed profile however, descriptions of the speed profiles are not available

It should be highlighted that the possibility to change the route choice method in Viswalk has no equivalent in Legion for Aimsun, and the availability of information on pedestrian parameters is significantly better for Viswalk.

To conclude on pedestrian behaviour, Viswalk offers more possibilities to modify the pedestrian behaviour in detail but it requires knowledge to understand the effects of different changes. Legion for Aimsun is limited in modification possibilities and in information available on underlying parameters and algorithms. Both software programs simulate pedestrians reasonably and the default behaviour and route choice is similar.

9.3 Examination of performance

The performance measurements are evaluated by their availability and, when applicable, default settings. In Table 9, the findings on performance measurements are presented, for *visualisation* (recordings of simulations for analysis and communication purposes), *numerical outputs* (values that can be calculated for a simulation) and *statistical certainty* (how statistical certainty can be improved for simulation results). For the modification possibilities of performance measurements, the available options for graphical presentation and adjustments of measurement scope and form are considered.

Table 9. Comparison of examination of pedestrian performance

Performance measurements		Viswalk	Legion for Aimsun
Visualisation	Default	Good. Peds are well visualised, both appearance and movements. However, the network does not by default include visual features such as road marks	Very Good. Peds are well visualised, both appearance and movements. Network automatically includes visual features such as road marks and traffic signs
	Modification	Very Good. Peds' appearance in 3D can be modified in detail	Very Good. Peds' appearance in 3D can be modified in detail
Numerical outputs	Availability	Very Good. Several outputs are available and effects for and of pedestrians can be detected. Yet, output files are demanding	Good. Several outputs are available and effects for and of pedestrians can be detected. Yet, only compiled outputs are available
	Modification	Very Good. The user can define measurement area, both size and location	Scarce. Only existing objects can define scope of measurement
Statistical certainty	Availability	Good. Easy to make multiple simulations but the result files are not compiled automatically	Very Good. Easy to make multiple simulations & average results are automatically obtained
	Modification	Very Good. Can choose number of runs and random seeds	Very Good. Can choose number of replications and random seeds

To conclude on performance measurements, a major difference is the default view settings; 2D view of a simulation in Legion for Aimsun, is more appealing than in Viswalk. More effort is required to make a presentable video of a Viswalk simulation, but it is possible to make appealing simulations in Viswalk as well. Yet, boarding and alighting PT passengers are more clearly visualised in 3D view in Viswalk, than in Legion for Aimsun. Several numerical outputs are available in both software, and the most significant difference is that it is possible for the user to define a measurement area in Viswalk but not in Legion for Aimsun. It is also noteworthy, that there are many differences between the software, regarding which outputs and scopes of measurements that are available.

10 Analysis

Phase 4 is an analysis of all the previous phases. Firstly, the utility and possibilities of pedestrian traffic simulations are analysed. Secondly, the two simulation software are analysed by conducting SWOT analyses, which can be used as support for choice of software. Finally, the derived SWOT analyses are applied on three potential situations, to show how the formulated SWOT can support identification of the most suitable software, and give guidance on whether or not a pedestrian traffic simulation is appropriate.

10.1 Possibilities with pedestrian simulation

This section analyses the utility of and possibilities for simulating pedestrians in interaction with other modes of transport. The first section considers general advantages and disadvantages with pedestrian traffic simulations, and the utility of such simulations. The second section considers possibilities of model construction, pedestrian behaviour, model modifications and performance measurements, as well as the importance of such possibilities. The final section considers how utility and possibilities depend on the situation.

10.1.1 Utility of pedestrian traffic simulation

One of the major advantages with microscopic traffic simulation is that after a model is constructed, different scenarios can easily be simulated and analysed. This enables both sensitivity analysis and comparison of different alternatives. Even if the input data is never fully reliable, and there may be a lack of guidelines for acceptable or desired traffic situation, simulations can be useful through the possibility of making several tests and comparisons and the inclusion of randomness. Results from several simulations of the same model but with different random seeds can be compiled in order to improve the statistical certainty, which is important for the credibility of the results.

Another major advantage is the visualisation, which can be used both for analysis – by giving an impression on the traffic situation and also inspiration for new ideas – and for communication – as incentive for a proposed design and as a base for discussion. In addition to the visualisation, numerical outputs can be derived. These can be especially useful when comparing different scenarios and proposed designs, and thus give an indication on which effect different measures would cause, how sensitive the model is to input data and which of different alternatives is the best. All these general advantages of microscopic traffic simulations are found to be valid also for traffic simulations including pedestrians and are an incentive for use of such simulations.

Since both microscopic traffic simulations and simulations of exclusively pedestrians are widely used and considered powerful tools, the potential of pedestrian traffic simulations should be great. The inclusion of the interaction between pedestrians and other modes of transport in microscopic simulations enables analysis of how pedestrians and vehicles affect each other. A positive effect of handling pedestrian planning and analysis the same way as vehicular traffic is handled, could be an improvement of the status of pedestrians as a mode of transport.

As for all simulations, it is important to remember that it is a model of the reality, not the reality, and a critical assessment should always be conducted. When the user does not have insight into the calculations and assumptions, the credibility is threatened. Pedestrians differ from other modes of transport by being more unpredictable and heterogeneous, and there is no software that can fully handle their complex behaviour and interaction. Yet, this study has found that there are many possibilities for pedestrian traffic simulations and there are software available that can simulate pedestrians in interaction with other modes of transport in such way that simulations are useful for analysis, design and communication.

10.1.2 Importance of software possibilities

It is found that there are many possibilities for model construction; in the studied software, there are several features for modelling pedestrians in traffic situations. This is a crucial factor; the user is limited by the possibilities offered in the software, and the specific situation must be possible to model. Yet, it is important to take into consideration that many situations can be simulated without an explicit feature, by being innovative and making proper assumptions. One situation that cannot be properly simulated in either of the studied software is shared space. If a feature for this was developed, it would enhance the possibilities for pedestrian traffic simulations.

The ease of construction may be of importance, not only for the required effort of modelling, but also for the correctness. Complicated and incomprehensive model construction increases the risk of mistakes and misleading results. There can also be positive aspects of complexity in model construction, since it may lead to more possibilities for the user to define details in the model.

It is found that microscopic traffic simulations can handle pedestrian characteristics and simulate the interaction between pedestrians and other modes of transport. A proper interaction is important when analysing traffic situations, to visually and numerically examine how pedestrians affect vehicles and how vehicles affect pedestrians. Reasonable interaction among pedestrians is not always required for traffic analysis, but it is important when the pedestrians have strong influence on each other and for the possibility to derive an appealing and trustworthy visualisation. One aspect of pedestrian behaviour that is not found in the studied software is the tendency of walking in groups. This, and other shortages, can be handled by innovative modelling and proper assumptions; solutions can be found but the user must be aware of limitations in the software.

It is found that the choice of entity and speed profile has a large impact on the performance of Legion for Aimsun models. The lack of information on what these profiles imply is a threat to the credibility, since the choice is found to have a significant effect but cannot be made consciously. The only way to examine these profiles is by observing performance visually and numerically. For Viswalk, the information on underlying parameters is available and they can be modified by the user. However, it is found to be demanding to achieve the desired changes in behaviour since knowledge in the social force model is required.

The possibility to include different pedestrian types in the same model is important when simulating an area where pedestrian groups with diverse behaviour are present. The diversity in behaviour is a characteristic distinguishing pedestrians from other modes of transport, and it can be important to analyse how this diversity affects the interaction with vehicular traffic.

A positive finding is that pedestrian simulations provide possibilities to analyse route choice. This can be useful when testing proposals on infrastructural design, to get indications on which routes will be attractive and how different measures may impact the route choice. Even if the route choice of real pedestrians is very complex and influenced by many external and internal factors, the simulated route choice can be helpful for identification of possible shortcuts and give guidance on the attractiveness of different routes. The possibility of altering route choice method in a Viswalk simulation can strengthen results and show several possible scenarios, which enables a better analysis. It can also be of importance that it is possible to steer the route choice, for example if it is desired to replicate observed routes or to simulate attractions such as ticket vending machines.

Modification possibilities are found in the software, with significant differences in what can be modified and to what extent. The importance of modification possibilities is highly dependent on the situation. When it is desired to construct a model with a pedestrian behaviour, that is carefully calibrated against an observed behaviour, the possibilities to modify the behaviour are crucial. In another situation the behaviour could be of less importance, for example if the purpose is to compare alternative designs and the credibility of results is secured by testing a variety of pedestrian behaviours. The importance of modification possibilities depends on how the default model differs from the desired model, i.e. how sufficient the default settings are, and which differences are considered acceptable.

In this study, available pedestrian performance measurements are identified, both visual and numerical. Derived outputs are found to be reasonable and numerical output can clearly represent the interaction between pedestrians and vehicles. It is important that the visualised pedestrian behaviour is realistic; otherwise the simulation will not be regarded as trustworthy. Density maps, showing LOS, is a recognised measurement for pedestrians and the availability of such and similar maps is therefor considered important. With good visualisation, a video or an informative map can hold much information and be a powerful tool for analysis and communication.

In addition to this, numerical outputs can be derived which support analysis and design. Numerical outputs are especially useful for identification of effects of changes or difference between alternatives, when applicable, even if there is a lack of calibration data or guidelines. It can also be used for verification of input, for example to check if the simulated pedestrians get desired speed or if the speed distribution should be changed. What numerical outputs and what measurement scopes the software offers is important for the possibilities of conducting numerical analysis and comparing scenarios. If details are ought to be numerically analysed, it may be desired to obtain outputs per pedestrian and to derive statistical values such as mean, minimum and maximum.

10.1.3 Situation dependency

If a pedestrian traffic simulation is useful and which software that is most feasible, depends on the situation. The infrastructural design, traffic demand and traffic regulations as well as the purpose of the investigation must be taken into consideration in the decision on whether to make a simulation or not, and which software to use. The purpose – to analyse, design or communicate – determines what performance measurements are useful; it is crucial to identify what is requested. The decision must be based on the specific situation: What to simulate? What is the purpose?

To support this decision, a tool is developed. On basis of pedestrian characteristics and problems in managing pedestrian issues, strengths that should be searched for in simulation software are found to be available features, simulated pedestrian behaviour and modification possibilities. The opportunities to consider are performance measurements and what possibilities the software offer for analysis, design and communication. It is important to be aware of weaknesses that can hinder proper simulation of the specific situation, such as limitations in the software and difficulties for the user. Furthermore, threats that can prevent proper use of the simulation, by causing misleading or unreliable results, must be regarded. With regards to these aspects, the software Viswalk and Legion for Aimsun are analysed and the major Strengths, Weaknesses, Opportunities and Threats are presented in the next section.

10.2 SWOT analysis of simulation software

SWOT analysis is an acknowledged tool for developing strategies and is useful for obtaining information required for strategic decisions (Ferrell & Hartline, 1998). It identifies positive and negative aspects, and organizes these in internal and external factors. The internal factors consist of *Strengths* and *Weaknesses*, and the external factors consist of *Opportunities* and *Threats*.

In the SWOT analysis of the software, Strengths represent what can be done in the software and Opportunities represent what the simulations can be used for. Weaknesses represent the obstructions of modelling and Threats represent obstructions of making use of a simulation

10.2.1 SWOT analysis of Viswalk

Table 10 presents the SWOT analysis of Viswalk as software for pedestrian integrated in traffic simulation. Positive aspects are found in the left column (Strengths and Opportunities) and negative in the right column (Weaknesses and Threats). The text in red represents the features that are found in Viswalk but not in LfA.

Table 10. SWOT analysis of Viswalk

Viswalk	
Strengths	Weaknesses
• **Interaction with vehicles on pedestrian crossing**: signalised or non-signalised, with priority for pedestrians or vehicles • **Pedestrian flow**: user defines origin and destination, intermediate destinations are available • **Import of files**: as background or pedestrian elements • **Pedestrians as PT passengers**: user defines route to PT stop, waiting area, boarding passengers per line, boarding distribution on doors, occupancy per line or per vehicle, share of alighting passengers per line, alighting distribution on doors, dwell time, route from PT stop • **Predefined pedestrian behaviour**: social force model, speed distribution and route choice models • **All pedestrian parameters can be examined and modified** • **Different behaviours can be included in one model**: for pedestrian types, routes, areas and time intervals	• No proper solution for simulation of **shared space** • **Overlaps and crevices** in pedestrian areas • **Unclear correlation** between the two features for input of flow (OD-matrix and input/route) • **Demanding modelling** of pedestrians as PT passengers • **Demanding output files**
Opportunities	Threats
• **Visualisation**: pedestrians' appearance, movement and interaction with other modes of transport • **Visual area evaluation**: visualising density or speed, according to industry standards (LOS) or a user-defined scale • **Visual pedestrian evaluation**: visualising speed or acceleration of pedestrians • **Numerical outputs**: per pedestrian, OD-pair or area, as minimum, mean and maximum • **Numerical area evaluation**: user defines measurement area • **Calibration**: user can modify pedestrian behaviour in detail • **Statistical certainty**: multiple simulations with different random seeds • **Sensitivity analysis**: user defines percentage to examine different traffic demands	• **Complexity**: many interfaces and parameters require careful and cautious model construction and behaviour modifications • **Default visualisation of network**: user has to modify view settings to attain well visualised environment

10.2.2 SWOT analysis of Legion for Aimsun

Table 11 presents the SWOT analysis of Legion for Aimsun as software for pedestrian integrated in traffic simulation. Positive aspects are found in the left column (Strengths and Opportunities) and negative in the right column (Weaknesses and Threats). The text in blue represents the features that are found in LfA but not in Viswalk.

Table 11. SWOT analysis of Legion for Aimsun

Legion for Aimsun	
Strengths	Weaknesses
• **Interaction with vehicles on pedestrian crossing**: signalised or non-signalised • **Pedestrian flow**: user defines origin and destination, intermediate destinations are available, pedestrians' focus can be defined as a point or segment • **Import of files**: as background or pedestrian obstacles • **Pedestrians as PT passengers**: user defines waiting pedestrians, boarding passengers per line, occupancy per line, alighting passengers per line, dwell time, route from PT stop • **Predefined pedestrian behaviour**: auto-navigation, entity and speed profiles • **Different pedestrian types can be included in one model**	• No proper solution for simulation of **shared space** • **Limited options for interaction with vehicles**: priority to vehicles requires detectors and signals, signalising precludes free route choice • The number of pedestrians walking to a PT stop and the number of **pedestrians boarding PT are not correlated** • **Limited options of pedestrian behaviour:** can only choose among predefined profiles for pedestrian characteristics and speed, cannot modify route choice model
Opportunities	Threats
• **Visualisation**: pedestrians' appearance, movement and interaction with other modes of transport • **Default visualisation of network**: well visualised network, further improvements and adjustments are possible • **Numerical outputs**: per entire system, OD-pair or pedestrian crossing, as mean values • **Statistical certainty**: multiple simulations with different random seeds, automatic calculation of average • **Sensitivity analysis**: user defines multiplying factor to examine different traffic demands	• **Scarce information on underlying parameters and algorithms**: entity profiles, speed profiles, route choice • **Numerical outputs** not obtained per pedestrian and not with deviation

Note that this SWOT analysis regards Legion for Aimsun without Legion Analyser. There *might be* further opportunities for visual and numerical performance measurements with access to Legion Analyser.

10.3 Applications of SWOT

This section aims to demonstrate applications of the elaborated decision support tool, hereafter referred to as SWOT, Table 10 and Table 11, by describing the use of the SWOT in three different potential situations. In short, these applications are conducted by firstly describing a potential situation. Then all strengths and opportunities applicable to the situation are identified through the SWOT. These are compared between the software, in order to identify the software that contains the most and greatest strengths and opportunities. Then the possible weaknesses and threats of this software are identified through the SWOT and by comparing and weighting the positive aspect towards the negative, it is decided if a pedestrian traffic simulation is appropriate.

10.3.1 Application 1: Redesign of saturated intersection

This potential situation is an existing intersection with interaction between vehicles and pedestrians with a high degree of saturation and low LOS on the pedestrian areas. The purpose is to find possible changes in infrastructural design that will lower the degree of saturation and increase the LOS. Minimum change in design with maximum positive effects for pedestrians is the ambition.

Strengths and opportunities which are relevant for this potential situation are identified in the SWOT. The interaction between vehicles and **pedestrians on a crossing** can be simulated by both software. However, if it is observed from field studies that pedestrians tend to cross the street outside the pedestrian crossing, where they do not have priority, Viswalk could simulate this more appropriately without limitations in route choice. The **pedestrian flows** can be steered by the user, based on observations by field studies or video recordings. Another applicable strength is the **import of files**; a map of the intersection can be used as background, for model construction as close to reality as possible. The **predefined pedestrian behaviour** can be used initially and compared to observation. If modifications are required, the **pedestrian parameters can be modified** to a greater extent in Viswalk. In Legion for Aimsun, the modification is limited to the different profiles. In order to get a variation in behaviour that agrees with observations, **pedestrians with different behaviour can be included in the model.**

A base model of the existing intersection is constructed, with **calibrated** and verified behaviour and performance, possible improvements in the design can be identified through visual examination. The base model is then modified according to the proposed changes in order to analyse them. The opportunity with this simulation is to compare the models with changed design, to the base model of the existing situation. This can be conducted by **visual evaluation** in Viswalk, e.g. speed of individual pedestrians or LOS for a pedestrian area. In addition, **numerical outputs** can be compared, both for pedestrian on certain routes, or in Viswalk, on certain **areas**, e.g. if a passage ought to be investigated in detail. The numerical outputs can be strengthened by **statistical certainty.** The credibility of the results is strengthened by **calibration** and verification of the base model towards observations in the **visualisation** of the intersection. This can be conducted with greater detail in Viswalk. However, the default visualisation might appear better in Legion for Aimsun. If the visualisation is to be communicated, improvements of a Viswalk default network may be needed. Lastly, the results can be tested in a **sensitivity**

analysis, where different traffic demands are tested to examine how they affect the final result. In this way, uncertainties in traffic prognoses can be handled.

In conclusion, Viswalk has more strengths and opportunities in this potential situation. However, the weaknesses and threats should be examined before a decision can be made on whether or not to simulate the potential situation in Viswalk.

Overlaps and crevices in pedestrian areas could lead to temporary problems which can be solved by careful and cautious model construction. In this potential situation, **the correlation between the features for input of flow** can be secured by using either OD-matrix or pedestrian input and pedestrian routes. If many numerical outputs are required, the management of them can be **demanding**. Yet, it is an opportunity that there is a variety of numerical outputs available. The threat of **complexity** in construction and modifications can be avoided by caution and experience in the software and the **default visualisation**, if applicable, could be improved. To conclude, all relevant weaknesses and threats can be handled, as long as the user is aware of them. A simulation in Viswalk is appropriate.

10.3.2 Application 2: Travel time optimisation of intersection

This potential situation is an existing pedestrian crossing that ought to be optimised with regards to travel time. The design is not evaluated but instead the regulations; available options are non-signalised and signalised. If a signalised option is found to be preferred, the signal phase shall be optimised.

The interaction between vehicles and **pedestrians on a crossing** can be simulated by both software. However, Legion for Aimsun limits the option of free route choice on signalised crossings. This is not of concern for this situation. Since only the interaction at the crossing is under evaluation, the size of the **pedestrian flow** is regarded, but not their routes. **Import** of a background representing the intersection will simplify the model construction. Both software provide **predefined pedestrian behaviour**, Viswalk provides modification possibilities whilst Legion for Aimsun provides the option of choosing between different entity and speed profiles. **Different pedestrian types** can strengthen the credibility, by presenting consistent results for different pedestrian types.

Since the alternatives are fixed – it is an existing crossing that just should be non-signalised or signalised, with the best signal phases – the purpose is not to find alternatives but rather compare and choose between the given alternatives. Models of the different alternatives are compared, and therefore, extensive **calibration** and verification against the pedestrian behaviour at the crossing is not required. An easier way of verifying the results can be conducted, for example by testing different entity and speed profiles for the pedestrians. If an alternative provides positive results for all entity and speed profiles, it is a good indication to choose this alternative.

The main opportunity with simulating this potential situation is the **numerical outputs** of travel time. Since the purpose is to optimise, the impact on travel time in the different alternatives, and maybe from different signal phases, it can easily be tested and also compiled in Legion for Aimsun. The same information can also be obtained by Viswalk. However, the altering of pedestrian behaviour and the output files would be more demanding compared to LfA where the mean of the replications is presented automatically. In addition to test the model with different pedestrian entity and speed profiles, the alternatives can be analysed based on **sensitivity** with regards to traffic demand prognoses, to evaluate the effects of a possible increase or decrease. An opportunity could also be the **visualisation** of pedestrians' behaviour and a **well visualised** network.

Both software has the required strengths and opportunities. In addition, for this potential situation LfA offers less demanding model construction and management of output data and a well visualised network by default. However, the weaknesses and threats should be examined before a decision can be made on whether or not to simulate the potential situation in Legion for Aimsun.

As mentioned, the weakness of **precluding free route choice** at signalised intersections is not an issue for this potential situation since routes are not examined. Furthermore, the **limited options of pedestrian behaviour** are not as relevant, since different profiles can be tested and a full calibration towards real behaviour is not required. The credibility of this simulation is based on consistent results of tests with several pedestrian entity and speed profiles; hence the **scarce information on underlying parameters** is not considered an issue as long as the results obtained for different pedestrian profiles agree sufficiently. **Numerical outputs not being obtained per pedestrian** is not a threat in this situation, since compiled mean values are compared with the purpose to optimise the entire system and not for individual pedestrians. A simulation in Legion for Aimsun is appropriate.

10.3.3 Application 3: Design of PT interchange facility

The potential situation is a major PT interchange facility that should be developed with metro station below ground and PT tram stops at the surface. The purpose is to find and analyse an appropriate design of the facility.

A necessary feature for this modelling is **interaction with vehicles on pedestrian crossing**, signalised or non-signalised might be tested but most importantly, pedestrians giving priority to trams. This could be conducted in both software, however Legion for Aimsun requires detectors and precludes free route choice. The route choice can be very interesting to analyse since this is a new facility, the **pedestrian flow** is not known and the **predefined pedestrian behaviour** provides the possibility to analyse the area with regards to route choice. In addition to the predefined pedestrian behaviour, the route choice in Viswalk can be modified and be based on e.g. shortest path, travel time or points of interest. By simulation, possible congestion or low LOS can be found and prevented before actual construction of the facility. Testing different route choice methods strengthen this identification of problematic areas. The simulation can provide a basis for analysing pedestrian flow, which is helpful when designing the facility, e.g. finding appropriate location and dimension of exits and entrances to the metro station.

Since there is no existing facility to compare with, it is of importance to make sure the pedestrians act reasonably, as observed in similar situations within the particular urban area. The strength in Viswalk that all **pedestrian parameters can be examined and modified** provides this possibility to full extent and adds credibility to the simulation. **Different behaviours can be included in one model,** a strength that provides the possibility to have a variety of pedestrian types, and makes sure the design is appropriate for all situations. Full correlation of **pedestrians as PT passengers** is obtained for Viswalk and the user can define in detail how the integration shall be conducted, e.g. share of alighting passengers per PT line, their distribution on doors and location while waiting. LfA provides a less complex integration which is straight forward but does not provide as detailed modelling possibilities as Viswalk.

A simulation of this potential situation provides several opportunities; designs can be tested and improved, by a **visualisation,** where pedestrians' flow and interaction with other modes of transport is well presented. This is also an opportunity when communicating the design. The default visualisation of the network is more appealing in LfA, Viswalk requires editing to be as well presented. In addition, the **visual area evaluation** and **visual pedestrian evaluation** in Viswalk, e.g. LOS density maps, can be used to identify where design dimensions need widening or can be narrowed, to retrieve optimal design.

Numerical outputs can also be used in order to analyse the area, e.g. to compare different design options or to see the impact pedestrians and trams have on each other, to minimize the negative effects. Numerical outputs can be obtained in Viswalk models as minimum and maximum values, which can be of use to make sure that they are within an acceptable range. In-depth studies of certain areas, e.g. a metro entrance, can be conducted with **numerical area evaluation. Calibration** is important to get desired pedestrian behaviour in the analysis. The modification possibilities of pedestrian behaviour also allows for **sensitivity analysis** where, in addition to testing different traffic demand prognoses, the model can be tested with different pedestrian behaviours. Another opportunity to strengthen the credibility of this simulation is by **statistical certainty**. In LfA, average for multiple simulations is calculated automatically.

In this potential situation, Viswalk has the most strengths and opportunities. The positive aspects of LfA can also be obtained for Viswalk models, but require more effort. However, the many modification possibilities and the route choice methods that Viswalk provides, cannot be obtained in LfA models. The weaknesses and threats should be examined before a decision can be made on whether or not to simulate the potential situation in Viswalk.

Viswalk provides many detailed features and modification possibilities; it is complex but provides great opportunities for analysing the area. The weaknesses and threats in Viswalk are due to the **complexity** and can be avoided by the user being aware of them and taking caution; **overlaps and crevices in pedestrian areas, unclear correlation between OD-matrix and input/route, demanding modelling of pedestrians as PT passengers** and **demanding output files.** The **default visualisation of the network** is sufficient for analysis but requires improvements if the design shall be communicated. This potential situation can be analysed in detail by modelling and simulation in Viswalk. A simulation in Viswalk is appropriate.

11 Discussion

The results and conclusions in this study should be regarded based on the comparative methodology. When conducting a comparison, differences and major similarities in features are highlighted. It is more problematic to determine what features are missing in both software programs. To handle this, the study also investigates what could be requested of a pedestrian simulation, in order to identify what to look for. The SWOT analyses display several features that are more or less the same in the software, which indicates that the study is both a comparison between software and an examination of possibilities for pedestrian traffic simulation. Another issue with a comparative study is that there may be features differing to such extent that they cannot be compared. In this study, the lack of information on Legion for Aimsun has limited the evaluation and made it challenging to make comparable models and understand the correlation between Legion for Aimsun and Legion SpaceWorks.

In this study it has been found that some features in Viswalk have high computational requirements, when using computers on the lower scale of what PTV recommends. Further examination of this with high capacity computers has unfortunately not been possible in this study. The simulation study has been adapted to these conditions to prevent misleading results, since insufficient computational capacity limits the visualisation and consequently the analysing possibilities. Also, features that are only available in one of the software have not been tested in Phase 3; hence they have not been examined through modelling and simulation. Finally, a comparison may lead to unfair evaluation. If a feature is superior in one of the software programs, it does not necessarily mean it is insufficient in the other. The study has been conducted with caution to this.

In addition to the SWOT analyses, there may be other factors influencing whether or not a simulation is appropriate and which software to choose, such as budget of project, time frame of project, availability of software, experience in software and available input data. These aspects are out of scope for this study but obviously need to be considered when using the SWOT analyses as decision support. To complement this study, further studies are recommended on gathering of pedestrian input and verification data, examination of demand on computational effort, evaluation of different route choice models and definition of guidelines for pedestrians in traffic. In addition, an examination of the possibilities to evaluate traffic safety through pedestrian microscopic traffic simulation is recommended.

The complex pedestrian behaviour cannot fully be handled by available simulation software, and there are more features and characteristics that could be developed. Still, pedestrian traffic simulation has great possibilities and is a helpful tool in replicating traffic situations for analysis. It provides the possibility to discover flaws in infrastructural design and improve it before construction, which can save time, money and road work. In addition, when cities increase in size, the pedestrian flows become larger and need further consideration when planning. As pedestrian traffic simulation is conducted more frequently, it gets calibrated, further developed and users gather experience. Since microscopic traffic simulations are widely used and recognised and pedestrian simulations are common for major events and constructions with large flows of pedestrians, the potential of pedestrian traffic simulations is high. Pedestrians can be given higher priority in traffic planning and greater recognition in traffic simulations simultaneously; as these two factors can enhance each other.

12 Conclusion

In conclusion, microscopic traffic simulation is a helpful tool for analysing and communicating pedestrian issues; it is possible to simulate the interaction between pedestrians and vehicular traffic in a reasonable and useful way. The utility of and possibilities for such simulations depend on the situation; what traffic situation to study, and for what purpose.

The decision whether to simulate or not, and which software to use, is supported by evaluation of Strengths, Weaknesses, Opportunities and Threats found in the decision support tool provided in this study. This evaluation must be conducted with consideration to the specific situation. The software programs Viswalk and Legion for Aimsun are able to simulate pedestrians in interaction with other modes of transport. Viswalk is transparent and enables the user to customize and deeply analyse the model and the simulated traffic situation. Legion for Aimsun is easy to use and provides well visualised simulations. In comparison, Viswalk is superior for in-depth analysis and Legion for Aimsun more appropriate for communication.

As long as simulations are critically assessed, there is great utility and many possibilities for integration of pedestrians in microscopic traffic simulations. Pedestrians are gaining more focus in traffic planning and deserve greater recognition in microscopic traffic simulations. These two improvements would enhance each other.

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Appendix I: Pedestrians as PT Passengers

This appendix contains description of how pedestrians are modelled as PT passengers.

Table 1 is a schematic overview of how pedestrians are constructed as PT passengers in Viswalk (PTV, 2012 & PTV, 2013). The table presents what feature is defined and for which mode, construction element and interface as well as how it is defined.

Table 1. Modelling of pedestrians as PT passengers in Viswalk

Mode	**Define**	**Construction element**	**Interface**	**How**
Vehicle	Platform edge	PT stop	Create PT stop	Tick Generate platform edge and choose left and/or right
Pedestrian	Waiting area (or platform edge)	Pedestrian area	Pedestrian area	Draw the areas shape and size, then chose: • Public transport usage: Waiting area (or platform edge) • For which PT stop(s) • Boarding location
Pedestrian	Boarding passengers' route	Pedestrian inputs & routes or OD matrix	Pedestrian input and routes or OD matrix	Analogue as for all pedestrians' routes. The waiting area is set as destination area. By default they will board the first PT vehicle that arrives
Pedestrian	Boarding passengers	PT stop	Passengers	Add a relative flow for each of the different PT lines on the PT stop
Vehicle	Alighting passengers	PT stop and PT line	PT Stop Data	Choose alighting %, alig. composition and alig. distribution on the doors. This has to be conducted for all PT lines on all stops
		PT line	Service rates	When creating each arrival, occupancy is set in ped/veh. The no. of alighting peds depend on both this and alighting percentage (of the occupancy) at the stop
Pedestrian	Alighting passengers' route	Pedestrian routes	Pedestrian routes	Create routes with platform edges as origins in order to have pedestrians continue their path after alighting
-	Maximum capacity & dwell time per passenger	Vehicle type	PT Parameters	Add alighting & boarding time in s/pass. Add maximum capacity in number of passengers. This refuse boarding if the vehicle is fully occupied

Vehicle	Dwell time	PT stop and PT line	PT Stop Data	Define options: • Departure time offset • Skipping possible • Minimum dwell time distribution • Late boarding possible
-	Doors	Base Data	2D/3D Model Distribution, Geometry	Add doors, position on the vehicle, width and usage (boarding, alighting or both)

Table 2 is a schematic overview of how pedestrians are modelled as PT passengers in Legion for Aimsun (TSS, 2012 & TSS, 2013). The table presents what feature is defined and for which construction element, interface and how it is defined.

Table 2. Modelling of pedestrians as PT passengers in Legion for Aimsun

Define	**Construction element**	**Interface**	**How**
Entrances & exits	PT stop	PT stop options	Select a PT stop and choose Generate Pedestrian Entrance/Exit
Boarding passengers' routes	Pedestrian exit at PT stop	Pedestrian OD-matrix	All pedestrian exits are found in the pedestrian OD-matrix. Define a number of pedestrians who have an exit at a PT stop as destination, they will go there and wait for PT
Boarding passengers	PT line	Timetables	Define mean and deviation for the number of pedestrians to board each vehicle. These will board equally distributed among all entrance doors. Note that these values have to correspond to the number of pedestrians who have the PT stops exit as destination, in order to avoid an surplus of pedestrians at the PT stop
Alighting passengers	PT line	Timetables	Define mean and deviation for the number of pedestrians to alight each vehicle. These will alight equally distributed among all exit doors
Alighting passengers' routes	Pedestrian entrance at PT stop	Pedestrian OD-matrix, a proportional matrix	An additional OD-matrix is automatically created for all pedestrian entrances at PT stops. In this matrix, define proportions for distribution of the alighting passengers to pedestrian exits
Dwell time	PT line	Timetables	Define mean & deviation of dwell time
Dwell time per passenger	PT stop	Legion settings	The user may adjust required dwell time for boarding and for alighting [s/passenger]
Doors & maximum capacity	Vehicle type	Vehicle properties	Define maximum capacity as a total number of people or as a length multiplying factor. Define at what distance to vehicle front doors are placed and their usage (entrance, exit or both)

Appendix II: The Social Force Model in Viswalk

In Table 1, parameters of the social force model in Viswalk are presented with default values, descriptions and denotations (PTV, 2012). The table shows all of the *parameters per pedestrian type*; they can have different values for different pedestrian types in Viswalk. All parameters are known, explained and in addition, the values are modifiable.

Table 1. Social Force Model in VISSIM

Parameter	**Denotation**	**Default value**	**Comment**
Relaxation time	τ (tau)	0.4	Within which time a ped tries to reach desired speed and direction. Gives the acceleration
Anisotropy factor	λ (lambda)	0.3	Makes objects influence a ped differently much according to their locations. The influence depends on λ and the angle between the pedestrian's direction and the object
Strength of force between peds	A	A_{soc_mean}=0.4 A_{soc_isotr}=1.6	The social force between two pedestrians depends on A, B, λ, angle, the distance between the peds and the unit vector between them
Range of force between peds	B	B_{soc_mean}=2.8 B_{soc_isotr}=0.2	
Impact of relative velocity between peds	VD	3	If VD > 0, the relative velocities between two pedestrians influence the force between them
Noise	noise	1.2	Random force. This prevents pedestrians to get stuck. E.g. if two persons can't pass each other, after a while one of them will step back and let the other one pass.
Amount of pedestrians influencing	react_ to_n	8	When calculating the total force of a pedestrian, only the n closest pedestrians are influencing the force.
Side preference	side_ preference	0	This parameter enables you to define on which side pedestrians prefer to pass each other. If it is set to -1 the pedestrians prefer the right side, 1 gives left side preference and 0 gives uncontrolled behaviour.
Queue order	queue_ order	0.7	Two parameters that determines the shape of pedestrian queues. Can have values in the range 0.0-1.0, the larger value the more orderly queues.
Queue straightness	queue_ straightness	0.6	
Grid size	grid_size	5	Maximum distance of influence

Appendix III: Numerical Output Options

The numerical outputs for each of the software programs are presented in tables below. The tables show which numerical output is retrieved for which measurement scope. Table 1 presents the evaluation options for Viswalk (PTV, 2012 & PTV, 2013). The output pedestrian record can also be obtained during simulation by double click on a pedestrian. Table 2 presents the evaluation options for Legion for Aimsun (TSS, 2012 & TSS, 2013).

Table 1. Numerical outputs in Viswalk

Output feature	**Measurement scope**	**Numerical output**	**Output obtained per**
Pedestrian travel time (compiled data)	Origin area to destination area	• Mean travel time • Total number of pedestrians	OD-pair
Pedestrian travel time (raw data)	Origin area to destination area	• Time pedestrian entered destination area • Distance travelled from origin to destination • Time travelled from origin to destination • Time delay • Time gained • Deviation of speed differences	Pedestrian
Pedestrian travel time (OD-data)	Origin area to destination area	• Same as above but outputs are displayed in an OD-matrix	OD-pair, displayed in matrices
Area measurements (compiled and raw data)	User-defined area	• Numbers of pedestrians • Density of pedestrians • Desired speed • Speed • X and Y component of speed vector • Deviation between actual and desired speed • Number of pedestrians who left area • Average of orientation vector, X and Y • World coordinates, x,y & z • Time entering • Time leaving • Total time delay • Total distance travelled • Total dwell time • Total time gain	**Compiled data** is obtained for the entire measurement area. Were applicable; mean, minimum and/or maximum **Raw data** per pedestrian in the measurement area
Pedestrian record	Entire network	• Location by construction element number and level • Current destination	Time step and pedestrian

		• Desired speed • Pedestrian attributes (height, length, width) • Direction of orientation vector, Y and X value • Partial route number and decision • Pedestrian type • Construction element number of previous destination • PT alighting, boarding and approaching (yes or no) • Queuing area number, direct distance to queue begin, time spent in last queue, total time spent in queue • Remaining distance to next destination • Speed • Simulation specific information, e.g. start time, simulation time • Static route number and decision number • Accumulated time delays • Accumulated time gains • Total distance • Total time in network • World coordinates x, y, z	
Queue	Queuing area	• Mean, minimum and maximum number of queuing pedestrians • Mean, minimum and maximum queue extent	Time interval and selected area.

Pedestrian queue is an evaluation feature that records queue by time interval and selected area. Compared to measurement areas, queuing areas cannot be drawn separately but instead has to be a constructed pedestrian area. The option queuing can be ticked in the pedestrian area interface if the area is rectangular and has intermediate points or is a route destination. The pedestrian will queue for a few seconds or according to the user defined dwell time distribution. A pedestrian area with PT usage cannot be set to a queue area. Hence, this feature calculates queue only when the user has constructed a queue and it cannot be done for PT users.

The numerical outputs available in Legion for Aimsun are presented in Table 2 and Figure 1.

Table 2. Numerical outputs in Legion for Aimsun

Output feature / Measurement scope	Numerical output	Output obtained per
Entire system	• Flow • Pedestrians In • Pedestrians Out • Mean Speed • Mean Travel time • Walking time • Stop time • Max stop time • Total distance travelled • Total travel time	Compiled for entire system
Pedestrian crossings	• Number of peds crossing • Pedestrian crossing time • Ped effective crossing time • Pedestrian waiting time	Crossing
OD-matrix	• Pedestrians In • Pedestrians Out • Mean Speed • Mean Travel time • Walking time • Stop time • Max stop time • Number of stops	OD-pair

Figure 1 is obtained for an individual pedestrian during the simulation rather than in a database after the simulation (TSS, 2013). The Figure 1 is an example, a result from the model of a general network, described in chapter 6.

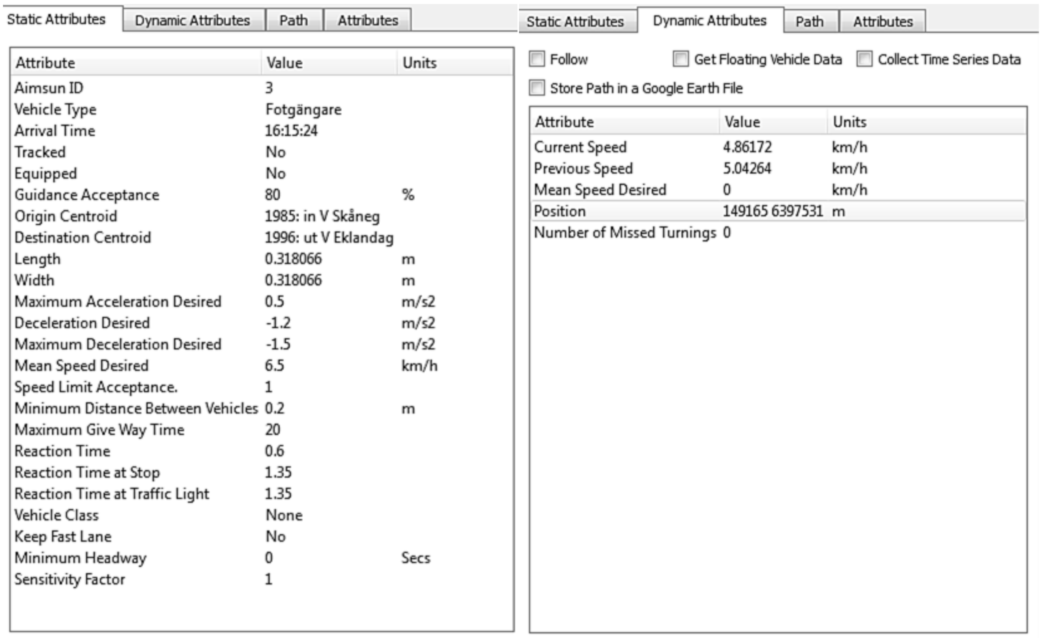

Figure 1. Individual pedestrian information obtained during simulation

Appendix IV: Description of Model Input

Korsvägen is a busy intersection in Göteborg with many different modes of transport. Many pedestrians use this intersection and there are several areas of conflict and interaction between pedestrians and vehicles. Therefore, Korsvägen is chosen as simulation study area. This section describes the input data used for construction of the models, with regards to infrastructural design, traffic regulations and traffic demand. The models in both Viswalk and Legion for Aimsun are constructed with equivalent input data.

Infrastructure design & traffic regulations

Korsvägen is a major station for public transport, with a high frequency of both trams and buses. The intersection is designed as a circulation for private transport, with crossing lines for public transport. In the middle, there is a triangular square with a kiosk and a waiting hall. The intersection in the south is regulated by traffic signals and the whole intersection is surrounded by pedestrian and bicycle paths. The infrastructural design and traffic regulations in the model are based on a map in CAD format provided by WSP, satellite photos from GoogleMaps and observations from field studies, see Figure 1.

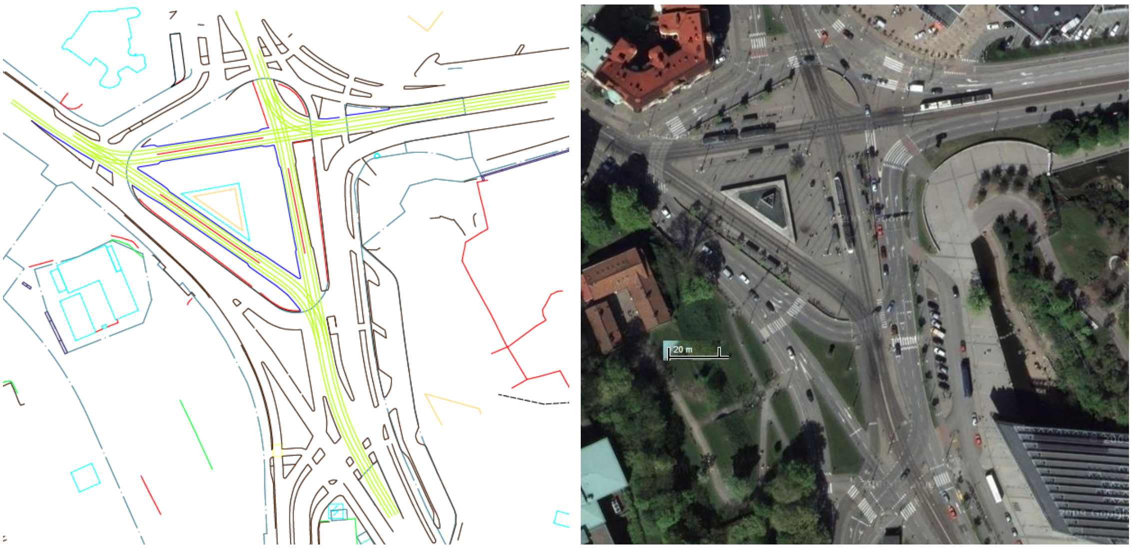

Figure 1. Drawing and satellite photo of Korsvägen (WSP, 2013) & (Google, 2013)

Field studies are supporting the choice of which areas to define as walkable. All areas assigned for pedestrians are defined walkable in the models, but also some other areas such as refuges. The widths of zebra crossings are estimated from satellite photos.

The traffic regulations ruling this intersection are primarily the absolute priority of trams, the priority of pedestrians at zebra crossings and the priority of vehicles within the circulation. There are several zebra crossings where pedestrians ought to cross the roads. There are also barriers, to prevent people crossing the roads at other spots. To cross a tram track, pedestrians may choose to cross anywhere where there is no fence. There are fences along each platform, between the rails, to prevent people from crossing the rail directly by the platform. The conflict areas are numerous, and a large share of these is between pedestrians and other modes of transport. There are numerous conflict areas between pedestrian/private transport, pedestrian/ bicycle, pedestrian/tram, pedestrian/bus as well as pedestrian/pedestrian (the square) at Korsvägen.

Traffic demand

The models represent Korsvägen during the maximum load hour in the afternoon, 16.15 – 17.15, on a week day in 2013.

The traffic matrices for private vehicles and bicycles are based on information from a situation analysis for the intersection conducted in 2012 (Refsnes, 2012) and traffic accountings in the intersection from December 2012 (WSP, 2012). The information from these two references is weighted into OD-matrices and used as input in the models. In total, 3223 private cars per hour are put in the models.

Regarding the public transport, the local public transport operator Västtrafik is the source of tram and bus lines that pass Korsvägen, and their frequency during the maximum load hour (Västtrafik, 2012). In total there are 6 different tram lines with a total of 79 trams during the maximum load hour and several different bus lines with a total of 128 buses during the maximum load hour. The number of passengers alighting and boarding at each PT stop is calculated from statistics provided by Västtrafik. The latest accountings are performed in 2006 (Larsson, 2013). According to Västtrafik, a 20 % increase in PT passengers is assumed from 2006 to 2013 and therefore the values provided from Västtrafik are increased with 20 % before inserted in the models. The tram and bus lines in 2006 differs from the PT lines in 2013 and therefor the alighting and boarding passengers in the model are weighted based on the PT stop and distributed on the PT lines for each of the PT stops. In the model, 1584 persons per hour alight at Korsvägen. Out of these, 850 board another bus or tram. 780 public transport passengers start their journey at Korsvägen, which makes the total number of persons boarding 1630.

The pedestrian flows are shown in Figure 2 below. These values are based on both statistics on public transport passengers as described above and on adjusted values from accountings performed during spring 2012 (Refsnes, 2012). Figure 2 presents the pedestrian flows in the microscopic models (Pedestrians arriving in pedestrians per hour / Pedestrians leaving in pedestrians per hour). The red letters represent public transport stops and the size of a letter is greater the more passengers using this stop.

The available pedestrian accountings do not distinguish between different directions or the two sidewalks along a road. Therefore, qualified assumptions and calculations were necessary to distribute the pedestrians within the models; to construct a complete OD-matrix. A primarily OD-matrix was made based on the accountings and the assumption that the number of pedestrians coming to Korsvägen equals the number of pedestrians leaving. In addition to this, the flows in this matrix were recalculated to include the public transport passengers and the distribution among PT stops. In total, the pedestrian flow is 2714 pedestrians per hour.

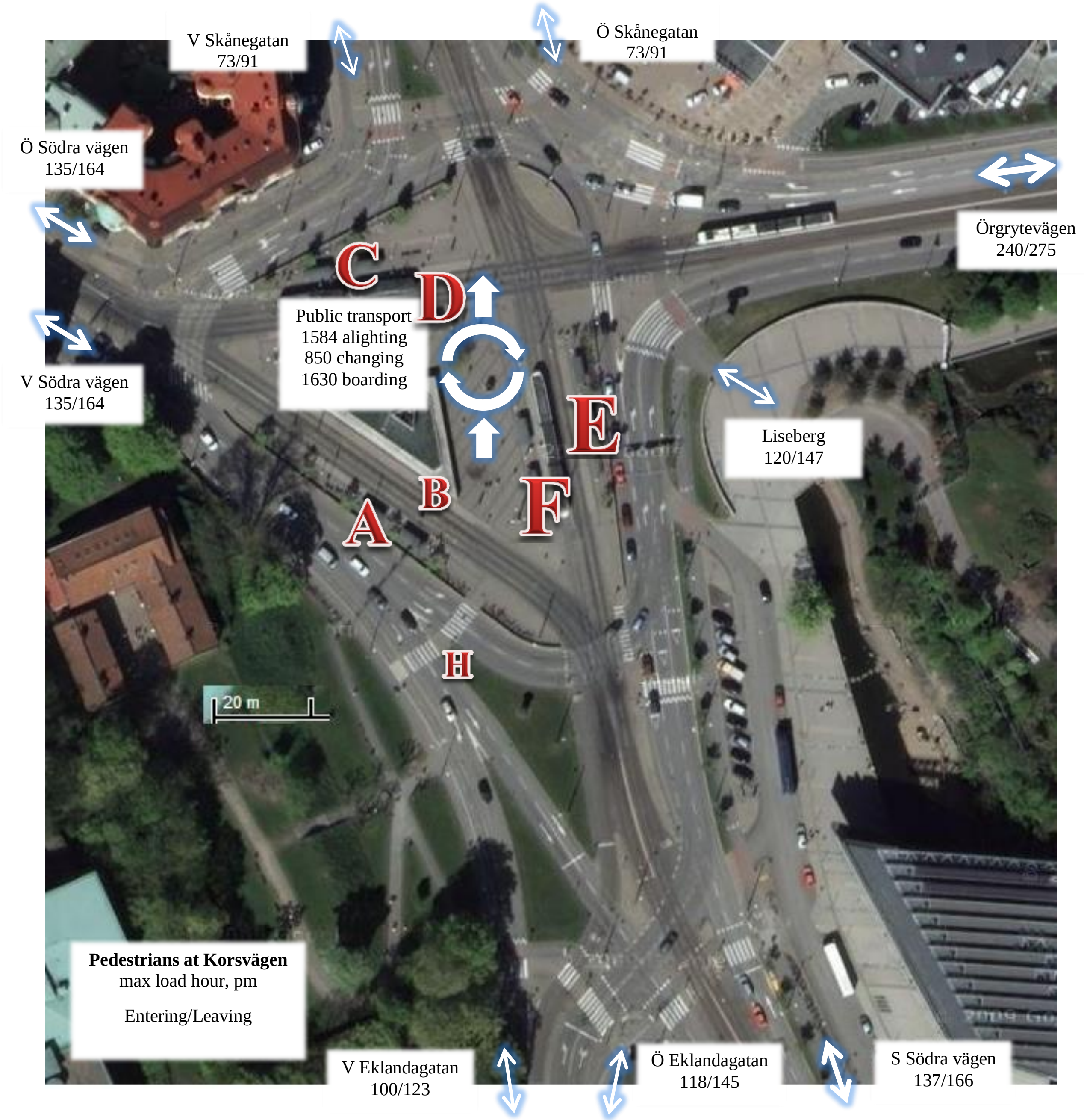

Figure 2. Input pedestrian flow in the models

Vehicles' desired speed are set according to the traffic regulations, 50 km/h and default dimensions of private vehicles are used. The dimensions, capacity and speed of public transport vehicles are average values based on information from the company Göteborgs Spårvägar (Johansson B. E., 2013) & (Zettermark, 2013). The public transport vehicles are modelled equally in both software programs as Table 1 presents.

Table 1. Speed, length and capacity for PT vehicles in the models

Vehicle	Speed [km/h]	Length [m]	Capacity [persons]
Tram	15	30	192
Bus	25	12	82