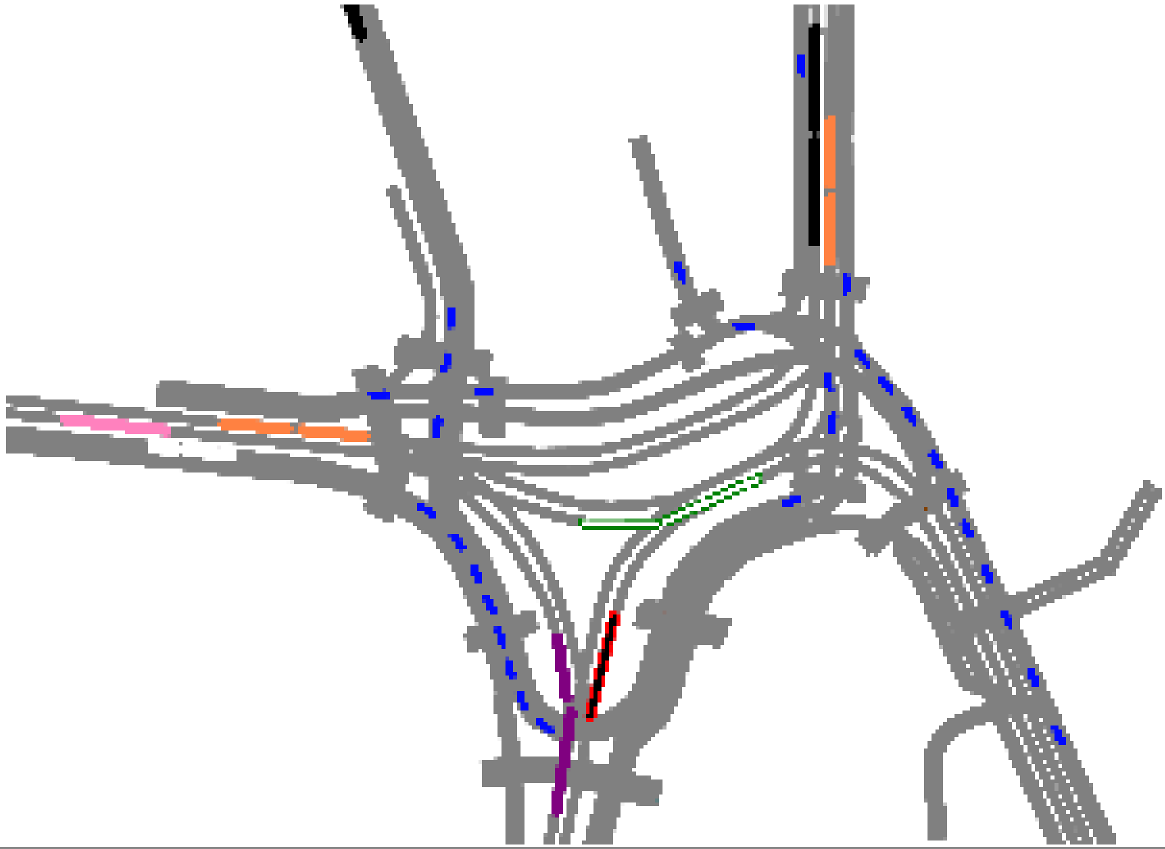

Master thesis

Simulating the traffic impacts of the closure of the Limmatquai

Ingelin Blix

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IVT Institut für Verkehrsplanung, Transporttechnik, Strassen- und Eisenbahnbau

ETH Zürich

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Ingelin Blix
ul. Debowa 13
81-623 Gdynia, Poland

Student number: 1061046

Email: I.Blix@gmx.de

done for:

Faculty of Technology, Policy and Management
Delft University of Technology
The Netherlands

Thesis committee (TU Delft):

Prof. Dr. K. A. Brookhuis,	Section of Transport Policy and Logistics Organisation
Ir. M. W. Ludema (first supervisor),	Section of Transport Policy and Logistics Organisation
Ir. P. H. M. Jacobs (second supervisor),	Department of Information, Communication and Systems

External supervisors (ETH Zürich):

Prof. K. W. Axhausen,	Institut für Verkehrsplanung, Transporttechnik, Strassen- und Eisenbahnbau (IVT)
Dipl. Ing. P. Fröhlich,	Institut für Verkehrsplanung, Transporttechnik, Strassen- und Eisenbahnbau (IVT)

Abstract

The City of Zürich has a long history of traffic policies favouring public transport over individual traffic, considerable research has been done about this topic. Nevertheless – as in all bigger cities – problems with the private vehicle traffic exist and have to be dealt with. The Limmatquai, a street going parallel to the Bahnhofstrasse but alongside the river Limmat, is at the moment during the peak traffic hours filled up with cars, with the trams stuck in between. This spoils the otherwise beautiful promenade.

After long discussions and a failed attempt, the people of Zürich voted 1999 in a ballot that this situation should be changed and part of the Limmatquai should be closed.

In the scope of this master thesis the historical events leading to this decision as well as in the same context the traffic policies of the City and the Canton of Zürich are investigated. A detailed microscopic simulation model of the area directly surrounding the Limmatquai, reaching from Central over Heimplatz to Bellevueplatz, is created with the help of the simulation software VISSIM (PTV AG, 2001).

The present work examines whether the envisioned changes to the traffic flow can be handled by the alternative routes together with the planned measures. For this different scenarios for the situation before and after the closure are modelled. This work builds up on previous projects done at the IVT, specifically an assignment model of the City of Zürich (see [Müller, 2002]) and a small part of the area already modelled in VISSIM (see [Angst, 2002]).

The results of this thesis suggest that the proposed measures are sufficient to justify the closure of the Limmtaquai. Furthermore concrete suggestions for improvements are given and critical spots in the area highlighted. The created model presents a good basis for further analysis and testing of alternative solutions.

Keywords

Zürich – Limmatquai-closure – traffic planning – microscopic model – VISSIM – ETH Zürich – Institut für Verkehrsplanung und Transporttechnik, Strassen- und Eisenbahnbau (IVT)

Executive summary

Zürich, with a population of approximately 340’000, is the largest city in Switzerland. Around 1.2 million people live in the 171 municipalities that make up the Canton of Zürich. Zürich’s old town is situated along the banks of the river Limmat, where it leaves Lake Zürich and like all big European cities, Zürich has traffic problems.

In 1999 a decision was made by referendum to close one of the main streets in the centre of town - the Limmatquai - for all traffic except public transport and residents plus shop owners, which have to use the street. The street will be changed into a pedestrian zone, with two tramlines remaining. Since the Limmatquai is one of the main streets for traffic going through town, this decision will result in major changes in the traffic pattern of the city. However it is still not entirely clear if the proposed measures are sufficient to cope with the new traffic flow distribution.

It is the aim of this thesis to verify if the alternate routes, after the closure of the Limmatquai, will be able to handle the changed traffic flow. In order to assess if the closure is possible the effects of it on private vehicle traffic, public transport vehicles and pedestrians have to be investigated.

The first step to reach this aim was to put the whole problem of the closure of the Limmatquai into a broader context for better understanding of all the issues involved. The direct democracy system present in Switzerland allows the people to put issues they are concerned about to the ballot (Initiative) and to vote about decisions that have been taken (Referendum). This is possible throughout all levels of the Swiss system from the federal down to the municipal level. The main events in the historical background of the decision are the vote for the downgrading of the status of the Limmatquai (allowing its later closure) in 1999 and the agreement of the voters to an object credit of 1.75 million CHF necessary to finance the traffic measures on the alternative routes in 2002. After this last vote all major objections from ACS, TCS and FDP were withdrawn clearing the way for the closure in spring 2004. This closure is in accordance with the transport policies of the City and Canton of Zürich. The canton started in 1999 to develop a new Comprehensive Transport Concept and the city – with a history of public transit priority – started up a new mobility strategy in 2000, both concepts aiming at sustainable development as well as the comprehensive understanding of traffic problems.

A microscopic traffic model for performing a simulation of the area of the Limmatquai is chosen as the way to answer the research questions as it has some important advantages in

this particular case of a closure: the possibility of testing of a future situation and the opportunity of easily experimenting with different alternative measures. Making comparisons to similar cases of street closures in different cities would not be a good way to asses the local effects, since each traffic network is special in its own way. Therefore answering the research question is done with the help of a detailed traffic model of the current and future situation created in the simulation software VISSIM (PTV AG, 2001).

After establishing the tool to be used in the simulation it is possible to proceed to the system analysis part. The boundaries of the problem have to be drawn and input and output variables identified. The area to be modelled is cut down to just the closest neighbouring area of the Limmatquai, forming a triangle with the corners Central, Bellevueplatz and Heimplatz. The area chosen includes only the part of the total traffic flow of Zürich (and only part of the alternative routes), but is a subsystem that can stand on its own.

In order to be able to depict the area in the model accurately it is necessary to get accustomed to the software and its possibilities. VISSIM allows to create the underlying street network together with priority rules, traffic light programming (vehicle actuated), public transport lines and car routing through the network. With the experience gathered in the course of this project some observations about the software's usability and usefulness could be made resulting in a chapter on suggestions for improvements in VISSIM in the appendix.

As a next step the input and output variables have to be specified and necessary data must be gathered. Assumptions and simplification were necessary in order to be able to model the system. Around 9'000 cars are input into the model per hour together with twelve public transport lines serving their stops approximately every 7 minutes. The number of vehicles and the routes these vehicles choose is taken from an assignment model of the Zürich area created in [Müller, 2002]. The output variables necessary to asses the research question are travel and delay times on certain routes and overall, forced public transport stops, queue length at junctions and car losses. For the current and the future situation, scenarios with different number of cars are run for the evening peak hour from 5 p.m. to 6 p.m. which is sufficient to characterise the system behaviour.

The creation of the models themselves (current and future – according to officially planned traffic measures described in [Stadt Zürich, 2001b]) is the most time consuming part of the project. All streets together with priority rules, speed limits and public transport lines have to be input manually. The traffic light programs (VAP) for ten signal controlled junctions have to be designed and implemented together with their traffic detectors.

The finished models are then verified and validated. This step is necessary to ensure that the results obtained are sensible and useful. This includes observing the running model and executing different testing modes for the signal controlled junctions. Extreme runs with very little cars or only public transport vehicles are performed together with a sensitivity analysis in order to validate the model. Finally it is judged to be correct and can be run to produce outputs from which results can be summarised and analysed.

The travel and delay times on the measured routes are overall stable, only the routes directly effected by the closure have a considerable gain in their travel time.

Overall delay and total time in the network decreases significantly in the future situation though part of that is caused by a different distribution of the cars on the routes going through the model and not based on an improved traffic situation.

The queues in the future situation are found to be distinctively different in two aspects from the ones in the current situation. They are significantly shorter but also spread over more junctions.

The situation for the public transport after the closure improves drastically for the two tram lines (line 4 and 15) which routes are going for the major part on the (then closed part of the) Limmatquai. For the other lines the differences are small, both improvements and losses are observed.

The measured car losses allow some indirect conclusions about problems in the model. As the number of removed cars decreases significantly in the future situation it can be concluded that the traffic situation is less critical. Furthermore, as altogether approximately the same number of cars are lost in the current and the future situation, problems with the sub-optimal length of green phases at certain input streets in the future situation are remaining.

Altogether no strong indications are found why the closure of a part of the Limmatquai should not be possible. From a viewpoint of the traffic situation in the modelled area, the alternative routes should be able to handle the detoured traffic of the Limmatquai. The public transport will be influenced positively on routes going through the Limmatquai, other routes will experience only little changes. For pedestrians the situation will improve as the closed part of the Limmatquai will be used as an additional pedestrian zone while there are no negative changes due to the detoured traffic. This nice boulevard alongside the river Limmat will be a valuable addition to the living quality in Zürich and increase the attractiveness of the area for shop and restaurant owners as well as tourists. From the perspectives of the cantonal and city transport policies, the closure is a valuable addition and in good conformance with the set aims and goals.

However, it must be said that there are still some remaining problems with the model itself. These problems lead to a not optimal depiction of reality. In the majority of the cases these problems occur due to certain limitations of the software, e.g. in the lane changing algorithm.

Nevertheless a number of recommendation can be given. A main point will be the adjusting and optimisation of signal green times for nearly all junctions, especially at Bellevueplatz, as the right turn into Rämistrasse will have a significantly higher traffic volume in the future situation. The, through the closure directly influenced, junction Limmatquai/Mühlegasse can be redesigned completely, the traffic lights might be removed or new turning relationships established. As a last point, the dependence of the model with respect to a different number of pedestrians should be investigated thoroughly, maybe in conjunction with a research on exact pedestrian numbers and routes in the modelled area.

The created model is useful for a number of purposes. The City of Zürich can use it for optimising and testing of traffic light settings and for public relations, as the running simulation is able to give a broad audience an impression of the traffic situation after the closure. Furthermore many interesting further investigations can be based on the created model, starting with a further evaluation of the obtained data and testing of alternative measures by small changes to the model. Expansion of the model to cover a wider area and other alternative routes allows for a better judgement on the effects of the closure as well as for a dynamic creation of car routes through the network in VISSIM.

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Abbreviations

ACS	Automobil-Club der Schweiz
CHF	Swiss Francs, currency of Switzerland
ETH	Eidgenössisch Technische Hochschule (Swiss Federal Institute of Technology)
EVP	Evangelische Volkspartei (Evangelical People's Party)
FAQ	Frequently Asked Questions
FDP	Freisinnige Demokratische Partei (Radical Free Democratic Party)
GeoZ	Geomatik + Vermessung, Stadt Zürich
IVT	Institut für Verkehrsplanung, Transporttechnik, Strassen- und Eisenbahnbau (ETH Zürich)
OD	Origin-Destination
PTV	Planung Transport Verkehr AG, Germany
SCJ	Signal controlled junction
SVP	Schweizerische Volkspartei (Swiss People's Party)
TCS	Touring Club Schweiz (Switzerland)
VAP	Vehicle Actuated Programming
VISSIM	Verkehr in Städten – Simulation (microscopic traffic simulation software)
VISUM	Verkehr in Städten – Umlegung (software to create assignment models)
VisVAP	Visual VAP, software included with VISSIM to facilitate easy traffic lights programming by means of flow diagrams
VBZ	Verkehrsbetriebe Zürich
XML	Extensible Markup Language

1. Introduction and problem outline

Zürich, with a population of approximately 340'000, is the largest city in Switzerland. Around 1.2 million people live in the 171 municipalities that make up the Canton of Zürich. Zürich's old town is situated along the banks of the river Limmat, where it leaves Lake Zürich. The city is spread over 92 km^2 with a population density of 3'860 persons per square kilometre (all numbers from [Nash and Sylvia, 2001]). Like all big European cities Zürich has traffic problems.

In 1999 a decision was made by referendum to close one of the main streets in the centre of town - the Limmatquai - for all traffic except public transportation and residents plus shop owners, which have to use the street. The street will be changed into a pedestrian zone, with two tramlines remaining. Since the Limmatquai is one of the main streets for traffic going through town, this decision will result in major changes in the traffic pattern of the city. Several studies have estimated the new flows and routes of the traffic through the city after the closure of the Limmatquai (see [Stadt Zürich, 2001b] and [Müller, 2002]). However, it is still not entirely clear if the proposed measures (see chapter 6.7 and [Müller, 2002]) are sufficient to cope with the new traffic flow distribution.

1.1 Aim of the research

The aim of this thesis is to verify if the alternate routes, after the closure of the Limmatquai, will be able to handle the changed traffic flow. This will be done with the help of a detailed traffic model of the neighbouring area of the Limmatquai created in the simulation software VISSIM (PTV AG, 2001).

In order to assess if the closure is possible the effects on private vehicle traffic, public transport vehicles and pedestrians will be investigated. For the private vehicle traffic this will be done by examining the alternative routes the cars will take and by measuring and comparing properties, like travel time and average speed, of the traffic flow before and after the closure.

1.2 Outline

In order to put the whole thesis into context and to familiarise the reader with information necessary for understanding the problem, *Chapter 2* gives background information on the highly developed direct democracy system of Switzerland as it played an important part in the decision of the closing of the Limmatquai. The processes leading to and following this decision are given and the closure is put into context of the traffic policies of Zürich, both on a city and cantonal level.

The system analysis is elaborated on in *Chapter 3*. It contains the description of the system parts and boundaries including the area to be modelled enclosed by Central, Seilergraben, Heimplatz, Bellevueplatz and Limmatquai as depicted in Figure 1-1. The area marked green shows what is part of the model.

Figure 1-1: Map of modelled area.

Source of map (without marked region): [Müller, 2002]

Chapter 4 provides a description of the traffic modelling software VISSIM 3.6 used for creating a model of the area surrounding the Limmatquai. The software is able to model individual vehicles and pedestrians with priority rules, traffic lights and public transportation on a micro level.

The data used for the creation of the model together with the assumptions and simplifications made in order to proceed with the analysis are discussed in *Chapter 5* together with a description of the output variables measured in VISSIM.

Chapter 6 describes the model in detail. In order to make it easier for potential future users of the model it is shown exactly how each element was created, including information about model calibration, creation of signal controlled junctions and priority rules. The changes made to the model to reflect the future situation are described in this chapter as well.

In order to be sure that the model created is representing reality to a satisfactory degree, it is necessary to perform verification and validation of it. This is done in *Chapter 7*.

Chapter 8 presents the results of this work, simulation outputs are summarised and discussed.

Finally, *Chapter 9* concludes and develops recommendations as well as giving future users and uses of the created simulation model.

The *Appendix* contains additional figures and some suggestions on how to improve the VISSIM simulation software.

The model together with additional material, like photos of the modelled area and scanned plans, are provided together with this report on an attached CD for further reference and experiments.

After this outline of the report and a description of the problem together with the research questions, it is necessary to familiarise the reader with the processes leading to the decision to close part of the Limmatquai. For a true understanding of this problem it is necessary to take a historical look at the events that lead to this decision and put it into the context of the traffic policies of the City and the Canton of Zürich.

2. Background information

In order to understand the processes around the closure of the Limmatquai, it is necessary to have a basic understanding of the Swiss legal and administrative system. After presenting this together with references for further reading, this chapter provides the historical background up until the present time on the processes leading to and following the decision to close a part of the Limmatquai and the parties involved in that decision. Finally the transport policies for the City and Canton of Zürich, especially Zürich's Transit Priority Program, are examined in more detail to see if the closure can be justified and is compatible with respect to the aims of these policies.

2.1 Swiss legal and administrative system

Switzerland is a federal state composed of 26 cantons (of which 20 are "full" cantons and six "half" ones as represented in the federal legislature), that have attributes of sovereignty such as the right to manage internal cantonal matters.

Switzerland has a complex division of the administrative system which consists of (given in top down order): confederation (Eidgenossenschaft), cantons (Kantone), districts (Bezirke) and municipalities (Gemeinden).

The Confederation's *legislative authority* – the United Federal Assembly (Bundesversammlung) - consists of two chambers: the Council of States (Ständerat) and the National Council (Nationalrat). Here the difference between a full and a half canton is visible, where the Council of States consists of two representatives of each full canton and of one representative of each half canton. This is regardless of the size of the population of a canton. The National Council has 200 representatives elected proportionally to the population of each canton (there has to be, however, at least one representative of each canton).

The Confederation's *executive authority* lies with the Federal Council (Bundesrat), which consists of seven members elected by the United Federal Assembly. Elections are made every four years, but the President of the Confederation – who is elected from the members of the Federal Council - changes every year (he or she is considered "Primus inter pares", first among equals). The members of the Federal Council head the departments of foreign affairs; home affairs; justice and police; defence, civil protection and sports; finance; economic affairs; environment, transport, energy and communication.

The *judicial authority* of the Confederation lies with the Federal Supreme Court (Bundesgericht), which is seated in Lausanne.

The duties of the cantons include: education, transportation (cantonal roads) and social institutions. Each canton consists of several districts, with the duties of education and judicature. On the lowest level of the Swiss administrative division lie the municipalities. Each district consists of a number of them. The duties of the municipalities include: local services (electricity, water, police etc.), transportation (municipal roads), schools and taxes.

Switzerland is the European country with the most thoroughly developed system of direct democracy. A strong emphasis is put on the initiative and the referendum of the people, the reason for this arising out of the belief that the will of the people is the final national authority. This system of direct influence of the people is implemented throughout the whole hierarchy of the Swiss political system, from the federal level down to the level of municipalities. Naturally different rules and regulations demand different prerequisites and conditions for these distinct levels in the system. Nevertheless the general ideas stay the same. There is the people's *Initiative* which enables the people to put issues they are concerned about to the ballot, i.e. the effected public (depending again on the level in the system) has to vote on it. On the other hand, the *Referendum* allows the people to veto an administrative or legislative decision putting it to the ballot in the same way as the Initiative. For the federal level these rights are fixed in the Swiss Constitution (see [International Constitutional Law, 2002]), different other laws and orders regulate the procedures and preconditions on the other levels, but the exact rules are not relevant for this work. The interested reader is referred to e.g. [Stadt Zürich, 1998].

For the City of Zürich, the separation of powers works similarly to the federal level. The administrative authority lies with the City Council (Stadtrat) the members of which lead the different departments of the city, like fiscal, police or city engineering department. The legislative power is in the hands of the Town Council (Gemeinderat). These two councils work together to govern the city and solve the upcoming problems.

The information provided in this section is taken from [Information about the Administration of Switzerland, 2002] and [Swiss Federal Chancellery, 2002].

2.2 Historical background

This section gives, in chronological order, important incidents and events in the process that lead to the decision of the closure of the Limmatquai and that followed this decision. The information here – if not specified otherwise – is taken from [Müller, 2002] and newspaper articles from [Tagesanzeiger, 2002].

September 1987 – the population of Zürich votes (very closely) *against* the closure of the Limmatquai. The whole process was initiated by R. Aeschbacher (EVP) who proposed a closure similar to the one accepted in 1999. The left wing parties proposed as an alternative a more radical solution, namely closing the whole Limmatquai between Central and Bellevue. Together with the lack of plans for rerouting the traffic, the alternative drew some votes onto its side so that in the end none of the two proposals was accepted.

Summer 1995 – Limmatquai is closed for five months due to construction work on the tram tracks. The head of police and the City Council think as a result of traffic counts during this period that the closure of the Limmatquai is feasible from a traffic perspective.

March 1996 – the City Council wants to close the Limmatquai in order to make the inner city more attractive for pedestrians. This is met by opposition from FDP, SVP, ACS and TCS.

June 1996 – the City Council requests from the Town Council the downgrading of the Limmatquai between Rudolf-Brun-Brücke and Münsterbrücke from a district street for through traffic to a normal district street (gewöhnliche Quartierstrasse). This would allow the closure of the Limmatquai by the City Police.

July 1998 – Limmatquai is closed for construction work on the tram tracks for the duration of two months.

January 1999 – the head of police concludes from the traffic counts made during the closure in 1998 (summarised in [Stadt Zürich, 1999a]) that the Limmatquai can be closed to the through traffic without any drawbacks.

7th April 1999 – the Town Council agrees to the downgrading of the Limmatquai and thus sets the prerequisite for the closure. The decision is taken with a clear majority of 94 against 25 votes (of the SVP). Furthermore this matter is put voluntarily to the ballot as otherwise a referendum against it was expected anyway. In the same meeting a motion to the City Council is made to ease the traffic flow on the alternative routes (Motion Eggler, FDP). As a result of this the City Council investigates a rerouting concept with the help of the engineering firm E. Basler + Partner (see January 2001, below).

May 1999 – the automobile clubs in Switzerland, ACS and TCS, are against the proposed closure of the Limmatquai. They claim not to be against the closure as such but they do not see how the traffic should be detoured over alternative routes without creating congestions and longer queues. All the parties in the Town Council (with the exception of SVP) are however in favour of the closure.

13th June 1999 – the people support the downgrading and thus the closure of the Limmatquai with a 59.5% yes-vote. Although nominally the decision taken by the people regards only the downgrading of the status of the Limmatquai (between Rudolf-Brun-Brücke and Münsterbrücke) in the communal traffic plan (see the voting announcement in [Stadt Zürich, 1999b]), the ongoing discussions in the media – filling the front pages of the newspapers in Zürich – before the ballot left no doubt that the Limmatquai will be closed for normal traffic after the necessary legal step (the downgrading) was taken.

March 2000 – the Canton of Zürich (kantonale Baudirektion) is agreeing to the downgrading of the Limmatquai and with that also to the closure. As a result of that the Limmatquai is listed in the communal traffic plan (kommunaler Verkehrsplan) as a normal district street.

July 2000 – the Department of Police starts the legal process necessary to close the Limmatquai. Objections go in the first instance to the City Council, then to the governor (Statthalter), after that on the cantonal level to the Regierungsrat and finally on the federal level to the Federal Council. If the whole range of opposing measures is employed by the opponents, the process is expected to last three to five years.

August 2000 – twelve objections are registered and have to be decided by the City Council. Among those are ACS, TCS and FDP objections – the last one as a means of insuring that their ideas about changes on the alternative routes (see above, Motion Eggler) are realised.

January 2001 – finished report of the engineering firm E. Basler + Partner together with the City Engineering Department (Tiefbauamt der Stadt Zürich), conducted on behalf of the City Council (see [Stadt Zürich, 2001b]). This report develops a traffic concept with measures and alternative routes in order to facilitate the closure of the Limmatquai. The total costs are estimated at 1.6 million CHF, split up into 700’000 for construction, 500’000 for new traffic lights and adaptations of the existing ones and 400’000 for changes to the road markings and sign posts to mark the new routes across town. Note however that this money will be used for all alternative routes, not just the ones in the modelled area looked at in this study.

March 2001 – the City Council accepts the report as a basis for the closure and dismisses all twelve objections against it.

June 2001 – of the twelve individuals or groups only four continue their objections at the level of the governor, the ACS, TCS, FDP and a group of individuals.

October 2001 – the political process is slowed down as the FDP is not satisfied with the measures proposed by the report of E. Basler + Partner. As a result of this a special commission is put into place to find a compromise and propose changes to the measures.

January 2002 – the Town Council hears the results of the special commission and accepts the proposed changes which increase the total sum needed to 1.75 million CHF with a majority of 85 to 24 votes thus closing the Motion Eggler. Furthermore the commission suggests that the City Council should report to the Town Council about the state of affairs in the second year after the closure.

February 2002 – the TCS with the support of SVP takes the referendum against the decision of the Town Council for the object credit of 1.75 million CHF and brings this matter again to the ballot.

2nd June 2002 – 71.6% yes-votes for the object credit by the people of Zürich (with a 41% turn out). This result is even clearer then the initial decision to close the Limmatquai and can be considered as its strengthened confirmation.

June 2002 – as a result of the ballot the TCS, ACS and FDP withdraw their objections at the governor against the closure.

If no major obstacles come up in the further process, the closing of the Limmatquai is planned to take place in the spring of 2004 so that the people of Zürich can enjoy the summer strolling along the Limmat.

2.3 Transport policies of Zürich City/Canton

2.3.1 Transport Policy of Zürich Canton

Since 1999 the Canton of Zürich has been working on a Comprehensive Transport Concept (Gesamtverkehrskonzeption, see [Kanton Zürich, 2001]) with the overall aim of integrating the conflicting interests of mobility and quality of living in order to increase the attractiveness of the Zürich metropolitan area. Within the concept not only transport policy but also problems of spatial and environmental planning are taken into account to coordinate and rank transport projects as well as control them. The work on the concept is still ongoing but enough has been done already to give an overview of the aims and components of the concept.

The leading idea of the whole concept is to contribute to a lasting increase in the attractiveness of the whole region, economically as well as from a quality of living perspective. By balancing different interests, the transport policy of the Canton of Zürich tries to improve the conditions of the society, the economy and the environment while at the same time supporting the interests of the surrounding regions and of Switzerland as a whole.

The main aims of the Comprehensive Transport Concept are:

- Guaranteeing *basic mobility* of the whole population.
- Achieving an improved *quality of traffic* consisting of maintaining the present quality of the traffic system and creating a sound basis for traffic within the economic catchment area of Zürich and national as well as international connections to the outside.
- Minimising risks in the transport system and thus providing *security* for all travellers.
- Increase the quality of living through *spatial awareness*, using spatial planning to create as little new traffic as possible and relieving heavily burdened areas.
- Coordination with *environmental aims* in the areas of energy consumption, noise control and air pollution.

The realisation of these aims is governed by these general principles:

- Using each mode of transport in the area of its individual strength and trying to achieve that public transport accommodates at least half of the total traffic growth (not including walking and cycling).
- Maintaining and using current transport capacities as well as focused expansion of the infrastructure (streets and tracks).
- Efficient usage of existing financial means.

- Taking advantage of possibilities for innovation.

Within this cantonal framework each city has to take over the detailed planning regarding its own area in coordination with the Canton. For the City of Zürich this means a lot of cooperation as the main traffic challenges of the canton originate or are associated with the City of Zürich.

The closure of the Limmatquai is in accordance with several aims of the cantonal transport policy and indifferent to the rest of them. The Limmatquai is in the modelled area the street with most pedestrians using and crossing it (without traffic lights) as it is situated alongside the river and between the main pedestrian zones in Zürich (Bahnhofstrasse and Niederdorf). The security of these pedestrians is increased as the Limmatquai is cleared of car traffic while the increased traffic on the alternative routes does not endanger as many pedestrians. The direct environmental effect of the exhaust fumes on the pedestrians is for the same reason decreased. The traffic quality is influenced positively provided the alternative routes can handle the detoured private vehicle traffic which is researched in the course of this work. This is the case since the public transport lines 4 and 15 are no longer blocked by cars on the closed part of the Limmatquai. Furthermore the closure might lead to a mode change from cars to public transport which has its individual strength in close to medium range transport in inner city areas.

2.3.2 Transport Policy of Zürich City

The City of Zürich is an example of a city that combines its transport policies in such a way as to discourage private vehicle traffic by mainly supporting public transport combined with some alternatives (promotion of bicycling and walking). All information provided in this section is based on [Nash and Sylvia, 2001] and [Stadt Zürich, 2001c].

A strong support for public transport developed in the 1970s when the Social Democrats designed the transit priority initiative as an alternative to the campaign for an U-Bahn/S-Bahn system that was at that time discussed as a way to improve the public transport within the City of Zürich. The proposal for a mass transit system was developed by a group of transportation professionals and students and was called the People’s Initiative for the Promotion of Public Transport.

In March 1977 this initiative was approved by the people with a vote of 51.3% to 48.7%.

Transit priority was introduced in the city by means of:

- adjustments to traffic regulations
- minor roadway changes made throughout the city in order to provide transit vehicles with priority on all routes
- designing and building a unique traffic signal prioritisation system
- adopting system operating techniques such as proof-of-payment (that frees the transit driver from collecting fares and enables all vehicle doors to be used for boarding)
- constructing a systems' operation centre, maintaining schedule stability and service quality
- redistributing road space from mixed traffic to transit only in order to create exclusive right of ways for transit vehicles

In addition to this in 1987 the Town Council passed a resolution approving the following transport policy principles:

- public transport must be promoted
- private traffic must be reduced
- private traffic must be channelled - living areas must be kept peaceful
- environmentally friendly modes of transport should be supported
- the number of parking places must not be increased, but rather decreased

Concerning the last point above a new direction was taken however in 1990 when the Town Council decided as a compromise with the shop owners that the number of parking places in the city centre will be kept constant at the (then) current level. This is today known as the 'historical compromise'.

In order to promote public transport, complementary programs were implemented. The first one is to create alternative ways of transport different from private transport. For that purpose the city constructed a bicycle network and created a large pedestrian network in the old city and in the downtown areas. The decision to close the Limmatquai is in this respect a decision logically following the city's traffic policy.

Zürich introduced a policy of traffic calming in residential areas and in the old city. This policy includes creating wider sidewalks, creating pedestrian zones, introducing speed limits, introducing speed bumps and one-way streets and in some cases prohibiting traffic on some streets during the night. This helps to channel the ordinary car traffic to the main streets.

The effects of these measures can be seen when comparing the mode split in 1980 to 1990, (see Table 2-1) which clearly shows that the efforts taken succeeded and more people are using the public transport (or other means) as an alternative to the car.

Table 2-1: Mode split development for Zürich City from 1980 to 1990.

	City residents working in the city				Commuters into the city		Commuters out of the city	
	Walk	Bike	Public Transport	Private Car	Public Transport	Private Car	Public Transport	Private Car
1980	14%	5%	55%	26%	47%	53%	34%	66%
1990	16%	6%	61%	17%	58%	42%	42%	58%

Source: [Nash and Sylvia, 2001], pages 44/45

As a continuation of its traffic policies the City of Zürich made several small improvements to these concepts in the following years. The next big step was taken in May 2001 when the City Council decided on the new mobility strategy (Mobilitätsstrategie) which was taken after a comprehensive analysis of the current situation with respect to the traffic policies in the year 2000. This new strategy is embedded in an initiative to create a mobility culture and to keep the population involved and informed about the progress. For this purpose a web page was set up (see [Stadt Zürich, 2001c]).

The mobility strategy is not looking at the different sectors of traffic independently but takes a total, comprehensive view and consist of three main elements, coordinated between each other:

- *Sustainable development* (nachhaltige Entwicklung) focuses on fulfilling today's needs in such a way as not to destroy possibilities for future generations to satisfy theirs. Development of new projects and repair of existing installations both have to be tackled equally and conflicts of interest should be solved by compromise and taking a comprehensive, total view of the problem.
- The *focus of action and sectoral strategies* (Handlungsschwerpunkte und Teilstrategien) try to
  - optimise and interweave existing possibilities
  - support and develop innovation
  - supplement the infrastructure at the locations required
  - increase transparency and flexibility with respect to financing
  - open horizons for mobility in the city

  Each of these points will be worked out into a sectoral strategy.
- The *implementation rules* (Umsetzungsregeln) make sure that all measures taken conform with the mobility strategy (controlling) and try to facilitate the discussion process about mobility in society. This happens in an environment where the public participates in the process and the different departments of the city cooperate closely with each other.

The closure of the Limmatquai is in accordance with these city policies. The transit priority policy fits well with the closure as the tram lines 4 and 15 can go without disturbance by private vehicles through the closed part of the Limmatquai. This improves the connectivity of these lines that had to share part of their tracks with the car traffic. However, other public transport lines should not be influenced negatively on the alternative routes the car traffic will take. To assess this is one part of the aim of this thesis.

Now that the problem is put into its context, historically as well as on the level of transport policies, the next step to take is the clearer definition of the problem itself. First is has to be argued with the help of which means the research question can be answered best. Then the boundaries of the problem have to be drawn and input and output variables have to be identified. This is accomplished in the next chapter.

3. System analysis

This chapter contains the system analysis consisting of the description of the system parts and boundaries including the area to be considered together with input and output variables. It is argued that creating a microscopic model of the area is a good way to answer the research question whether detoured traffic (because of the closure of the Limmatquai) can be handled on the alternative routes.

Creating a microscopic model and performing a simulation of the area of the Limmatquai has some important advantages in this particular case of a closure. First of all, it enables the testing of a situation that is not yet present, but will occur in the future. This can be done in an inexpensive way. There is no other way to do that, as experiments with the real system cannot be done easily[1]. However the most important advantage offered by the simulation is that different alternatives can be tested in a simple way. These alternatives do not need to limit themselves to the official changes required by the closure, but can be extended by additional ones. The model might also show whether all the changes proposed are really necessary or if maybe some do not need to be implemented to get satisfactory results. None of these points can be checked in the real system.

Making comparisons to similar cases of street closures in different cities will not be a good way to asses the local effects. Such comparisons will never help to depict closely what will happen in Zürich, each traffic network being special in its own way, take e.g. the highly developed and unique transit priority system present in Zürich.

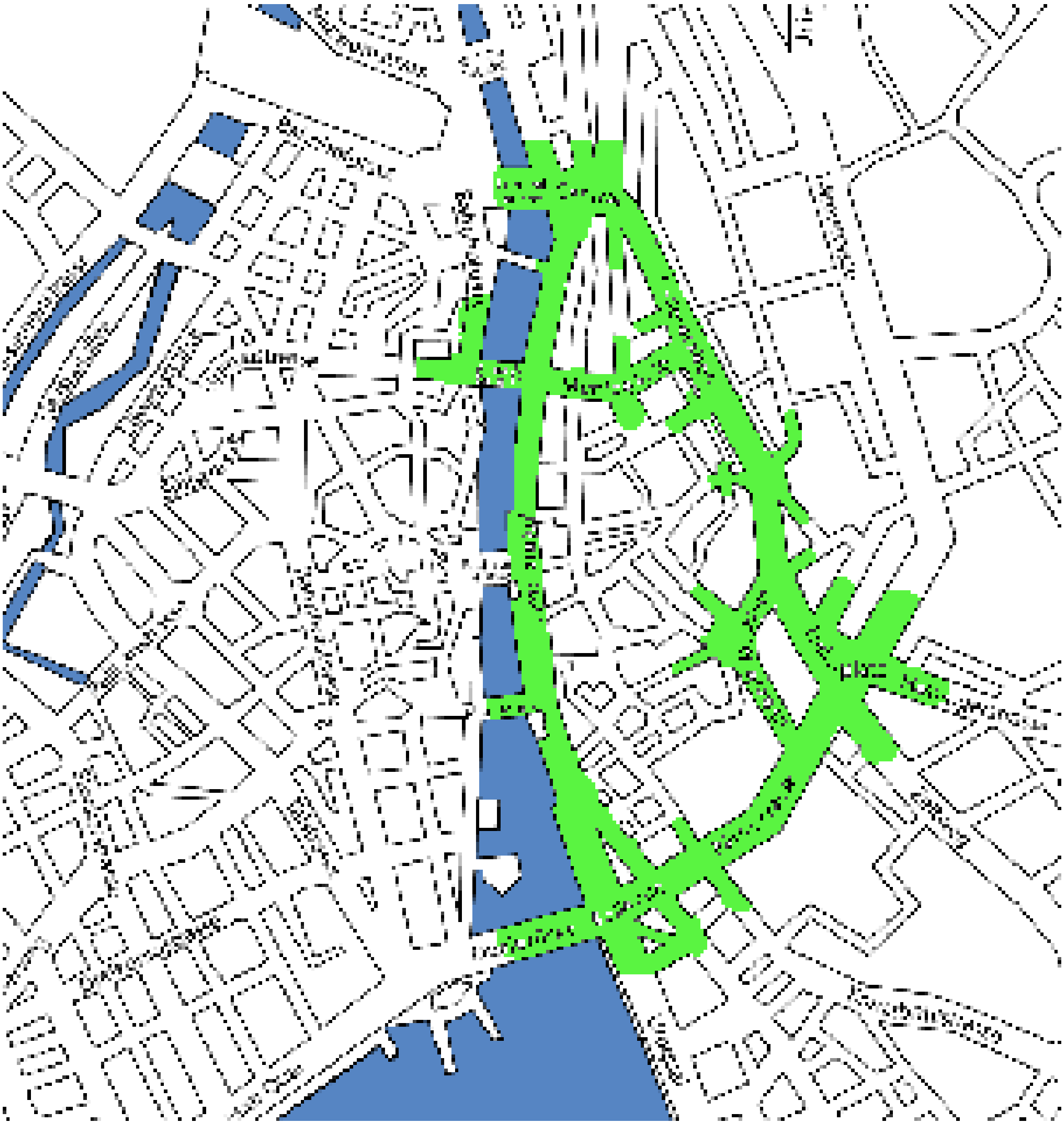
Therefore the traffic simulation software VISSIM will be used to create a model that can help in answering the research questions.

The area enclosed by Central, Seilergraben, Heimplatz, Rämistrasse, Bellevueplatz and Limmatquai with all (main) inbound streets is modelled in this project. This whole system is part of the the traffic system of Zürich City which in turn is part of the overall traffic system of the region of Zürich. An overview of the inner city area of Zürich is given on the map in Figure 3-1. The area coloured green shows all the streets (or part of streets) included in the model. Not all streets within the area bounded by the coloured streets were represented in the

[1] Natural experiments, such as the temporary closures due to construction work, excepted.

model, only the main streets were taken into account together with side streets which serve as origin and destination of traffic generated inside the area.

Figure 3-1: Map of Zürich (inner city) with highlighted modelled area.



Source of map (without marked region): [Müller, 2002]

The vehicle types modelled in the simulation are: cars, trucks, trams and buses. Bicycles are not simulated because it is assumed that they have little influence on the rest of the traffic. The reasons for this are the presence of extra bicycle lanes which are available along some of the streets and in general wide enough streets so that other vehicles can overtake easily.

All vehicles are input at inbound streets at the border as well as at small side streets inside the modelled area. At the same points (unless the inbound street is a one-way street) the vehicles are removed from the model when reaching the end of the street in the outward direction.

The main *input variables* are the number of cars and their routes through the network together with the characteristics of the network itself (traffic lights, allowed speeds, connections, priority rules, etc.).

The *output variables* of interest are:

- travel and delay times on certain routes
- overall delay and total time a car spends on average in the network
- length of queues forming at junctions
- forced public transport stops, meaning stops of public transport vehicles that are a result of the traffic situation, not for a normal regular stop to pick up passengers
- car losses, meaning cars that could not be put into the model because the capacity of their input streets was too small or because the car had to be removed from the simulation

The variables were chosen to be able to answer the research questions concerning private vehicle as well as public transport traffic. Furthermore they represent nearly the whole available spectrum of aggregated measurements VISSIM provides.

Pedestrians are modelled, but not as a coherent, connected flow through the whole area. They are only modelled at individual crossings, when a pedestrian crossing influences the traffic flow, e.g. when vehicles have to stop after turning in order to let pedestrians cross the street or when the lights for pedestrians turn to green only on request. Not having to create a coherent, connected flow of pedestrians greatly simplifies the task of modelling. Otherwise, origins and destinations of pedestrians would need to be found and routes the pedestrians take through the area would have to be defined. All this would require extensive research on the behaviour of pedestrians in the modelled area. This would be an interesting topic for a research project of its own but clearly is out of the scope of the present work.

For pedestrians no measurements are made, as their situation does not change significantly. They have right-of-way at pedestrian crossings, anyway, and the traffic light programs are not adapted in the future situation. Consequently the only major change in the future situation is the availability of the Limmatquai between Rudolf-Brun-Brücke and Münsterbrücke as a pedestrian zone with very limited traffic.

The simulation software VISSIM will be used to create the microscopic model of the area delineated above and to conduct the measurements of the output variables described. The next chapter will give an introduction to this software, explaining everything that is necessary to understand the further descriptions of the created model.

4. Simulation software VISSIM

In order to find out if the alternative traffic routes, that will be used once the Limmatquai is closed, can handle this new situation a model is created with the simulation software VISSIM.

"VISSIM is a microscopic, time step and behavior based simulation model developed to model urban traffic and public transit operations." [PTV, 2000]

VISSIM enables the user to create his/her network of streets (including all required parts and conditions like signal controlled junctions, priority rules, speed limits, etc.) and to input vehicles and their routes in order to simulate the traffic flow. A speciality of VISSIM is the model used to simulate the driving behaviour. This is not based on constant speeds or a deterministic car following logic, but the psychophysical driver behaviour model (psycho-physisches Wahrnehmungsmodell) developed by Wiedemann in 1974 is used instead. This behavioural model has been calibrated in several studies.

A VISSIM simulation is controlled by two different programs. The first is the traffic simulator VISSIM itself. The second is the external signal state generator VAP which controls vehicle actuated traffic lights. It takes the detector information from the traffic simulator on a discrete time step basis and determines the signal status for the following second and returns this information to the traffic simulator.

Streets are modelled as links, which are drawn on a background map, enabling the user to easily input a correct network. Links can have multiple lanes and are joined together with connectors. Together these two elements make up the underlying street network, forming the basis for the simulation, i.e. the street space on which vehicles are allowed to go. Additional elements like priority rules, stop signs and traffic lights are then placed on the links and connectors to control the traffic flow. At the start of links cars can be input and routes through the model can be set for these cars. A more detailed description of the abilities of VISSIM is given in the following section 4.1.

4.1 Detailed description of VISSIM

4.1.1 Calibration of background map

In order to simulate traffic it is necessary to create a network of the area to be represented. In order to do that a base map or a drawing of the area has to be imported into VISSIM. The map or the drawing to be used as the background in VISSIM needs to be in the bitmap format. After importing the bitmap file into VISSIM, the map has to be calibrated to have the appropriate scale. When the background map has been calibrated the network can be identified against it.

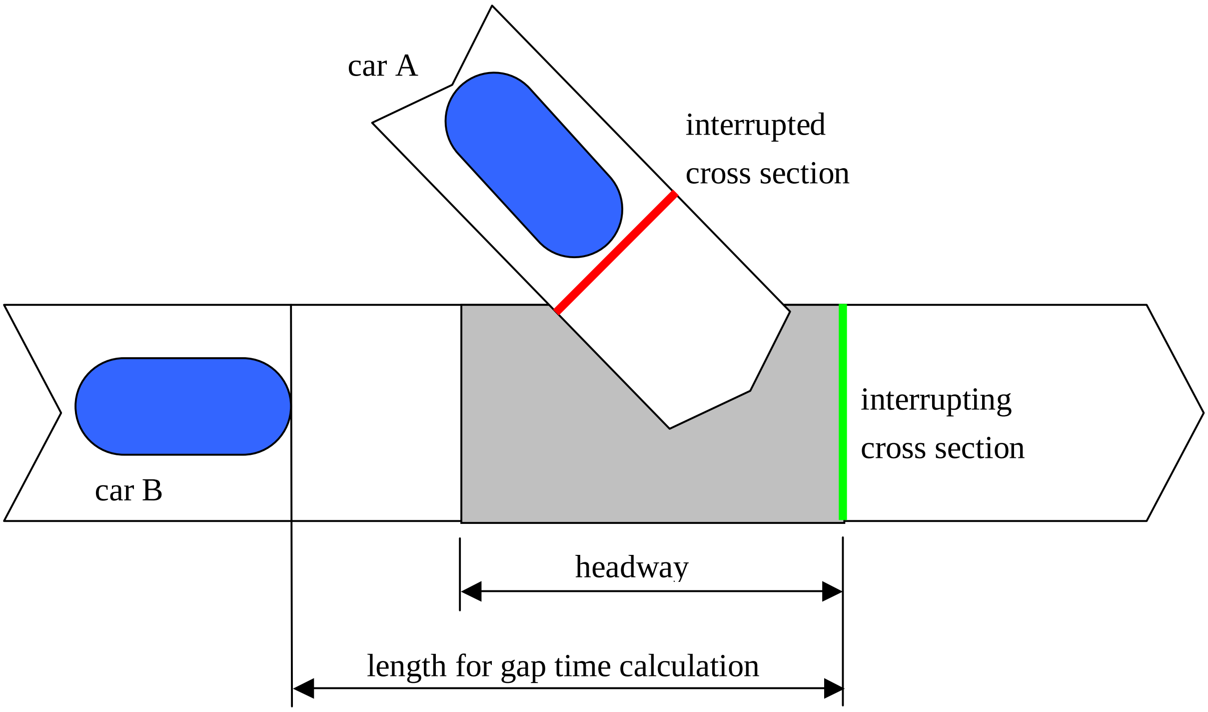
4.1.2 Priority rules

In VISSIM in order to show the right-of-way for cars on conflicting car paths it is necessary to input priority rules. A priority rule determines where a vehicle should yield to other vehicles.

A priority rule is implemented in two steps: the location where the yielding car has to stop (depicted as a red line, the interrupted section) and the place for which it stops (depicted as a green line, the interrupting section). There can be more than one green line for each red one meaning that a car has to yield at one position to multiple other lanes, e.g. when turning left at a non signalised intersection. The section for which the vehicles have to stop is characterised by three parameters: a (minimal) headway and a (minimal) gap time and a (maximum) speed. These parameters define completely how the car approaching the interrupted section behaves (see Figure 4-1).

The *minimal gap time* defines the minimum amount of time a car B on the interrupting lane has to be away from the location of the interrupting cross section in order to allow for a car A on the interrupted street to go and not to have to yield to car B. This time is calculated with the current speed of car B. In case of a traffic jam, however, car B might be standing just before the interrupting section and would not be detected as a reason for car A to yield (although it is standing in A’s way) as car B takes an infinite amount of time to reach the cross section with its current speed of zero. Therefore the *minimum headway*, a length in metres back from the interrupting cross section, defines an interrupting piece of street. If there is a car B on this part of the street, the car A approaching the interrupted section will yield to car B. These two parameters are sufficient in most normal situations.

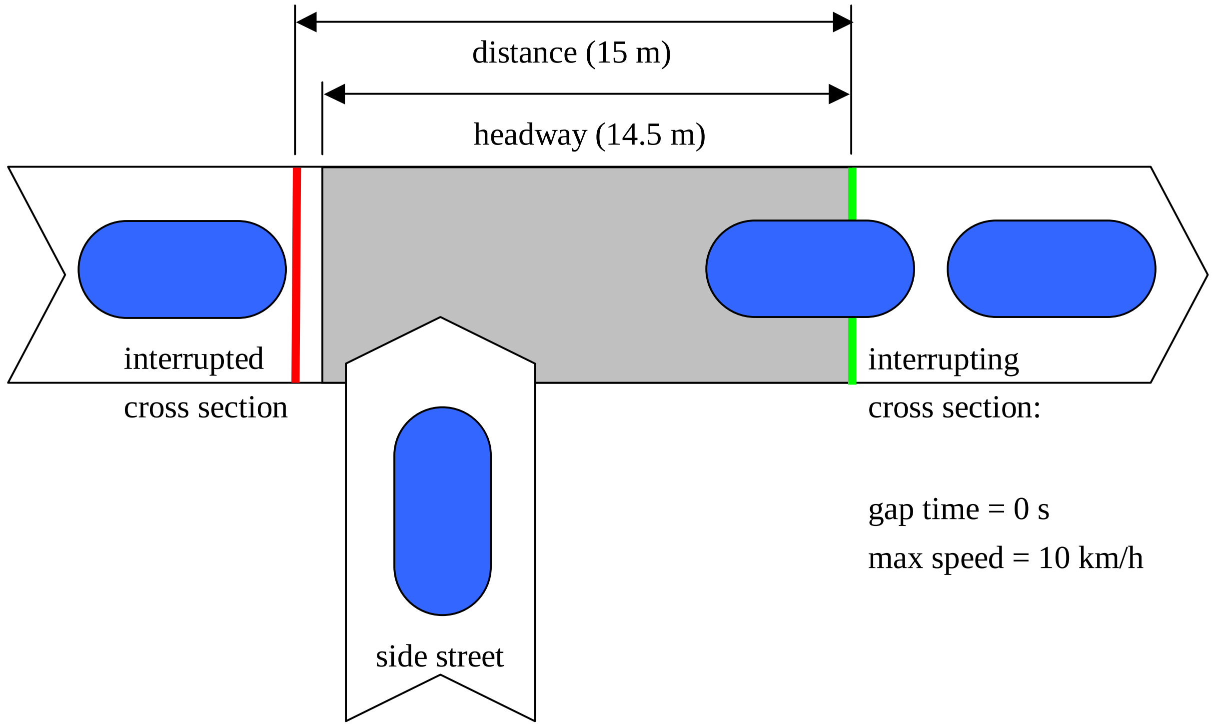
Figure 4-1: VISSIM priority rules – definition of terms.



The third one, the *maximum speed*, can normally be left at its default of 360 km/h, meaning that all cars on the interrupting sections are considered. If you decrease this velocity to e.g. 10 km/h then all cars that go faster than 10 km/h are not considered. This is useful e.g. for the case where cars on a street with a traffic jam leave a gap for cars merging from a side street. In this case, the interrupted and interrupting cross sections are on the same street, the main street. The interrupting section is e.g. 15 meters down the street from the interrupted section. The headway of the interrupting section is set to 14.5 meters and the gap time to 0 seconds while the maximal speed is set to 10 km/h. This produces the above described behaviour of cars leaving a gap in case of a traffic jam and is depicted in Figure 4-2.

Stop signs are modelled in the same way as priority rules, the only difference is that the car is required to stop at the interrupted cross section.

Figure 4-2: VISSIM priority rules – leaving a gap.



In earlier versions of VISSIM it was necessary to pay special attention so that cars would not get into a situation where they have to yield to themselves or to each other as this would create a deadlock and the cars would remain standing. These situations can easily happen at more complex junctions – the interested reader is invited to take a look at the implementation of priority rules at Central to get an impression of a complex situation. In VISSIM 3.6 these direct deadlocks are detected and resolved in most situations. However there is no way to detect indirect deadlocks (as described in chapter 7.1) automatically, the user has to make sure that these deadlocks do not occur.

4.1.3 Signal controlled junctions

In VISSIM every signal controlled junction is assigned a signal controller that is responsible for it. Each signal controller has a number of signal groups, which are its smallest control unit. A number of these signal groups constitute one signal stage of the junction. The device showing the picture of the appropriate signal group is called a signal head, in reality the actual traffic light. Therefore it is possible for one signal group to have multiple signal heads.

Signal controlled junctions can be modelled in VISSIM by using either a built-in, fixed-time control or by using the external signal state generator VAP (vehicle actuated programming). The ‘program’ for the built-in type can be input directly in VISSIM without the help of any external program. This is done in a graphical editor which shows all signal groups and the durations for which each signal group has a green light. However, this type of SCJ is not able to be influenced by the current traffic (and detectors) in any way. It always has the same fixed sequence of green light phases.

The external state generator on the other hand needs so called VAP files. These are text files created with the help of a graphical editor called VisVAP or written by hand. The external signal control logic generator sends information to VISSIM for each signal controlled junction. Other signal control logic add-ons are also available, however VAP is the easiest to learn and was therefore chosen as the signal state generator for this project.

VisVAP allows to do the programming in a graphical way using flow diagrams. The main elements of these are the start and end elements, the conditional element and the statement element for normal commands. The commands allow to change the picture of single signal groups or to switch from one stage to the other. In addition to that, there is the possibility of defining subroutines, conditions and constant parameters to ease the programming. For additional information to the VAP programming language and the VisVAP editor, see the appendix A and B in [PTV, 2001]. The VisVAP files are saved with the ending .vv and can be translated from within VisVAP to the necessary .vap files. These .vap files in turn are used by the external signal control logic generator VAP to send the state information of the signal groups to VISSIM. Signal groups are updated at the end of each simulated second, meaning that the program is run once every second. This procedure is performed for each signal controlled junction, with different programs for each junction of course.

Normally the programming of traffic lights is done by defining different stages which last for a certain duration and follow each other according to some predefined logic. Detectors measure the current traffic situation and deliver the information which is used to decide the duration of the stages and the sequence of them. Between these stages preset interstages (inter green times) take place which define how the transition takes place exactly. The stages themselves together with the description of the interstages are contained in a text file with the ending .pua which is also needed by the VAP generator.

4.1.4 Car traffic routing

There are three ways of assigning routes to cars in VISSIM: either by implementing static routes using *routing decisions* or *direction decisions,* or by using *dynamic assignment* of routes with the help of OD-matrices. Of the first two, the VISSIM manual suggests using routing decisions instead of direction decisions, since handling them is much easier and the vehicle flow can be defined more precisely.

Direction decisions allow only to define directions at each junction separately unlike routing decisions that allow to set a whole route over more than one junction. The direction decision option is a left over from the time when there was no possibility of making routing decisions in VISSIM and therefore will not be described here further.

Routing decisions

“A route is a fixed sequence of links and connectors from the routing decision point […] to a destination point […].” [PTV (2000)]

Each routing decision point can have multiple destinations. Routing decisions enable modelling car paths across the whole network. For every routing decision point a relative flow has to be defined for all its routes (destination points). The number of cars going on a particular route starting from one routing decision point can be defined by the following formula:

$$c_i = \frac{f_i}{\sum_i f_i} \cdot C$$

where f_i is the relative flow on route i, C – the number of cars (without an assigned route) passing over the routing decision point and c_i is the number of cars on route i. In VISSIM a car which already has a destination point assigned to it does not change its destination during the simulation until it reaches its destination point. Therefore C takes into account only the cars that do not have any route assigned to them yet.

Dynamic routing decisions

Dynamic routing decisions are used when the origins and destinations of cars are known but it is not clear which routes the cars will take on their way. This can only be used if the Dynamic Assignment module is installed as an add-on to VISSIM. The origins and destinations are defined as parking places, and the OD matrix must be given to the program in order to define how many cars want to go from which origin to which destination. Then VISSIM can run iteratively simulations of the model, normally starting with the shortest paths for all vehicles. The model run is evaluated according to a generalised cost function (which might e.g. include the distance as well as the time travelled). Through a changing of routes through the network VISSIM is trying to minimise the overall costs of the users for each iteration, hopefully reaching a stable minimum after a number of these iterations are performed. It is additionally possible to take into account the dynamic changing of routes because of certain events, like a parking lot being full.

4.1.5 Public transport

Modelling public transport requires defining the stops and routes including the stops served and the schedules. The routes are selected in a similar way as described above in section 4.1.4 for the routing decisions. By defining start and end point VISSIM automatically creates a route between these two points. This route can be altered if necessary in the case of multiple possible alternatives. All the stops – which have to be defined in a separate step – along the route are by default served by the public transport vehicle but this can be selectively disabled. For each of these routes the vehicle type has to be selected (tram or bus geometry and characteristics) as well as a starting schedule created.

To create realistic stop times at public transport stops, two methods are available in VISSIM. The simple one uses a dwell time distribution for each stop and picks randomly a duration from this given distribution making the vehicle stand for that amount of time. If however the amount of passengers getting on and off the public transport vehicles are known for all stops, it is possible to calculate the dwell time depending on the number of people getting on and off the vehicle. In addition to that it is also possible to impose a schedule for a public transport line, meaning that the vehicle stops at least so long until its designated departure time is reached.

4.1.6 Speed limits

There is a possibility in VISSIM to model sections of streets with different speed characteristics. This is done by creating an area with a specific speed distribution assigned to it. When a vehicle arrives at such a section it is given a new desired speed from the selected distribution. After leaving this zone the vehicle is automatically re-assigned its previous desired speed. This enables to model streets with speed limits as well as areas where careful slower driving is required, like e.g. curves.

The reader should now be familiar with the basic functionality of the VISSIM simulation software. The different alternatives available for routing cars and the implementation of priority rules together with the ways to program signal controlled junctions were described in order to help in understanding the finished model and the design decisions made (described in chapter 6). Before the model can be created, though, the specification of the input parameters and a more detailed description of the output parameters must be accomplished. The sources for these numbers are given and necessary assumption and simplifications are made in the following chapter.

5. Specification

This chapter describes the sources of the input data used in the model. Where possible and necessary assumptions were made in order to simplify the model. Furthermore the output variables measured in VISSIM are described in more detail.

5.1 Data sources

The data used for programming the signal controlled junctions together with the junction (Knoten-/Spurenplan) and detector plans was provided by the City Police (Stadtpolizei Zürich) and can be found on the CD in folder 'Source data/Junction plans'. Each junction has, apart from the name, its unique number. These numbers are used in VISSIM and for naming the traffic light programs for the external logic generator VAP. Each junction plan assigns an number to each lane. These numbers are kept in the same way within VISSIM.

For the purpose of modelling the street network a background map was obtained from GeoZ. This map can be found on the CD in the 'Model' folder. The distance from Central to Bellevueplatz, basically the height of the model, is approximately 1 kilometre.

The number of cars and their routes used for the simulation of the peak hour were based on [Müller, 2002]. Over the whole day, around 22'000 cars travel through the Limmatquai. In the simulated peak hour, the inputs into all streets in the modelled area add up to around 9'100 cars in the current and 8'900 cars in the future situation.

The departure times for buses and trams needed to model public transportation arrival times at stops are taken from [VBZ, 2001], on average the public transport vehicles are going every seven minutes during the peak hour. Information about speed limits for trams was provided by the City Police and the VBZ.

The junctions of Limmatquai/Mühlegasse and Heimatwerk/Rudolf-Brun-Brücke were already simulated in [Angst, 2002] and were used directly by extending them to include the surrounding area necessary for this study.

5.2 Assumptions and simplifications

Only the peak hour of the day, which is considered to be between 5 p.m. and 6 p.m, is taken into consideration during the simulation. It is assumed that if no problems arise during that hour, the traffic can be handled during the rest of the day as well. The analysis leading to this result cannot be reproduced in this report, as it requires an in depth consideration of the traffic pattern over time for several streets in the modelled area. The interested reader is pointed to section 5.1 in [Müller, 2002] and section 2.2 in [Stadt Zürich, 2001b].

There was no data available about the amount of pedestrians at the pedestrian crossings. Therefore some assumptions had to be made. It was assumed that there are 150 pedestrians per hour at each crossing each way (that means altogether 300 pedestrians per hour at a single pedestrian crossing). For most junctions which are regulated by traffic lights, the number of pedestrians crossing is irrelevant as the pedestrian stage is not colliding with any other stages. Only on a few occasions cars turning right have to yield to the pedestrians. Here, as the pedestrians are collected together into packs waiting before a red light and then cross the junction in this pack, the number of them does not have a big influence either. Non-signalised pedestrian crossings appear mainly on the Limmatquai and thus influence the current but not the future situation.

At Central, however, this number of 300 pedestrians per hour had to be reduced. During the peak hour there are three traffic wardens (working together in coordination) present at different positions around the junction. There is no option for modelling traffic wardens in VISSIM. The only way to remotely do what they would be doing is by modelling them as signal controlled junctions. However, to capture the intelligent behaviour of the traffic wardens well in a computer program, making logical deductions from various detector settings, would be a nearly impossible task. Therefore the junction at Central was modelled only with priority rules. However the amount of pedestrians had to be reduced since the junction did not work with the high numbers.

When modelling the streets their gradients were not taken into account as there are no steep ascents present in the modelled area.

In the modelled area there are no special speed limits for cars. However, VISSIM does not automatically reduce the speed of vehicles going round corners. This has to be modelled with speed limit areas in the curves. For cars a linear velocity distribution between 10 and 15 km/h in the tight curves and 15 to 20 km/h in the other curves is chosen, for trucks these speeds are reduced even more.

The tram default speed used in the simulation is an average of 36 km/h (linear velocity distribution between 33-39 km/h) corresponding to the maximum allowed velocity throughout most of the area. This seems low but corresponds to the requirements in reality. In some cases (for example between Central and Kunsthaus) the trams are allowed to go faster. This is however disregarded, since it concerns only two cases – on the way from Central to Kunsthaus and from Kunsthaus to Hirschengraben and only in these directions. Implementing it would require having the higher speed as the default speed for trams and having to make special speed limits everywhere else. In the places where there are switches, trams need to go at 18 km/h (linear velocity distribution between 15-20 km/h). Those areas include Central, Bellevueplatz and Heimplatz. Furthermore the velocity has to be reduced in curves. This happens on the Limmatquai around house number 42 where trams go with a speed of 30 km/h (linear velocity distribution between 27-33 km/h) and around house number 20 with a speed of 24 km/h (linear velocity distribution between 21-27 km/h). The velocity distributions chosen are going over the upper limit of the allowed speed. This is because it is assumed that it is not possible to drive at, e.g. exactly 24 km/h and it can therefore happen that the trams exceed their allowed speed.

Traffic lights and routes for trams that are not part of the regular service (e.g. when trams need to divert from their routes) are not modelled. Thus the following tracks are not included in the model (as shown on plans provided by the police and included on the CD in folder 'Source data/Junction plans'):

- Bellevueplatz (Brückenkopf) - lanes 18 and 19
- Bellevueplatz (Schöck Str/Utoquai) - lane 7
- Bellevueplatz (Odeon) - lanes 14 and 16

In some cases pedestrian crossings were not modelled. This was only done for the crossings between two tram tracks where pedestrians are required and assumed to give way to trams anyway. They do not obstruct the passage of the tram and thus the following lanes were not modelled:

- Heimplatz/Rämi-/Zeltweg – lane 14
- Heimplatz/Hottinger-/Rämistrasse – lane 21
- Neumarkt/Seilergraben (Künstlergasse) – lanes 3 and 8 (blinking light for pedestrians to warn them about approaching trams)
- Heimstrasse/Hirschengraben – lane 11

Special traffic light settings for the regional bus arriving on lane 2 at Bellevueplatz (Brückenkopf) are not taken into consideration. Modelling them would create additional complications in the programming of this already complicated crossing and neglecting them does not have a significant influence on the rest of the traffic light programmes at Bellevueplatz. The extension or shortening of other signal durations due to the bus is only in a range of 2-3 seconds in a total cycle of 90 seconds. Additionally a bus would not appear every cycle. Therefore it was decided as a simplification to not model these busses at all.

Traffic lights' schemes of Bellevueplatz (Brückenkopf) and Bellevueplatz (Urban) appear to have additional stages for the trams. Modelling it in such a way would require coming up with assumptions as to how these are selected, which of the trams gets the green phase and would prove very complicated. Therefore in order to simplify, instead of making an additional independent tram stage and decisions which tram gets the green phase, the original tram stage gets extended in case of a tram coming and the conflict between the approaching trams is handled by priority rules. An example of that is lane 6 of the junction number 603 (see folder 'Source data/Traffic lights/603 – Bellevue…' on the CD). Normally the traffic light for this lane goes to green at 16 seconds and to red at 25 seconds and again to green at 32 seconds. However with the assumptions made, it goes to green at 16 seconds and to red at 25 seconds only if the tram is not coming, otherwise the green gets extended to the 41st second. Since then all the trams have green stages at the same time (even when on colliding paths) priority rules have been implemented in VISSIM to deal with this problem.

5.3 VISSIM measurements

The results are based on measurements of different scenarios, for each of which five replications are executed. These replications are done with different random seeds as VISSIM allows to set this seed in order to reproduce the same run over and over again when necessary (as it is e.g. for testing purposes). The number of replications was chosen because of the time constraints of this study. Each simulation takes approximately an hour of real time and should be supervised during the run, in addition to that comes the time for the post-processing of the data created during the run. Nevertheless in order to asses the different scenarios some statistics are required, so five runs are considered a compromise between these colliding requirements. All of the runs are performed for the peak hour between 5 p.m. and 6 p.m. In order to have the network filled with cars at the start of the measurements, it is run for additional 20 min before the measurements are taken. This time was chosen as a compromise between the overall time necessary to run the model and the necessity to reach an equilibrated state.

The runs are made for both the current situation and the future situation (after the closure of the Limmatquai).

The different scenarios are for:

- 90%
- 100%
- 100% randomised
- 110%

number of cars taken from an assignment model of the City of Zürich by [Müller, 2002]. This means that the number of cars obtained from the assignment model (for both the current and the future situation) are input into the model which gives the scenarios with 100% cars. 90% cars means that the overall number of cars at all inputs within the model is reduced by 10% and in the case of 110% increased by the same percentage. In the case of runs with 100% randomised cars a +/- 10% random change is made to the input numbers of cars. After that these inputs are scaled in such a way as to set the overall number of cars to the same as for the default 100% cars scenario.

This means that only the car (and truck) vehicle input numbers are changed, public transport and pedestrian volumes remain exactly the same in all scenarios for the current and future situation.

More details on the measurements will be given here while Chapter 8 discusses the results in detail. All measurements (unless noted otherwise) are conducted for the duration of one hour after the start-up period is finished.

Figure 5-1: Map of routes through the network.

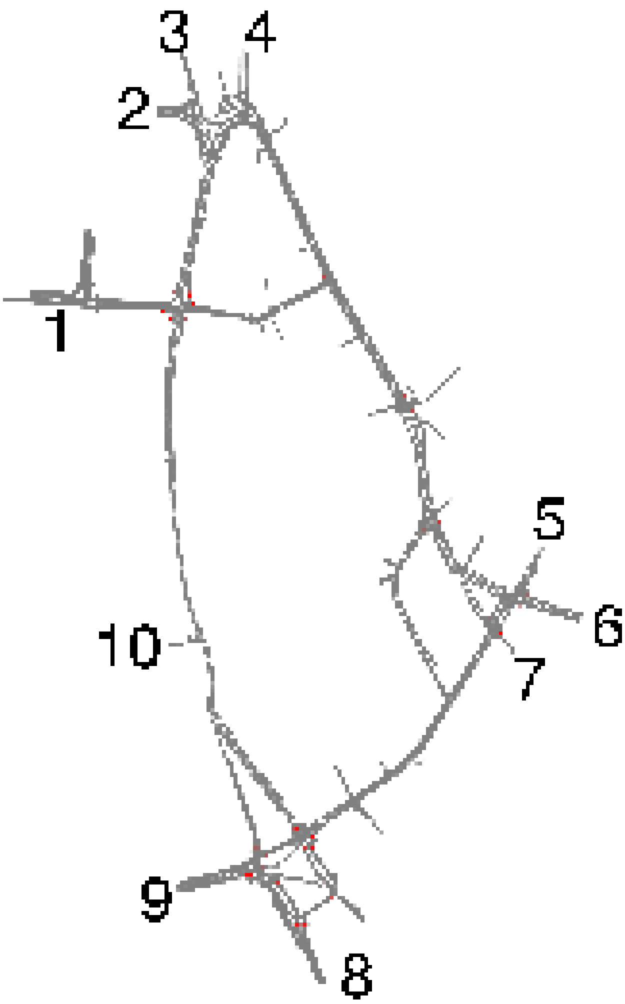


Table 5-1: Routes for travel and delay time measurements.

From	To	Distance [meters]
1	6	1018
2	7	1028
3	1	520
5	9	675
6	1	1021
7	2	1006
8	4	1368 (future: 1477)
8	10	515
9	5	822
10	8	564

The *travel and delay times* are measured on certain routes through the network. Figure 5-1 shows the beginning and end points of these routes and Table 5-1 gives the routes themselves. All routes are defined in such a way as to take the shortest available way. The routes were chosen to be available in the current and the future situation but notice that route 8-4 is in the current situation going up through the Limmatquai and in the future situation has to take Seilergraben which means a detour. Furthermore the routes are covering most of the network so that it is possible to make statements about the travel and delay time over the whole network. VISSIM creates output files with the ending .rsz and .vlz which contain the necessary data for the evaluation, the travel and delay times are averaged over the whole hour. This is necessary to obtain a valid average value as some routes are travelled by too few cars to allow a finer segmentation.

The *overall delay and total time* in the network is measured together with the number of cars that are in the modelled area during the time of the measurement. This information is extracted from the car protocol file (.fzp) which stores certain information, which can be set in VISSIM, about every car (and truck) in the model, for every time step. Among them are the car number, the delay time and total time the vehicle spent in the model; this last value is set when the car leaves the model the last time the car is listed in the file, before that the value is zero. As for this evaluation only the delay time and total time in the model are of interest, the .fzp file is filtered to only include the last line that mentions each car. The total time value is not set for the cars that remain in the model at the end. However it can be calculated as both the end time and the time when the vehicle entered the network are known.

The *queue lengths* at all crossings are also looked at. What constitutes a queue can be defined in VISSIM globally. For this work these values were left at their default, meaning that a car goes into the queue condition if it is slower than 5 km/h and it leaves the queue condition if it goes faster then 10 km/h. The length of the queue is measured from designated points at each crossing. If there are gaps longer than 20 meters the queue is broken. The numbering scheme for the queue counters is given in section 6.6.3. Available as output values are the average and maximum queue length as well as the number of stops made by vehicles in the queue.

The forced *public transport stops* are also measured, meaning all stops that are not scheduled at the regular public transport stops. VISSIM puts all these stops into the file with the ending .ovw from which they are imported into Microsoft Excel. There they are sorted according to public transport line and direction. Note that it is not possible to restrict the time for which VISSIM records these public transport stops so they are recorded for the whole duration of the run including the start-up period.

The *car losses* reflect two situations. First a certain number of cars cannot be put into the model. This is caused by input streets not being able to handle the traffic that is put into them, the cars cannot flow off the link fast enough and thus a traffic jam on the input link is created. If this traffic jam has reached the end of the link, no more cars can be put in so VISSIM creates an outside queue of new cars. At the end of a run the number of cars (together with the link number) that could not be put into the model is reported by VISSIM and written into an error file (with the ending .err).

The other source of car losses consists of cars that had to be removed from the running simulation. This is the case when a car on a route needs to change its lane to stay on its designated route. If there is heavy traffic the car might not be able to change the lane and stands on the wrong lane trying to get in. In reality the driver of such a vehicle would force his way into the flowing traffic on the other lane. In theory this should also be the case for VISSIM but in certain situations this does not work. As the car waiting to change its lane is blocking all the traffic behind it, it creates a queue which would not be produced in reality because of the above mentioned behaviour of real, intelligent drivers. The solution to this problem is that cars waiting for a lane change more than 30 seconds are automatically removed from the model by VISSIM, they are considered to have forced their way into the other lane.

Now the model is conceptualised and fully specified so that it can be created. The resulting models for the current and future situation are described in detail in the next chapter.

6. Simulation models

Figure 6-1 shows a comparison of the map of the modelled area with the resulting VISSIM network. On the right side in the model view all side streets that were modelled can be seen easily. To get an impression of the number of lanes in the different streets see the plan of the lane configuration in Figure 6-2. It is not easy to see this information in the VISSIM network at the scale of Figure 6-1.

Figure 6-1: Map of modelled area together with VISSIM network.

Source of map (without marked area): [Müller, 2002]

Figure 6-2: Plan of lanes.

Source: [Müller, 2002], p. 19

6.1 Calibration of background map

The map used as a background for the network was provided by GeoZ. The co-ordinates for the lower left and the upper right corners of the map were provided and therefore enabled the map's calibration. This was done by calculating the length of the diagonal of the rectangular map. This distance was then used in VISSIM as a calibration length. With the lower left co-ordinates being y/x = 682 186.50 / 245 657.00 and the upper right y/x = 684 571.10 / 248 376.25, so the resulting diagonal is equal to 3616.7164 m.

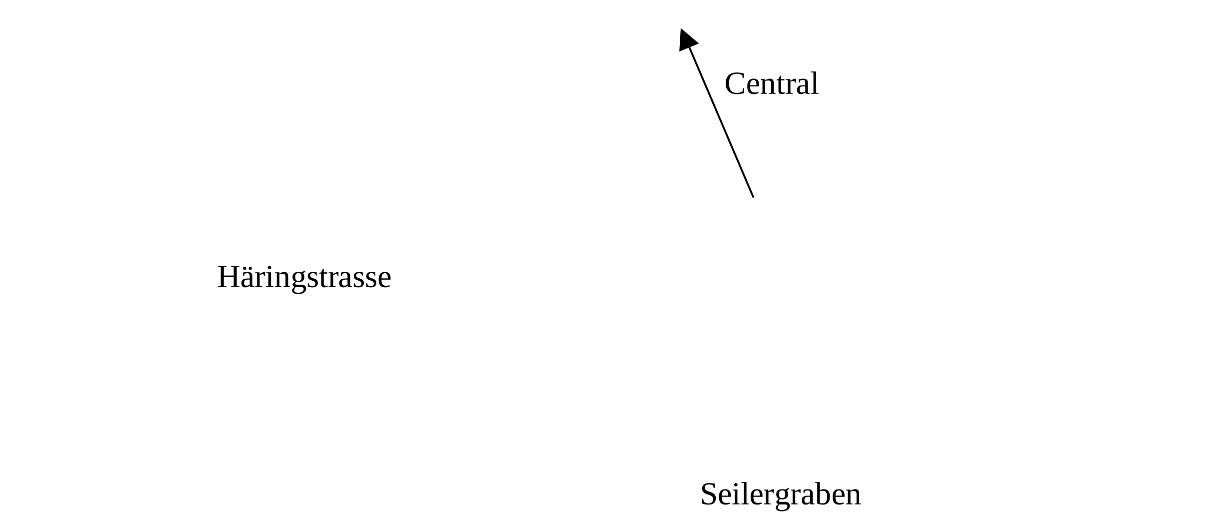
6.2 Priority rules

Switzerland has a right-sided priority rule. In order to enforce this rules VISSIM priority rules had to be applied wherever there is a possibility of a collision. For a description of the way these rules are implemented see section 4.1.2.

The cars are always made to yield to pedestrians and to trams (and buses which are using the same lanes as trams). They also have to yield to buses leaving bus stops and joining the traffic flow.

Almost always cars give way to the cars which are coming from the right. However in a few places the opposite is implemented. In cases where the cars coming from the left side have to cross double tram lanes and after that another car lane in order to get into a side street. Normally the car wanting to turn left would have to wait until all three lanes (two tram and one car lane in the opposite direction) are free. This takes usually a long time during which a jam behind the car is created. Furthermore if the car would cross the first tram lane (thus not creating a car jam behind itself) and the cars coming from opposite direction would not yield there could occur situations when trams would have to stop for the cars standing on their lanes. This could create delays for the trams which should be avoided if possible. However when the cars coming from the opposite direction yield there will be no such problems. It is assumed that most of the time that will be the case, since in reality Swiss drivers seem to be friendly and often yield even when they are not required to do so. This is the case for example for cars wanting to go from Seilergraben into Häringstrasse (see Figure 6-3). Here the cars coming on Seilergraben from the direction of Central yield to cars coming from the opposite direction, even though they are on their left side.

Figure 6-3: Left turn from Seilergraben into Häringstrasse.

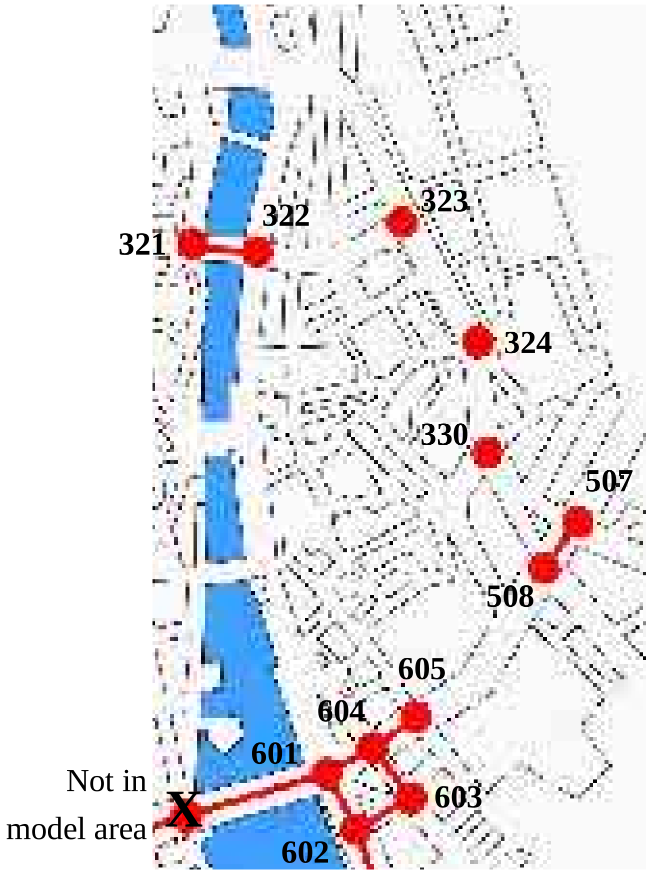


At Bellevueplatz trams are on conflicting routes (due to assumptions that had to be made, see chapter 5.2). The priority rules are implemented for them in the same way as for the car traffic. This means that a tram has to yield to a tram coming from the right side and that a tram going straight has priority over a tram turning left.

6.3 Signal controlled junctions

In the area modelled 10 signal controlled junctions (SCJs) had to be created. Altogether there are 12 SCJs in the modelled area; two of them (321 and 322) were taken directly from [Angst, 2002]. Figure 6-4 shows all those junctions together with their junction number. The big red dots represent the junctions and the lines connecting some of these junctions mean that these junctions are coordinated.

Figure 6-4: Position of signal controlled junctions with junction numbers.



Source of map (annotations added): [Müller, 2002], p. 18

The easiest way to program a SCJ is with fixed time signal control. The length of all green phases is preset and does not depend on the current traffic situation. VISSIM contains a graphical editor to input this type of control program easily. Unfortunately it cannot be used to model any of the junctions in the simulated area since all junctions are both traffic actuated and give priority to public transport.

Therefore all junctions in the model are specified with the help of VisVAP. VISSIM together with the external signal state generator VAP allows to define signal control logics including traffic actuation and transit priority. Both of those features are needed for the model.

SCJs can have different operating logics and therefore are programmed and work in different ways. In the modelled area there are two different types of signal controlled junctions present.

The first type works in a fixed cycle that is continuously repeated. Green lights for individual lanes can be shortened or extended (or left out altogether) based on detector readings (tram or traffic jam detection). Nevertheless the cycle time stays fixed. All of Bellevue's junctions are coordinated and run in such a cyclic fashion with a cycle time of 90 seconds (see section 6.3.1):

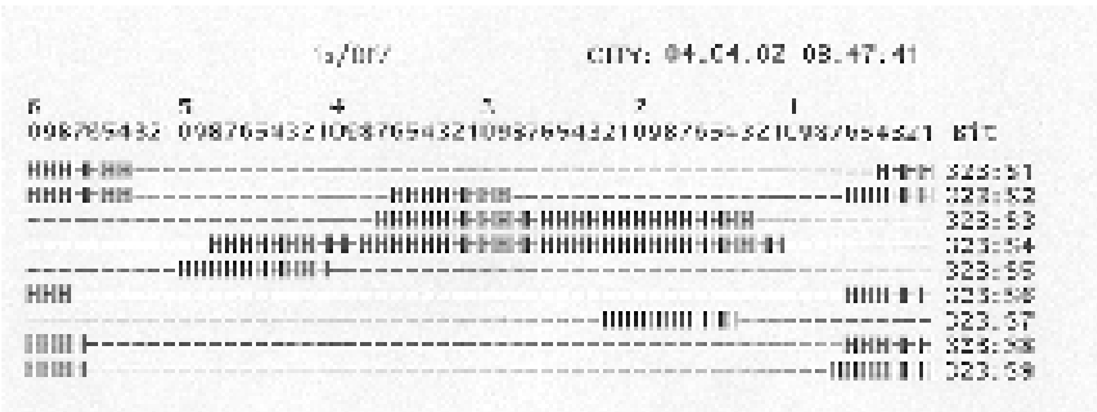
- Bellevueplatz (Brückenkopf) - 601
- Bellevueplatz (Schöck Strasse/Utoquai) – 602
- Bellevueplatz (Urban) - 603
- Bellevueplatz (Odeon) - 604
- Rämi-/Stadelhoferstrasse - 605

The second type of SCJs present in the modelled area is based on stages. These stages combine together lanes that have a green phase at the same time. Switching between the different stages is junction specific. This can be done always in the same cycle, e.g. stages A-B-C-A-B-C-A and so on, but note that this is not equivalent to the first type of SCJs as the length of each stage may vary and thus the overall cycle time does not stay constant. Another alternative is an non-cyclical scheme, where the stages may be switched in (nearly) any order according to the current traffic situation. In order to have a smooth switching between the stages, interstages (inter green times) have to be defined. These set how long it takes for vehicles to clear a crossing and in that way when the different signal groups are allowed to be switched in relation to each other.

The SCJs that are programmed in this manner are:

- Heimatwerk[2] – 321
- Limmatquai/Mühlegasse[2] - 322
- Mühlegasse/Seilergraben – 323
- Neumarkt/Seilergraben – 324
- Heimstrasse/Hirschengraben – 330
- Heimplatz/Hottinger-/Rämistrasse – 507
- Heimplatz/Rämistrasse/Zeltweg – 508

Figure 6-5: Example printout of traffic light pictures for junction 323.



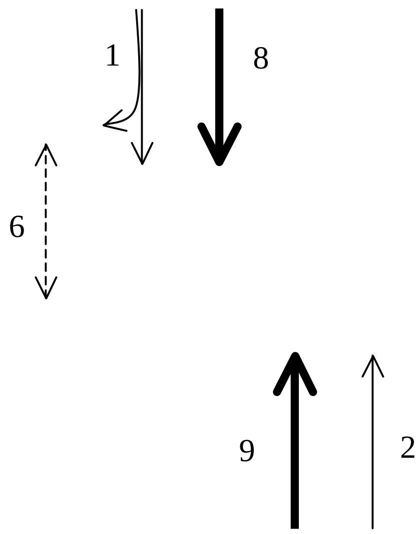
For this type of SCJ no schemes were available, since they do not operate in a fixed cycle. Instead their logics were explained by Mr Stange and Mr Schneider of the City Police and a set of print outs of the actual green light periods occurring at some times during the day were given (these can also be found on the CD in folder ‘Source data/Traffic lights’). Figure 6-5 gives an example of such a printout. Each row represents one signal group, the description at the end of each row gives the junction number (here 323) and after that the lane (signal group) number corresponding to the junction plans. The time given at the top right is the start time of the measurement corresponding to the entries in the leftmost column. An ‘H’ represents a green signal and a ‘-‘ a red signal of the lane. Each character represents the duration of one second and each printout is done for the duration of 60 seconds. However, sometimes two printouts were available that had overlapping intervals. In this case, the printouts were copied together at the right spot to form one consecutive (longer than 60 seconds) interval.

[2] modelled in [Angst, 2002] with only marginal error corrections applied

The junctions of Heimplatz/Hottinger-/Rämistrasse and Heimplatz/Rämi-/Zeltweg (number 507 and 508) provide additional difficulty since they are coupled (which means that they are dependent on each other and inter-connected). For these crossings independent printouts were available as well as special printouts which show the situation at both crossings at the same time. The latter are included on the CD in the folder 'Source data/Traffic lights/507 and 508 - Heimplatz'.

From the printouts and explanations it was possible to derive the different stages of each SCJ (Figure 6-6 shows an example of such a stage) but not all the logic present in reality in these traffic lights could be incorporated. This is because of the sophisticated nature of these – over the course of years - highly optimised traffic light control programs. As an example, in junction 324, a special pedestrian phase is initiated in the case of an approaching tram under the condition that the pedestrians waited longer than a certain amount of time. These special cases would increase the complexity of the programs a lot and also increase the need for more and more detailed information. Considering the time constraints of this work it was therefore decided to model these crossings simplified. Note however that the principal characteristics of the crossings are nevertheless captured in the created programs.

Figure 6-6: Stage 1 for junction 323 – Mühlegasse/Seilergraben.



The dotted line (lane 6) depicts a pedestrians crossing, the bold lines (lanes 8 and 9) show tram lanes and the rest (lanes 1 and 2) car lanes, all given with their corresponding lane number and the direction in which these lanes are allowed to go. All stage diagrams can be found in appendix B; they were not included in the running text as they would take up too much space there.

In the following sections an overview of the logic of each modelled crossing is given. These overviews cannot go into every detail and should best be read with running VISSIM and VisVAP programs at hand, to be able to take a 'live' look at the program logic and the simulated crossing.

6.3.1 Bellevueplatz (601 – 604) and Rämi-/Stadelhoferstrasse (605)

The four Bellevueplatz SCJs (601 to 604) and Rämi-/Stadelhoferstrasse (605) all have a cycle of 90 seconds. The signal programs were provided by the police and are available in a scanned version on the CD in 'Source data/Traffic lights'. These were a bit simplified (see section 5.2) but after that implemented one to one in VisVAP.

It is possible to set the cycle time for a crossing in VISSIM and then the current cycle time itself is automatically present in the VAP program under the variable name 't' – the counting starts at 1 and goes up to 90 seconds making second 0 equivalent with second 90. The programs for these junctions themselves have a straight forward structure. The current cycle time t is compared with all times at which an event happens (changing of the picture of a signal group). If a match is found, the relevant event is initiated and the program stops after that (for this second). The execution of the event might depend on some conditions (detector settings) that have been set earlier. As some of these conditions effect more than one SCJ, they have to be communicated to other SCJs with the help of the VISSIM SCJ channels (marker_put and marker_get commands).

The green times of signal groups can be extended or shortened based on detector readings. In the majority of the cases this happens when an approaching tram has been detected although in one case also when a bus is arriving (this however was disregarded, see chapter 5.2).

To help in understanding the traffic light plans, here a few remarks on how to read them. A vertical line, going through the line indicating a green time, defines alternate end or start of the green light. An example of that is the green phase of lane 5 from the junction number 601. If a tram is not detected (Tram Nachlauf 1 – tram detected at the junction number 602) then the green light is turned on in the 33rd second, otherwise it starts only in the 45th second.

The dashed lines indicate possibility of extension of the green light. For example the lane number 3 of the junction number 603 can have the green light extended to the 42nd second if a tram is not detected. Otherwise it ends at the 26th second.

6.3.2 Mühlegasse/Seilergraben (323)

This signal controlled junction has four stages shown on Figure B-1 in the appendix. The main stage 1 allows the cars together with trams on Seilergraben to drive straight (with the pedestrians on lane 6). Stage 2 is for the traffic coming from Mühlegasse and wanting to turn left (lane 5); stage 1 switches to stage 2 if a car is waiting to turn left. Otherwise – unless there is a traffic jam on Seilergraben down to Central (condition 'Stau') – stage 1 switches to stage 3 which allows the right turn from Mühlegasse (lane 4) together with the left turn from Seilergraben into Mühlegasse (lane 3) and the cars going towards Central (lane 2). The fourth stage is only a variation of the third one. It allows the pedestrians on lane 7 to cross the street and therefore has to stop the cars from going on lane 2; this stage is switched to from stage 1 in case of a traffic jam (Stau).

Usually the stages change from 1 through 4. All stages change back to stage 1 in case of an approaching tram or bus. If already in stage 1, this stage is prolonged to allow the public transport vehicle to still pass through while the signal is in the green phase.

6.3.3 Neumarkt/Seilergraben/Künstlergasse (324)

This junction has two main stages depicted in Figure B-2 in the appendix. Stage 1 allows for cars on Seilergraben together with trams to go (and pedestrians using crossing number 5). Stage 2 allows cars from Künstlergasse to go in all directions (together with all the remaining pedestrian crossings). However since the pedestrian lane number 9 has to be shut off this requires programming this stage as two different stages and therefore this junction has three stages programmed in VAP. The second and the third stage are identical apart from the pedestrian crossing on lane 9. The interstage between them is only 1 second long.

The first stage can be prolonged if there is either a tram coming on lane 11 or a tram waiting on lane 12. The stage is ended if it either reaches its maximum time or when lanes 1 and 2 are free of cars. The third stage is terminated when it reaches its maximum time or when a tram on lane 11 or 12 is detected or when lane 4 is free of cars. All stages have a minimum duration which depends for stages 2 and 3 on whether some pedestrians want to cross Seilergraben; if this is the case, the minimum durations are longer.

6.3.4 Heimstrasse/Hirschengraben (330)

This SCJ consists of four stages shown in Figure B-3 in the appendix. The first stage allows the trams and cars going straight between Heimstrasse and Hirschengraben to go (together with the pedestrians going in the same direction). Stage 2 allows only the left turn from Heimstrasse into Hirschengraben and the pedestrians on lanes 5, 6 and 7. The third stage is a variation of the previous. Additionally to the left turn it also allows the cars going straight on lane 2 and therefore has to turn off the green light for pedestrians on lane 6. The fourth stage is for the traffic going right and left from lane 4 (together with pedestrian crossings – 5 and 8).

All stages switch to stage 1 in case of an approaching public transport vehicle – if stage 1 is already active it gets prolonged by 4 seconds. Apart from that the signal control program switches to the stage that has the longest waiting time (that occurred the longest time ago). These switches are done when the maximum time for each stage is reached or there are no more cars going in the main direction of the current stage. Additionally each stage has a minimum duration, no switch will happen before that time.

6.3.5 Heimplatz/Hottinger-/Rämistrasse/Zeltweg (507/8)

The SCJs 507 and 508 work coordinated, their stages are depicted in the Figures B-4 and B-5 in the appendix. In principal there are two main stages for both crossings, one allowing the traffic to go straight through on Rämistrasse (stage 1 for both crossings) and one allowing the perpendicular directions through Hottingerstrasse and Zeltweg (stage 2 for junction 507 and stage 4 for 508). The coordination is important as only a limited number of cars fit on Rämistrasse between Hottingerstrasse and Zeltweg. In order for these cars not to build up traffic jams and block the crossings behind them, the SCJs have to work together.

Furthermore there are additional stages that can be switched to individually should the need (an approaching public transport vehicle) arise. These are stages 3 and 4 for junction 507 and stage 3 for 508. As a simplification to ease the coordination between the two junctions, junction 507 is strictly bound to junction 508 meaning that when 508 switches to stage 2 and to stage 4 a message is sent to 507 which results in a change of stage there (with a certain time delay).

6.4 Traffic routing

Dynamic routing decisions (for a complete description of the available routing methods in VISSIM see section 4.1.4) could not be used for routing the car traffic for several reasons. First the relatively small model does only allow for alternative routes for a few number of origins and destinations, in all other cases only one route from origin to destination exists. This situation does not permit dynamic routing decisions – finding the best route if only one alternative route is available is not a very reasonable task. Second, the Dynamic Assignment module requires quite some additional effort, especially during the simulation runs, as it would have been necessary for all tested scenarios to find iteratively the best dynamic routing decisions. This requires more runs than with the straight forward normal routing decisions. This additional effort would not pay off as the results of both methods (normal and dynamic routing) are expected to be nearly identical. This is so for the reason of lacking alternative routes and because of the generation procedure of the (normal) static routing decisions described below. Therefore the static traffic routing was chosen.

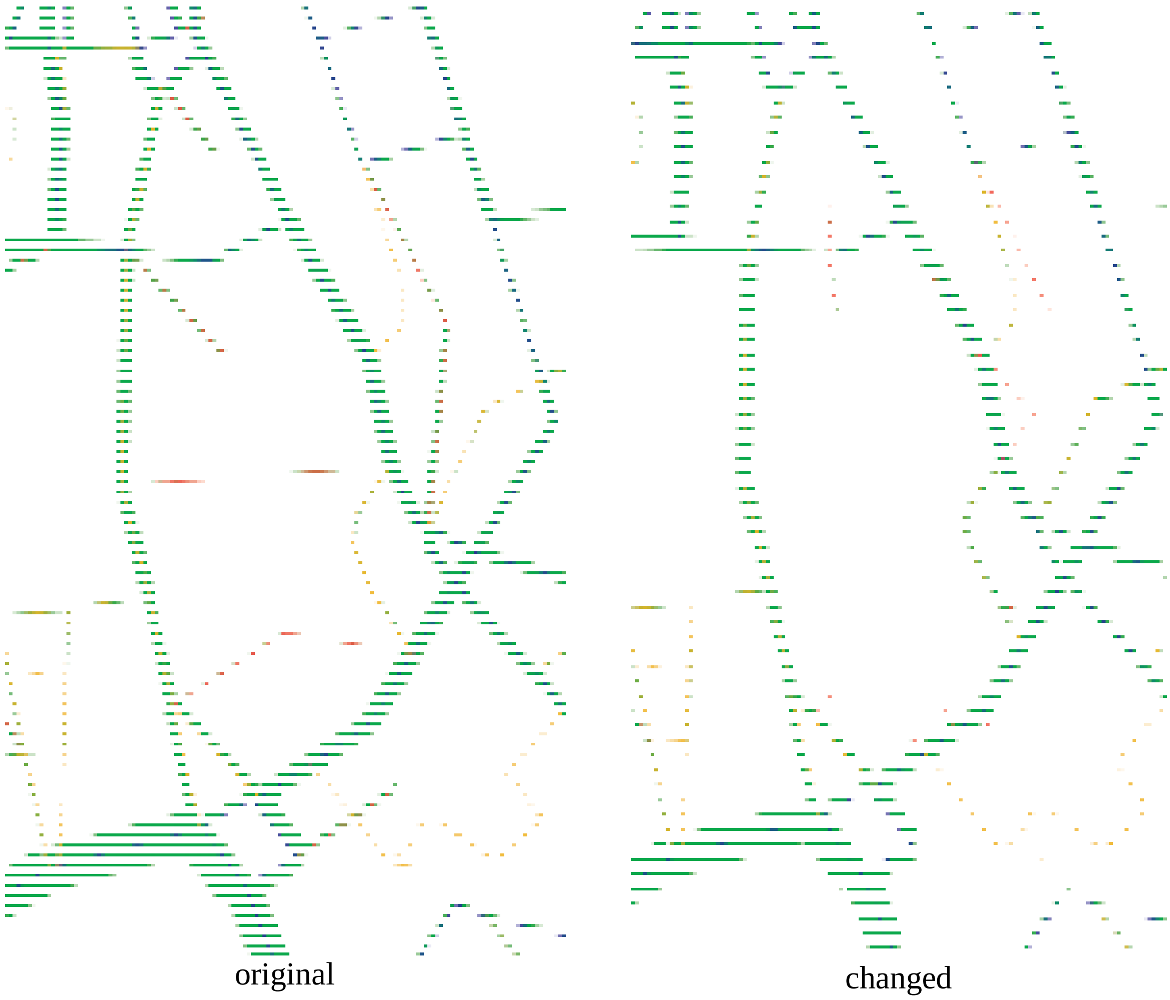
The car routes and the number of cars are based on [Müller, (2002)], in which Müller created an assignment model of the City of Zürich (using the software VISUM). VISUM offers the opportunity to create a VISSIM network from its own network with static routes set according to its current assignment. This network can sadly not be used directly for the simulation, as it lacks all regulatory elements like priority rules and traffic lights as well as all public transport – which was not considered in Müller's work. Therefore the routing decisions in the exported VISSIM network were transferred to the created network and the vehicle inputs were changed accordingly. However, in order to be able to do this, changes had to be done to parts of the VISUM model, due to oversights that were found (Müller's whole model covers a much wider area than was considered in the scope of this work).

There were a few cases where traffic was allowed in directions that are not allowed in reality. Additionally the connections of OD districts to the network had to be changed to reflect the existing streets in and out of the district. This is clearly visible on Figure 6-7, look e.g. at the junction Limmatquai/Mühlegasse or at the lower left corner of Central.

In the original assignment model there are streets, the above mentioned connections of the OD districts, that do not exist in reality. These might be allowable on the abstraction level of an assignment model but they are clearly forbidden in a detailed VISSIM model as was created in this work. A junction cannot have an additional street connected to it that does not exist in reality! Therefore these streets had to be taken out and in their place real streets inserted. Although VISSIM would allow to create (input) cars at the start of any link in the network, realism forbids to let this happen right on a crossing. As a result the small side streets are the sources and destinations of traffic originating or having its destination within the model.

Coming back to Figure 6-7, the thickness of the green lines on the streets represent the amount of traffic on this route, in the respective direction. As can be seen on the figure, these inevitable changes described above lead to a change in the load for some of the streets. Looking e.g. at the upper part of the Limmatquai directly below Central which shows less cars in the changed situation.

Figure 6-7: Comparison of VISUM models (current situation).



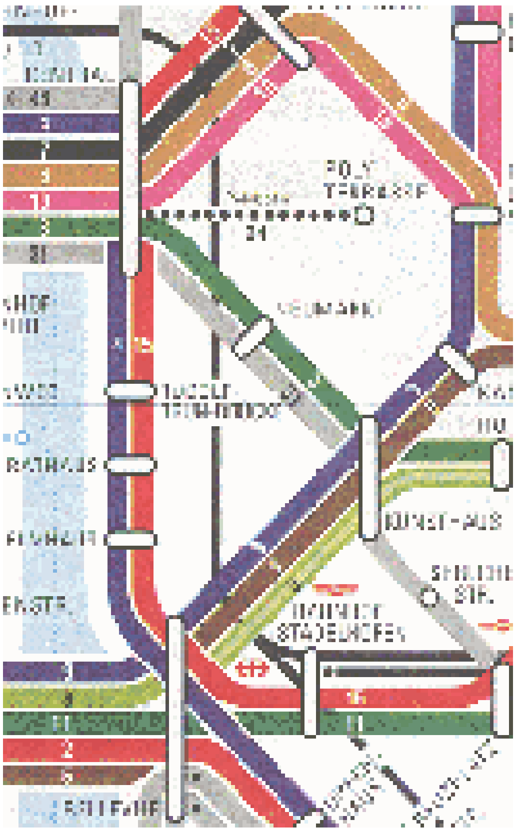
In the future situation the assignment model takes into consideration the closure of the Limmatquai when creating new routes choices and new car volumes. Printouts of those numbers (for both the current situation and that after the closure of the Limmatquai) can be created directly from the VISUM models themselves which are provided on the CD in the folder 'VISUM model'. The numbers are for the year 1999, as this is the date of the most recent study that was done on this topic.

The routes and car volumes used in this thesis were therefore taken from the changed model. The traffic composition used for the inputs consists of 2% trucks with desired linear velocity distribution of 47-53 km/h and the remainder being cars with desired linear velocity distribution of 45-60 km/h.

6.5 Public transport

There is one bus line modelled in the project – line number 31 – and eleven tram lines. Those tram lines are: 2, 3, 4, 5, 6, 7, 8, 9, 10, 11 and 15. Lines 5, 8, 9 are modelled between Bellevueplatz and Kunsthaus. Line 3 is modelled between Kunsthaus and Central. Lines 2 and 11 are modelled at Bellevueplatz and the remaining lines at Central. For an overview of the public transport lines see Figure 6-8.

Figure 6-8: Overview map of public transport lines.



Source: [VBZ, 2001]

In order to define how long a tram spends at a stop a dwell time distribution has to be input. The dwell time calculation was not an option as no numbers were available concerning passenger numbers in the peak hour for all the stops. As VBZ was not able to provide a dwell time distribution measurements had to be performed. The file trams_stopping_time.xls with 80 measurements done in the simulated area during the peak hour and the calculations are provided on the CD in folder 'Evaluation/Various'. The resulting dwell time distribution is supposed to be a normal distribution with a mean of 25 seconds and a standard deviation of 8 seconds.

Within the city different tram lines use different combination of wagons. In order to input the correct tram models (geometries) observations of what tram wagons (serial number) are used for each tram line had to be made. After that the serial numbers were compared with those given in [VBZ, 2002] and on this basis the geometries of the tram models for different lines were implemented. The bus characteristics were based on those provided at the same website for the Trolleybus Mercedes Benz.

The offset for the trams and buses reaching their first stop is not used. This is the time that it takes the tram or bus from being put into the model until they reach the first stop. However, these times are similar for all public transport lines within the area, as the distances between coming into the model and the first stop are approximately the same. Disregarding them makes not much difference as the more important thing, the relative arrival times between the different lines, are kept at their supposed values. It was not investigated, though, if the trams and busses are actually punctual during the peak hour. The model assumes that this is the case for the starting stop in the model area – the rest is a matter of the traffic on the public transport routes.

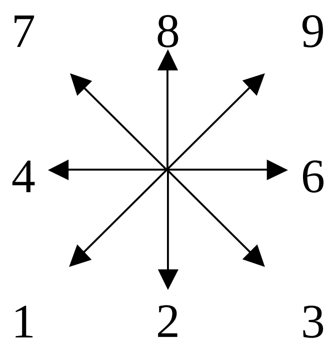
6.6 Numbering schemes

In the simulation a consistent numbering scheme is used for modelling buses, trams and their stops and for signal controlled junctions. Using a consistent numbering scheme helps enormously while developing the model and when doing evaluations as most things can be expressed shortest and most concise by a number. VISSIM consequently uses these numbers for all its outputs.

6.6.1 Public transport

For the public transport lines three digit numbers are used. The first two digits give the real line number of the tram or the bus (however the program does not allow for 0 as a first number, therefore the tram line number 6 has to be given as 6 and not as 06 as was originally intended). The last digit shows the direction in which the line is going. The directions are taken as the numbers on the numeric keyboard with 8 as north, 9 as north-east, 1 as south-west, etc.

Figure 6-9: Coding of directions.



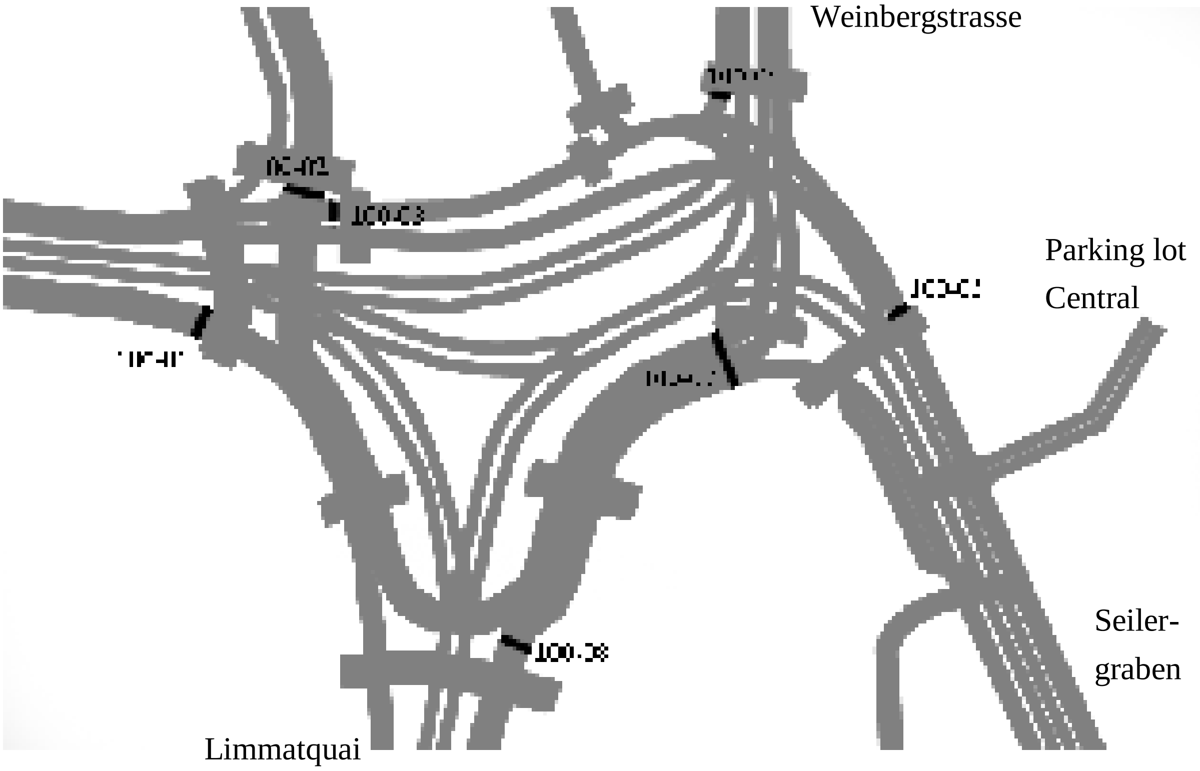
Four digits numbers are used for tram and bus stops. The first digit gives the area in which the stop is situated (1-Central, 2-Limmatquai, 3-Seilergraben, 4-Heimplatz, 5-Bellevueplatz). The two middle digits give consecutive numbers for stops within each area (01, 02, etc.). In order to distinguish bus stops from tram stops, the former starts with 9 (91, 92, etc.) in each area. The last digit gives the direction of the line, as in the case of numbering of the bus and tram lines described above.

6.6.2 Signal controlled junctions

A consistent numbering scheme is also used for signal controlled junctions. In VISSIM each junction gets the official City Police junction number (Knotennummer), e.g. crossing Heimstrasse/Hirschengraben has number 330. These numbers are part of the filename of the junction plans on the CD in folder ‘Source data/Junction plans’, too. The signal groups are numbered as the lanes given on these plans. Input files that had to be created for the external signal state generator VAP (.pua and .vap) have the same consistent numbering (for Heimstrasse/Hirschengraben they are called cross330.pua and cross330.vap).

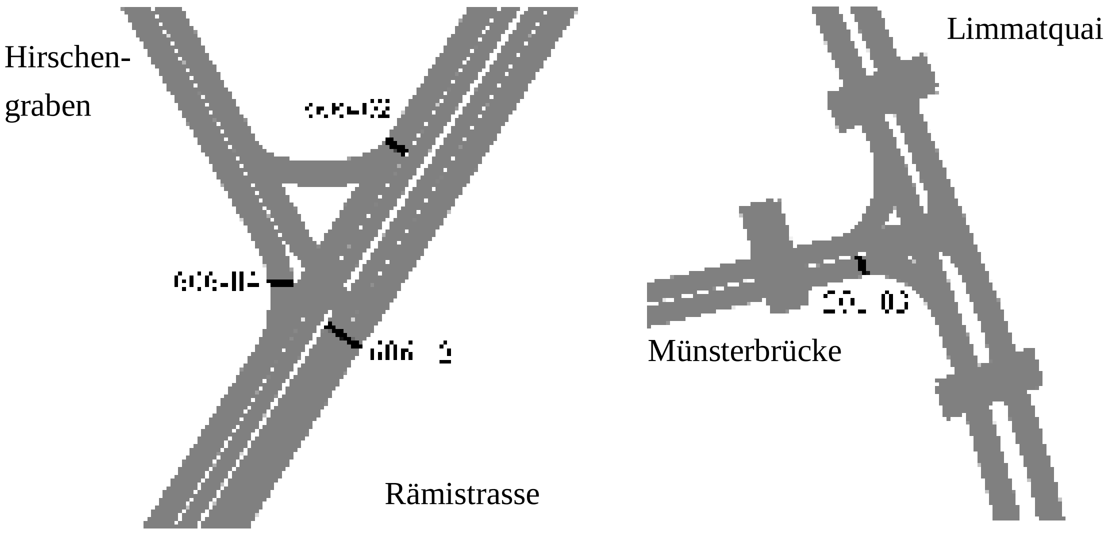
6.6.3 Queue counters

Figure 6-10: Position of queue counters at Central.



All queue counters have a five digit number. The first three digits are the same as the number of the crossing at which they are placed (e.g. 330 for Heimstrasse/Hirschengraben), the last two numbers are the same as the official lane number (see junction plans provided on the CD in folder 'Source data/Junction plans') or a combination of the lane numbers, e.g. a counter set at the end of lines 2 and 3 of crossing 601 gets the number 601-23 (VISSIM allows only integer numbers, so the hyphen is not present leading to 60123), this is unambiguous as there is no lane 23 at that crossing. Lane plans for Central, Rämistrasse/Hirschengraben and Münsterbrücke/Limmatquai were not available, therefore some way of numbering of the queue counters there had to be established. The first three digits for Central are chosen to be 100 and the queue counters are placed as on Figure 6-10. For Rämistrasse/Hirschengraben the number chosen is 606 and for Münsterbrücke/ Limmatquai 201 (see Figure 6-11).

Figure 6-11: Position of queue counters at Rämistrasse/Hirschengraben and Münsterbrücke/Limmatquai.



6.7 Changes for the future situation

For the situation after the closure of the Limmatquai, naturally some changes had to be introduced into the model, like closing the Limmatquai to all traffic. The official planned changes after the closure are described in [Stadt Zürich, 2001b]. This report is used as a basis for the modifications of the current model to create the future model. Apart from the following changes, all the information about the model given in the preceding chapters is still valid.

In the future the Limmatquai is to be closed for all private traffic between Rudolf-Brun-Brücke and Münsterbrücke – except for residents of that area, taxis and deliveries to the businesses which are allowed to use one direction of the Limmatquai from Münsterbrücke in direction of Central. The part of the street to be closed is high lighted on Figure 6-12. The traffic will still be allowed to go over both bridges, however the turns into the closed part of the Limmatquai will be forbidden. The traffic going over the closed part is neglected in the model as deliveries in the evening peak hour are not common. Therefore the part of the Limmatquai, that will be closed was removed from the model and only the tracks used by the trams remain.

Figure 6-12: Map highlighting the closed part of the Limmatquai.

Source of map (without marked area): [Müller, 2002]

Furthermore in the future it will be forbidden to turn right into Zeltweg from Rämistrasse as yielding to pedestrians blocks traffic wanting to go straight up Rämistrasse. Therefore the connector enabling this turn was taken out of the model.

There are plans to introduce a new signal controlled junction at Rämistrasse/ Hirschengraben that is coordinated with the traffic lights at Bellevueplatz so that the tram going up Rämistrasse is not blocked by the cars wanting to turn left into Hirschengraben and thus standing on the tram tracks. However there are no details available as to how these lights are supposed to be implemented exactly. Designing a signal program for this junction that would fulfil this plan is quite difficult and is not implemented in the model.

Very important and major changes between the current and the future situation will be at Central. In order to explain these, take a look at Figure 6-13 showing the current situation of Central together with the proposed changes in red and compare this with Figure 6-14 which shows the situation after the closure.

Figure 6-13: Changes to Central after closure.

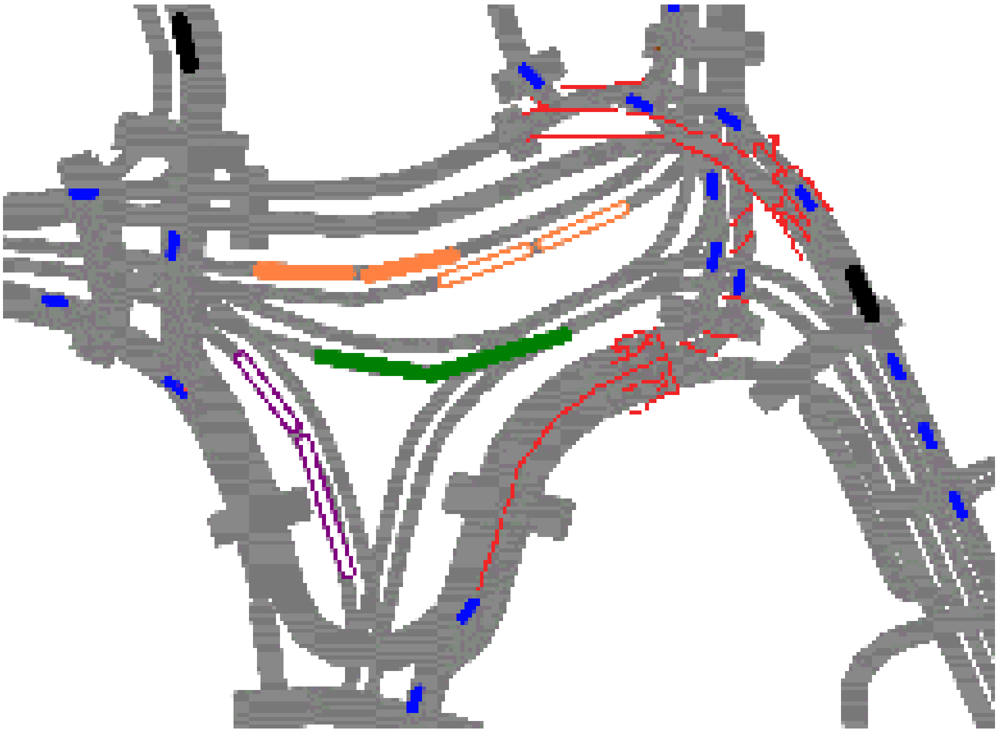


Figure 6-14: Central after closure.

In the current situation the vehicles coming down from Seilergraben in the direction of Central are not allowed to use the left lane which is reserved for the bus. The buses have to leave the part of the street which they share with trams and go onto this left lane in order to get to their stop. There are currently three lanes at the lower right part of Central coming from the Limmatquai – one used for turning right into Seilergraben and two for going either straight into Weinbergstrasse or half left into Stampfenbachstrasse or left towards the main railway station.

In the future situation (Figure 6-14) the vehicles coming down from Seilergraben towards Central will be allowed to use both lanes at the end of the street and mix with the bus line 31. The left lane will be a completely separate lane leading only left in the direction of the main station while the right lane is used for turning right into Weinbergstrasse and going straight into Stampfenbachstrasse. The important new feature is that cars going into Stampfenbachstrasse have now a separate lane and no longer block the cars going in the direction of the main station.

The number of lanes of the lower right part of Central will be changed from three to two, since less traffic is expected to come from the upper Limmatquai. One lane will still be used for turning right into Seilergraben, but instead of two lanes only one will remain for going straight and left at that point. This lane has then some additional security issues as then two lanes coming from Seilergraben have to be crossed in order to go straight or half left into Stampfenbachstrasse but the benefit of having disentangled the current one and a half lane situation before going into Stampfenbachstrasse compensates for this drawback.

In the future situation changes to the settings of traffic lights programs throughout the network will be necessary (especially at Bellevueplatz). Implementing this would require trying out a lot of possibilities, partly redesigning some SCJ programs to arrive at some satisfactory result. This was judged too time consuming to perform and was therefore not done.

There is no information available about what is to happen at the junction Limmatquai/Mühlegasse. Since there will be much less traffic and the junction practically turns from a four way to a three way crossing, it was assumed that it should be possible to handle the traffic without the signals. Therefore these were taken out from the model and additional priority rules were added (pedestrians, cars and trucks yielding to the public transport in order to be consistent with the public transport priority implemented within the whole model). The turning relationships – that are still possible – are left as in the current situation.

New car volumes and routes had to be input by hand into the changed model based on the exported VISSIM network created by VISUM. Those were taken again from the assignment model created by Müller (with the changes made to it described in section 6.4). In the future situation the assignment model takes into consideration the closure of the Limmatquai when creating new routes choices and car volumes. Therefore the traffic that after the closure would detour on a larger scale and therefore not be present any longer in the modelled area is taken into consideration, and is not included in the model run for the future situation.

7. Verification and validation

Before the created model (described in detail in the previous chapter) can be run to obtain results, it has to be verified and validated. This step is necessary to ensure that the results are sensible and useful.

In the verification step the model is checked for any possible errors. This can be done by checking the input data and parameters of the model and by observing the running simulation.

In the validation step data gathered from the model is compared with data from the real system in order to check, if reasonable results are obtained.

7.1 Verification

One of the input data that was checked is the number of cars and the routes they are taking through the model. This data was taken from the assignment model of the City of Zürich in VISUM (see chapter 6.4). The verification and validation of this model must be done using VISUM and was already performed by [Müller, 2002].

However some changes had to be done to Müller's model (see chapter 6.4). The connections of the districts had to be changed in order to reflect the existing streets, the origins of cars within the modelled area. Additionally, in a few cases mistakes in the turning relationships at junctions were corrected. Both changes introduced or removed possibilities to turn at crossings in the model that did not exist in the original assignment model. As the routes had to be input manually into the VISSIM model, these turning relationships could be easily verified and double-checked with the real traffic situation.

A starting point for this reality check is the map of the City of Zürich (also used as the background to model on in VISSIM). Furthermore the junction plans (see folder 'Source data/Junction plans' on the CD) and especially the photos of the streets made both by Müller and myself (CD folder 'Source data/Photos') have been very helpful for solving this problem. As a last resort, personal examination of the streets and locations cleared up any remaining questions.

Driving behaviour of the vehicle drivers, accelerating and decelerating characteristics of all vehicles, and models of cars and trucks were not checked individually but kept at the default values VISSIM provided.

Due to lack of data about the number of pedestrians certain assumptions had to be made (see chapter 5.2). No counts of the number of pedestrians were made due to lack of time – in order to get statistically sound numbers a large number of counts would have been necessary. This however should be done in the future for the relevant pedestrian crossings. Relevant denotes here those crossing that actually have an influence on the car traffic when vehicles have to yield after a turn, thus blocking any traffic behind them. The numbers of pedestrians at each crossing can be changed easily in the model.

During the creation of the network it is often necessary to input streets that are overlapping each other (at junctions). The software does not recognise that automatically and the vehicles at these points are freely driving over each other. Priority rules had to be implemented in order to minimise this ‘unnatural behaviour’ in the model.

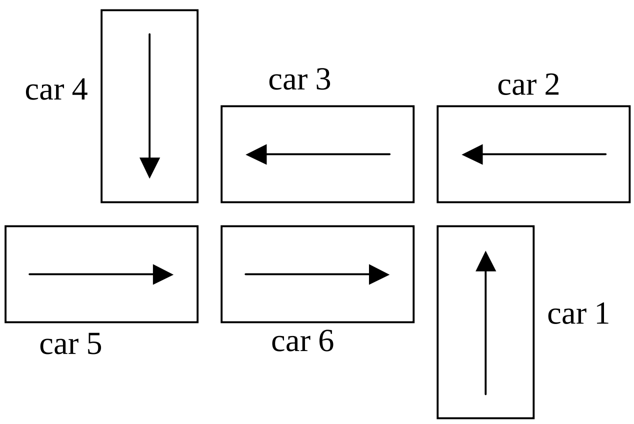
As the second verification step the running simulation was observed systematically. This insures that the priorities are implemented correctly (no cars running over each other) and that the traffic lights are working as intended.

There are several problems that occur due to the limitations of VISSIM, which influence the verification. They are described in more detail in appendix A and in the results, chapter 8. One of them is the lack of a possibility to implement inter-weaving. This leads to occurrences of traffic jams where they normally would not. It can be tried to correct this with the help of priority rules or the absence of them.

Priority rules in themselves are quite difficult and time consuming to implement. In the end it can still happen that in some cases their interrelations lead to deadlocks – vehicles block each other indirectly meaning car 1 is waiting for car 2, car 2 is standing behind car 3 which is waiting for car 4. Car 4 in turn is waiting for car 5 which is standing behind car 6 which is waiting for car 1. The problem is that the rectangle formed by these cars (and the ones waiting behind them, compare Figure 7-1. The figure shows cars with their driving direction yielding to each other and thus creating a deadlock.) is not confined to one single local spot in the network so it is hard to detect this automatically by the software which in fact does not try to do this kind of detection at all. It is very difficult to adjust priority rules in such a way as to prevent this from happening. Therefore in some cases it was necessary to leave out some priorities and allow the vehicles to drive over each other in order to prevent such deadlocks from occurring.

This problem of deadlocks appeared especially when there were most cars in the network, i.e. the scenario of 110% cars in the current situation. Therefore, as not all priority rules could be removed, the compromise was made to discard runs which produced these deadlocks. This is not an ideal solution but otherwise the missing priority rules would lead to many situations where cars are wildly going over each other which is not realistic and is bad for presenting the model.

Figure 7-1: Deadlock situation



The model was checked for consistent implementation of the public transport priority policy (throughout the whole network cars, trucks and pedestrians yield – wherever possible - to public transport).

Signal controlled junctions were checked in several ways. The first check was performed by using the debug mode for each .vap file. This allows to step through the VAP programs using VisVAP, stopping after the execution of each single command. In this way the flow of control can be watched and checked. The second check was executed by using the testing mode. This mode allows to run the program of a signal controlled junction without cars being present. The detectors can be activated by hand and in this way the correct response to different detectors settings can be verified. Furthermore this mode can be combined with the debug mode mentioned above. As a third means of checking the correctness of signal controlled junctions, VISSIM allows to monitor the actual outputs of the traffic signal programs (i.e. which signal groups show which colour) while running the simulation (for more information on how to do that in VISSIM see chapters 8.8 to 8.10 in [PTV, 2000]). This allows checking under 'real' conditions, with all cars being present. All these methods were used in order to verify the signal programs. It was checked that there are no conflicting stages and if there is enough clearing time for the vehicles – time between the stages so that cars can leave the junction before cars out of the next stage reach the conflict point.

Once again appropriate implementation of public transport priority was looked at, this time not just by static examination but by observing the running model.

It has to be stated here that there is a problem in the model at the junction Heimatwerk (number 321) which was programmed by Angst and incorporated into the model without changes (see [Angst, 2002]). In some cases this junction remains in one of its stages and does not change to another stage any longer. As this was discovered only late during the final runs of the model – relying on the verification and validation done by Angst – this could not be fixed any longer. Luckily however this problem does occur only in very specific situations (in some of the runs with 110% cars). The final runs made for obtaining the results were watched and if this junction showed the described problem the run was disregarded and a new one made. This problem seems to appear when there is a traffic jam evolving from Mühlegasse back over Rudolf-Brun-Brücke and into the junction Heimatwerk. The interaction between the signal program and the detectors on Rudolf-Brun-Brücke should be checked in order to locate the source of this error.

7.2 Validation

The problem with the validation in this case is that only little data is available for the real system that corresponds to what was depicted in the model. During the works done on the tram tracks in 1995 and 1998 the Limmatquai was closed creating a similar situation to the one reached after the planned permanent closure. At that time some travel time measurements were done, however only for routes that are longer then those in the model (they included parts of the network on both sides of the Limmat river). Therefore it could not be checked if these results obtained from the simulations correspond to the real system.

A possibility to validate the results would be to perform such measurements alone. That, of course, could be done only for the current situation. However these measurements are complicated to conduct and very time consuming so they were not performed due to the lack of means.

Another way to validate the model would be to extend it in such a way that the measured routes mentioned above are present in it. This would require a few more months of work, possibly a good suggestion for another thesis but clearly too far reaching for the scope of this work.

The validation that was made for the model was of a qualitative and not of a quantitative nature. The running model was watched and the positions of traffic jams were registered and compared to those that occur in the real system.

Furthermore *extreme runs* were made. This means that first only public transport vehicles were simulated in the model, all other traffic – including pedestrians – was removed from the simulation. By doing so, the uncongested delay (due to stops at traffic lights or yielding to each other) of public transport vehicles could be measured. Figure 8-8 on page 85 shows the actual public transport delay for the future situation, meaning the measured delay in the full model with all cars and pedestrians minus the uncongested delay. All the delays depicted are positive, the model behaves as expected, increasing the delay when more possibilities of conflicts (cars and pedestrians) are present.

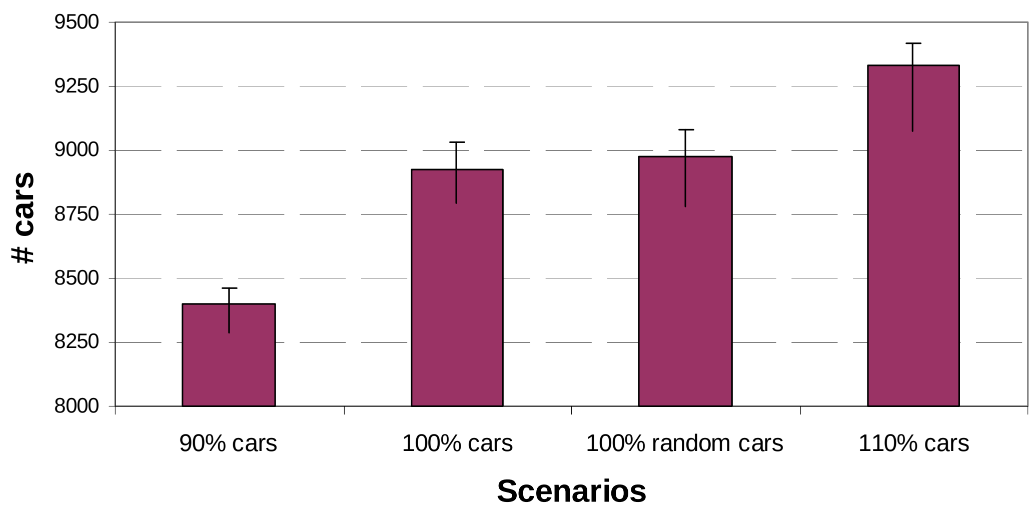
The second extreme situation that was checked was done by removing all public transport vehicles and all pedestrians from the model and running the simulation with only approximately ten cars on each route. It was assumed that these cars do not influence each other, as there are altogether about 100 cars in the model over the course of one hour. These cars were used to measure the uncongested travel time on certain routes through the network used for evaluation. As can be seen on Figure 8-1 on page 79, also these uncongested values (shown as thick grey bars) are smaller than all values measured in the real system with all cars. Both extreme runs are another indication that the built model is valid.

An *expert*, someone knowing the real system very well and thus being able to judge whether the simulation gives a good picture of reality, could be used, too, in order to validate the model. However due to a lack of time no such expert could be found. It is recommended that before extending the model such a screening should be done to verify the validity and maybe even pinpoint some areas where improvements are possible. Nevertheless, the running model was discussed with members of the IVT group at ETH Zürich and judged to behave reasonably.

The *sensitivity analysis* is another means of checking whether the model behaves as it should and as it is expected. For this reason, different scenarios were created with different number of cars input into the model (see also chapter 5.3). When increasing the number of cars in the model, output variables like total time per car should go up as well. The sensitivity can then be expressed as the change in the output variables divided by the change in the input variables. If you change the inputs and a certain output does not change, then this output is considered insensitive to the changed input. However, the opposite extreme, a 10% input change resulting in 100% output change, means that the output is very sensitive to the changed input, in other words, the system is at a critical point.

Up front a remark to the results presented here. For each scenario five replication runs were done. Naturally the values of these five runs differ by a certain amount. Presented in the following are the maximal, the median and the minimal value of these five values in order to give an impression of the average, middle value and of the deviation of the other values from this mean. From a statistical point of view the minimum and maximum values are rather inappropriate to express a deviation, as they are most likely to be extreme cases which happen only with a small probability. However with only five replications – this number was dictated by the available time – it is hard to come up with better means of expressing a deviation. So the right thing to do – and exactly that is suggested for further investigation – would be to conduct more runs to get sound statistical values. For the time being keep this remark in mind when looking at the following results.

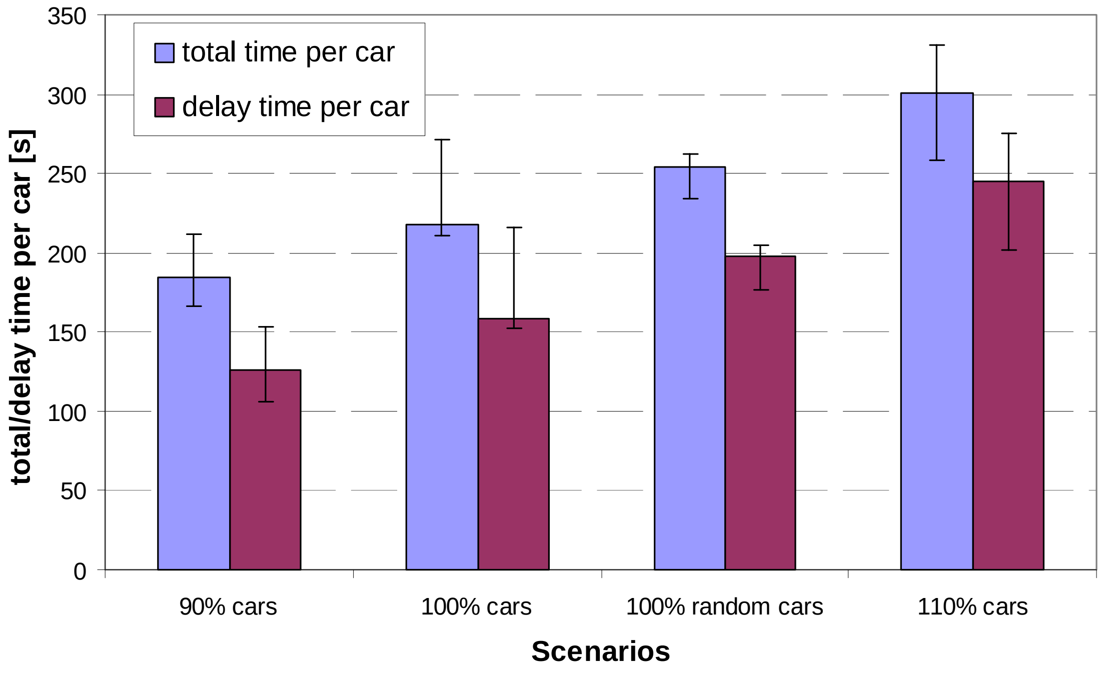
Figure 7-2: Minimum, median and maximum of total number of cars - current.



Considering the total number of cars in the network during the measuring period might sound illogical and trivial at first: changing the input number of cars and then looking at how many cars are in the system. But looking at Figure 7-2 some interesting results can be seen. The bars show the median value of the five replications done for each scenario and the small black lines indicate both maximum and minimum values in these replications. This shows that although the number of cars supposed to be input is the same over all replications of each scenario, the resulting measured number changes considerably. This is a consequence of the way VISSIM creates cars. If an input of 100 cars per hour is set then VISSIM puts *on average* 100 cars distributed over the duration of one hour. As the sequence of random numbers used by VISSIM is changed for each replication, the number of cars input changes as well. Nevertheless the ranges for the different scenarios do not overlap, meaning e.g. that the maximal value for the 90% scenario is lower than the minimal value for 100% cars – except for obvious reasons this is not true for the comparison between 100% and 100% random cars. The change in the (median) number of cars from the 100% scenario to the others is approximately 5%, although the change in the input numbers was both times 10%. This difference is explicable when considering that a certain number of cars are already present in the model (roughly the same number for all scenarios) when the measurements are started after the start-up phase. Consequently the input change by 10% causes a lesser change in the overall number of cars measured.

The situation shown in Figure 7-3 for total and delay time per car is similar to the number of cars described above but there are some important differences. First, the deviations are much larger in percent of the median values suggesting again the need for more runs. Second, the intervals between minimum and maximum values for the scenarios overlap slightly which indicates a stronger influence of the randomness introduced by the different replication runs than the influence of changed input numbers. Furthermore, not at once easily visible in the chart, the sensitivity of the output variables to the changed input number of cars increases significantly. The change of the total time per car from 100% to 90% scenario is around 20% and the change from 100% to 110% is nearly 40%, showing the critical state the model is in.

Figure 7-3: Minimum, median and maximum of total and delay time per car - current.



However, when looking at the maximum, median and minimum values for different scenarios for the output variable additional travel time (meaning the time necessary in excess of the uncongested travel time) on routes, then the picture is much less clear (see Figure 7-4). There the different scenarios show for some routes the same clear and logical behaviour as described above, but on other routes the intervals of different scenarios overlap or even the order of the scenarios is changed. Furthermore the spread of the measured values is much bigger, expressing the need for more runs and making the results harder to interpret as already described in the up front remark. The same values for the future situation (see Figure 7-5) look much better, though there are also still overlapping intervals for most routes.

After verification and validation are finished and the model is judged to be correct, the model can be run, outputs can be produced and the results can be summarised and analysed. This is done in the following chapter.

Figure 7-4: Minimum, median and maximum of additional travel times on routes - current.

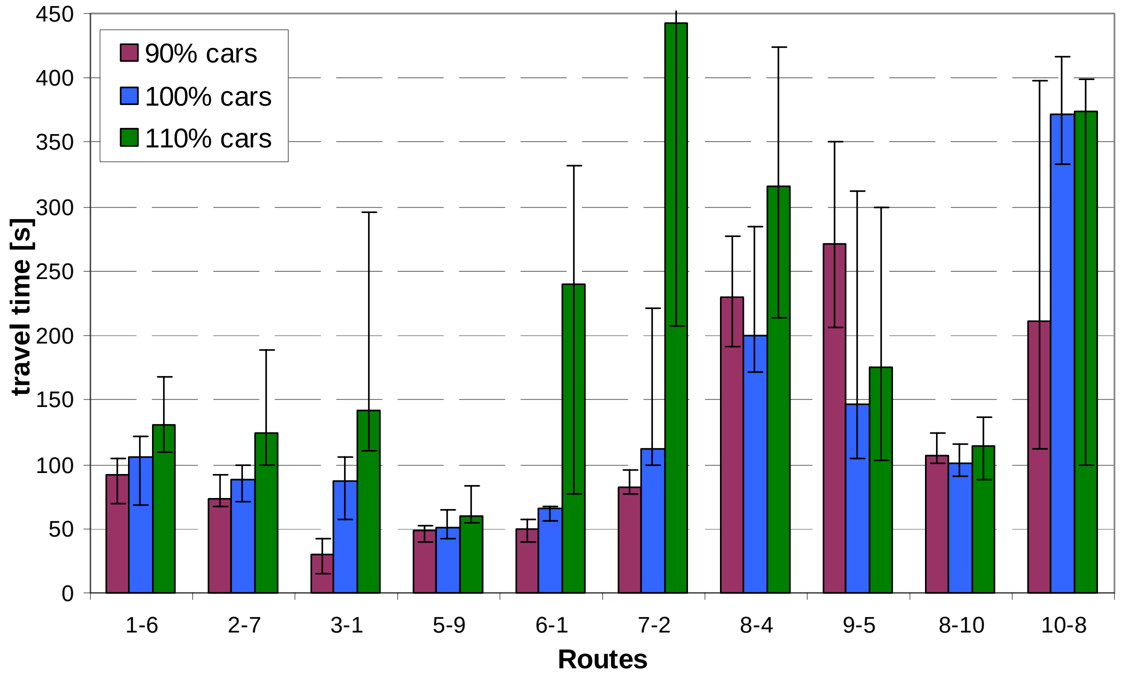
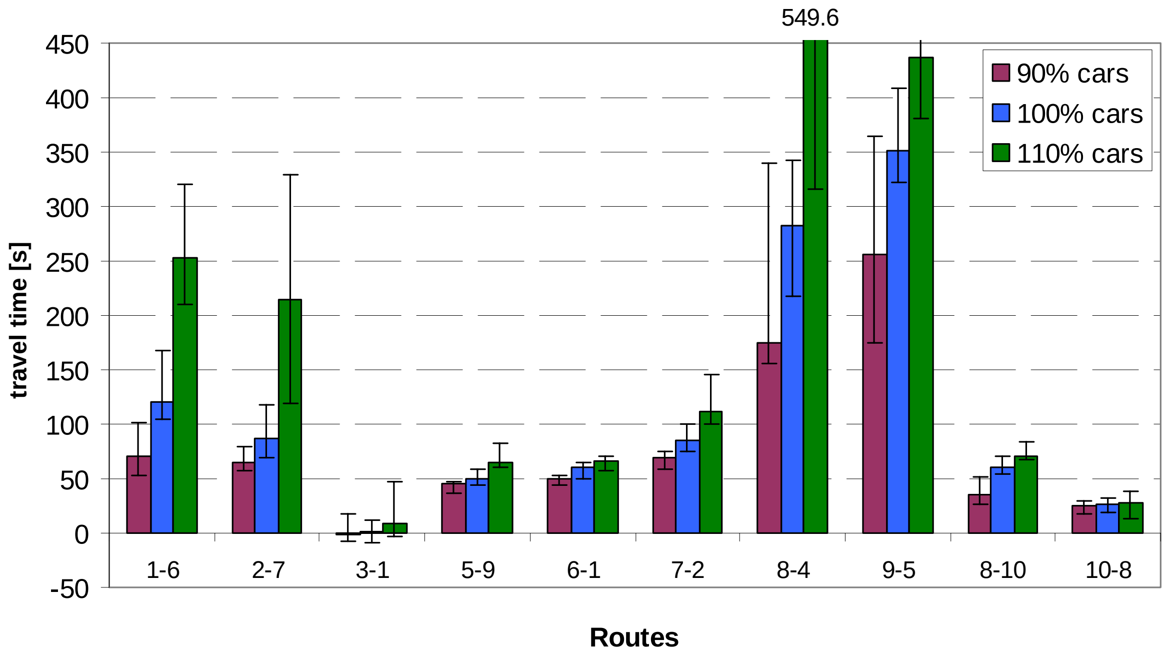


Figure 7-5: Minimum, median and maximum of additional travel times on routes - future.



8. Simulation results

This chapter presents the results of the simulations of the current situation as well as the future situation after the closure of the Limmatquai performed with the VISSIM model of the area Central-Bellevueplatz-Kunsthaus.

The measurements were conducted as described in chapter 5.3 and the results are presented here in the same order as they were discussed. For all results first the current situation is looked at, then the future situation and finally a comparison of the two. Not all charts can be shown here, so the interested reader should consult the CD which holds all the results as well as the data to do further calculations. In the folders 'Evaluation/Detail current' and 'Evaluation/Detail future' Microsoft Excel files (eval.xls) containing the results of each single run are kept while the summaries of the collected data are stored in the folder 'Evaluation/Summary'.

8.1 Travel and delay times

The travel and delay times are measured for certain routes through the network, see section 5.3 for a detailed description whereas Figure 5-1 on page 45 shows the start and endpoints of all routes considered.

The travel times for the *current situation* are shown in Figure 8-1. The values are always averages over five replications conducted for each of the different scenarios with 90%, 100%, 100% randomised and 110% cars. The uncongested values are the measured travel times for the case of the empty model, also averaged over all replications. Naturally all scenarios show for all routes longer travelling times than the measured uncongested values. What is left above these thick grey bars can be considered as the additional travel time due to other cars travelling in the network. In general it can be said that with a rising number of cars in the model the travel times rise as well, see e.g. route 7-2. When comparing these values with the delay times depicted in Figure 8-2 their resemblance is apparent. Both series show exactly the same behaviour, the only difference lies in the fact that the travel times have slightly bigger values, as the delay times only measure the extra time needed on a route – although they do not take delay caused by e.g. traffic lights into account. Therefore the delay times are not considered any further in this analysis.

Figure 8-1: Travel times on routes – current.

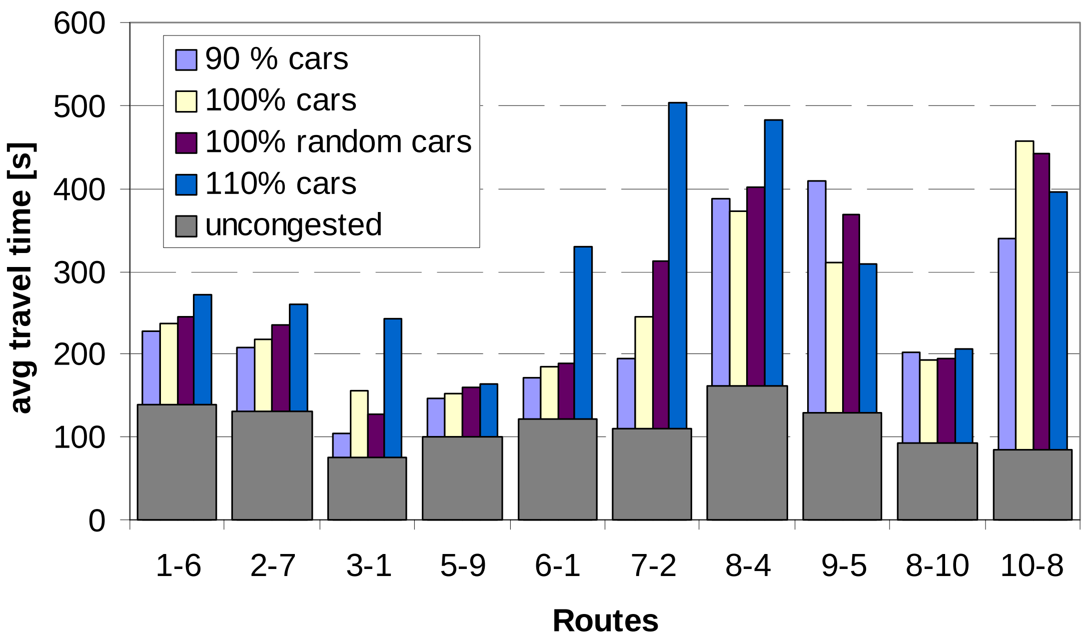
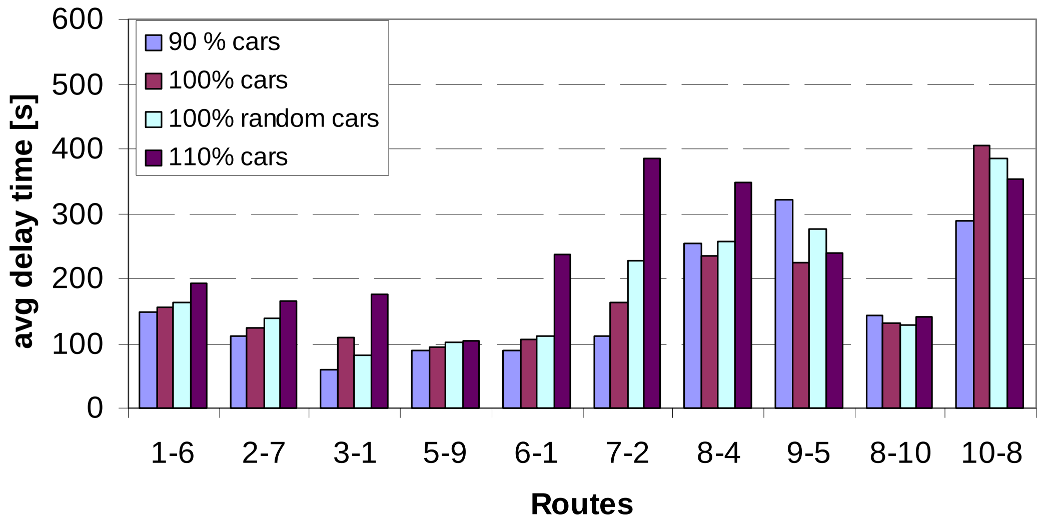
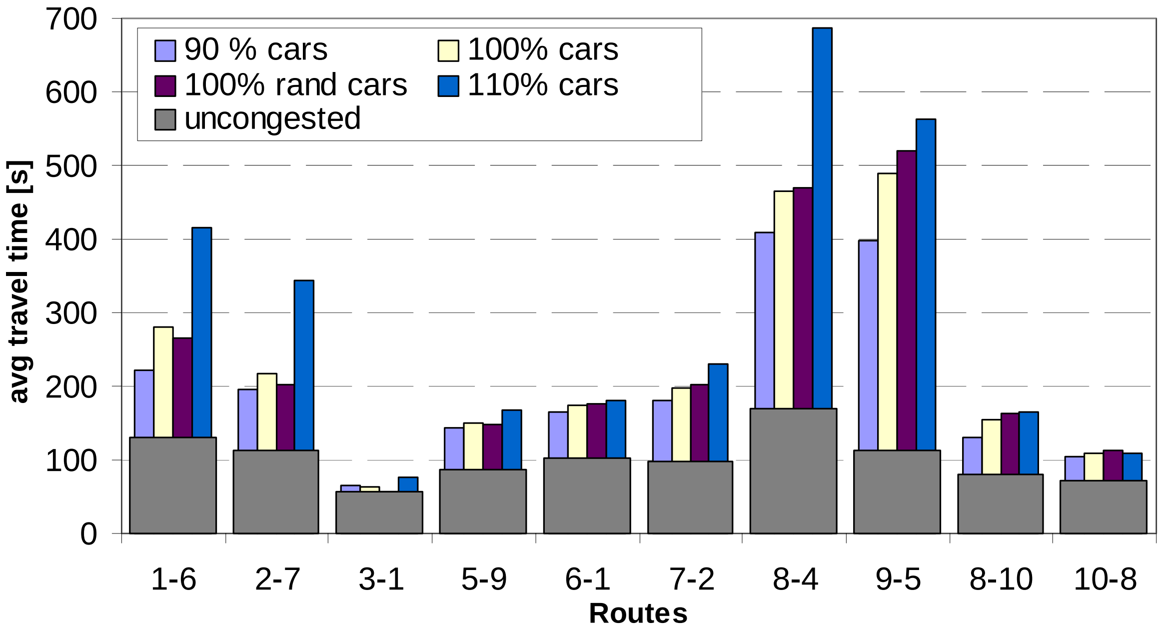


Figure 8-2: Delay times on routes – current.



The *future situation* depicted in Figure 8-3 shows the same output variables as the current situation. Apart from route 8-4 all routes have the same (but among each other different) length in the current and future situation.

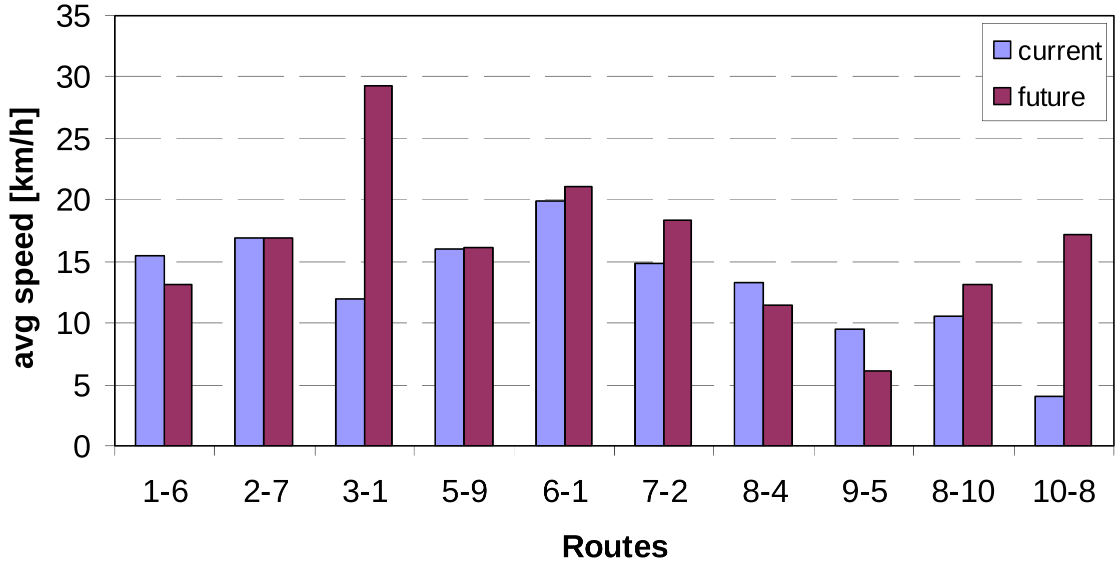
Figure 8-3: Travel times on routes – future.



Due to that if comparing the current and future situation it is best not to look at travel times but at the average travel speed which can be easily calculated with the travel time and the length of the route. Note that now higher values represent a better result, meaning a quicker journey on these routes. Figure 8-4 shows this *comparison* for the scenario of 100% cars. The first thing to notice is clearly the more than quadrupling of the speed for route 10–8 in the future, although that is not surprising as traffic is no longer present on the Limmatquai allowing the cars to go easily from Münsterbrücke south over Utoquai.

For the majority of routes the average speed grows in the future situation, although the speed for routes 8–4 and 9–5 decreases. The reason for this can be seen at once when observing the running future model at Bellevueplatz. As a consequence of the closed Limmatquai, hardly any cars are going straight at Bellevueplatz, Odeon (junction 604). Instead all cars try to turn right into Rämistrasse. The problem is that only one lane is going in this direction and four lanes are feeding cars into it (see Figure 6-2 on page 16). Additionally the traffic lights at this junction have not been adjusted, so the right turn does not get enough time over the 90 second cycle. Consequently the travel times on routes using this piece of street go up and so the average speeds go down. Route 7–2 is able to increase its average speed although it is sharing a long piece of way with route 8–4. This together with the fact that route 9–5 is also decreasing its speed localises this problem definitely at the right turn at Bellevueplatz into Rämistrasse.

Figure 8-4: Average speed on routes – comparison current and future, 100% cars.



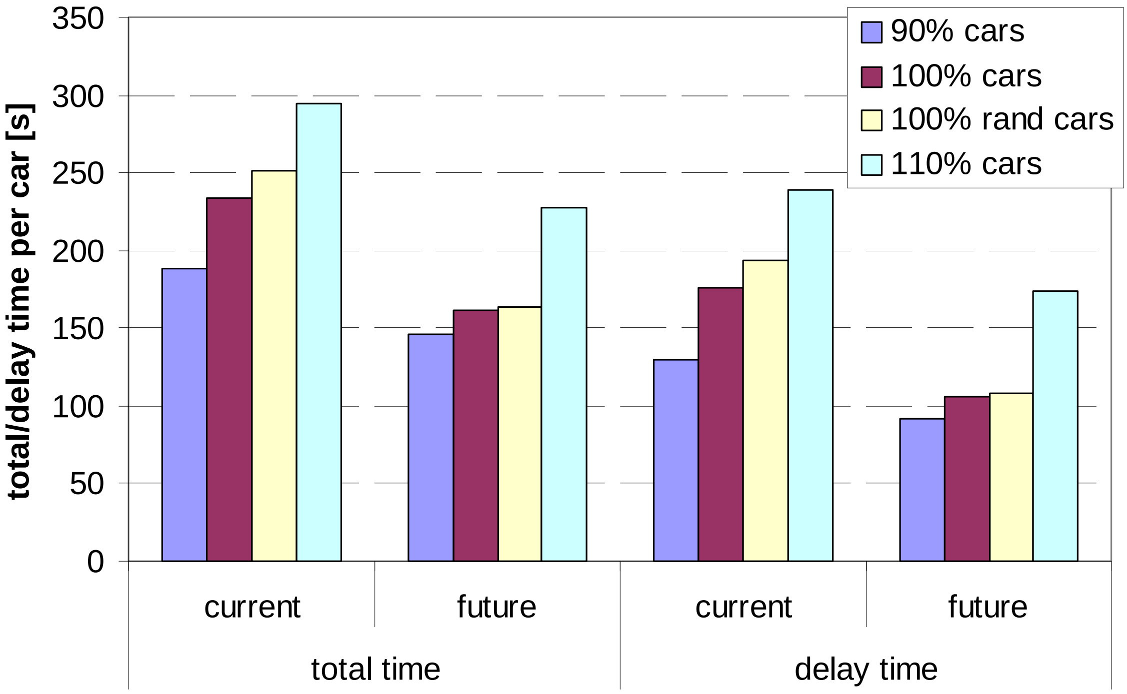
8.2 Overall delay and total travel time in the network

The total travel time of all cars together with the number of cars in the model allows to calculate the total time each car spends on average in the modelled area, the same can be said about the overall delay time (per car). Figure 8-5 shows these values (averaged over all replications) for the different scenarios both for the current and the future situation. The total number of cars in the models is not shown, it varies between approximately 8’400 and 9’300 for the current situation and 7’800 and 9’100 for the future situation. It has to be noted that these numbers vary but not in the same way as the change in the input numbers (90% and 110% cars) might suggest as there are always a number of cars present in the model when the measuring starts. This is the case because of the start-up phase after which these measurements start. The figure shows that both values increase with the scenarios – when the amount of cars increases, as it is expected. For the future situation the increase of the total and delay time from 100% cars to 110% cars is significantly higher than the one for the current situation.

Comparing the current and the future values with each other, it can be seen that for all scenarios the future values are below the current values meaning that each car in the future situation spends less time in the modelled area and is delayed by a smaller amount of time. This can be partly explained by a changed distribution of the cars onto the routes. When more cars take shorter routes through the modelled area, the total and delay time decrease. So it is not easily possible to conclude an improved traffic flow in the future situation only based on this number.

Also noteworthy is the fact that the difference between total and delay time for the current situation is nearly the same as this difference in the future situation. This is basically the same observation as it was already made for the travel and delay times in chapter 8.1.

Figure 8-5: Total and delay time per car – comparison current and future.

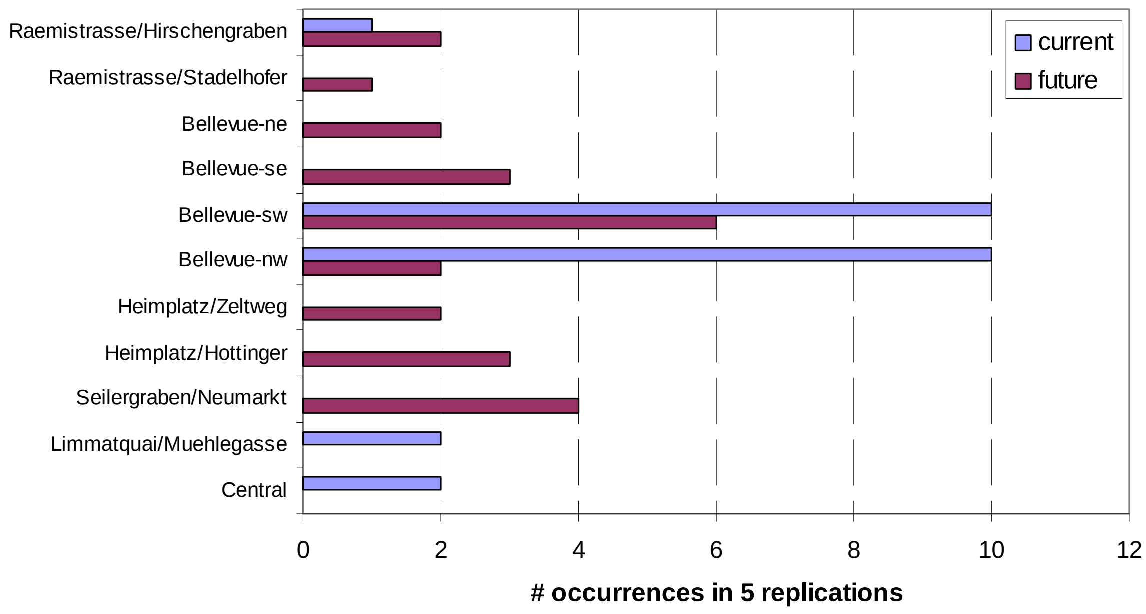


8.3 Queue length

The evaluation of queues delivers a wealth of information that is not easily depicted; besides the average and maximum length of a queue, the number of stops within the queue are given. Together with the fact that spread over the whole network there are approximately 55 queue counters it is impossible to display information about all of them. To connect the numbers of the queue counters with their geographical position provides additional problems in that respect. Therefore no results are shown for the current and future situation, instead two comparison charts are presented for the 100% cars scenario, one providing information about the length of the queues, the other providing information about the locations (though it is not possible to resolve this here up to the level of single lanes).

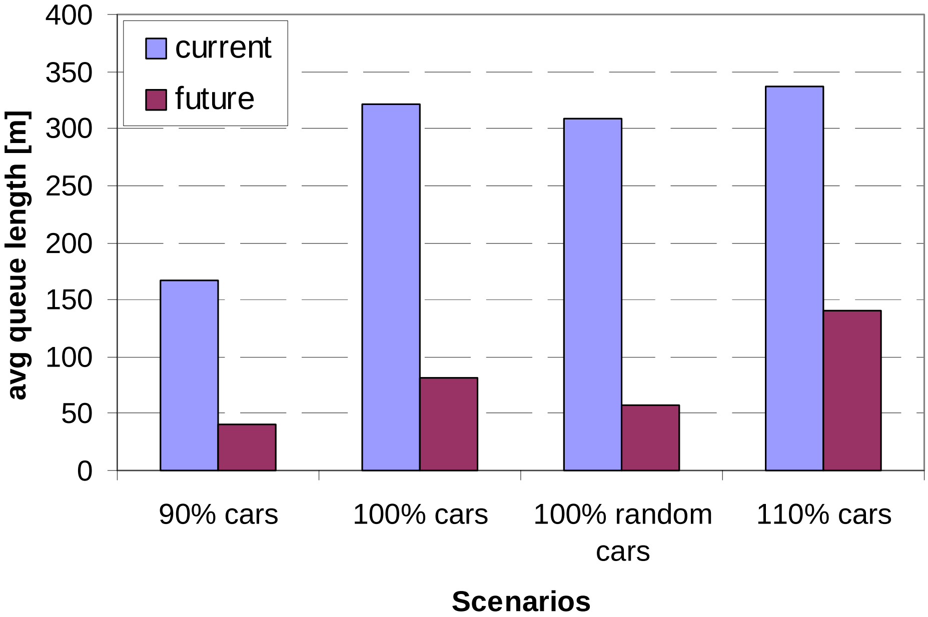
Figure 8-6 shows the location of the five longest queues for the 100% cars scenario. As always, five replications were done for the current as well as the future situation which leads to a total number of 25 'longest queues' each that are spread over the available junctions. For lack of space only those junctions that actually had at least one of the longest queues are listed in the figure. While in the current situation the long queues are focussed at Bellevueplatz (and there in the north-west and south-west corner, the junctions 601 and 602), the future situation shows a much wider spread of the longest queues but experiences no problems at Central. However the question remains how severe, i.e. long, these queues are.

Figure 8-6: Location of five longest queues – comparison current and future, 100% cars.



This can be answered with the chart depicted in Figure 8-7. It also takes into account only the five longest queues in each run of the model but this time the average length of these queues is depicted. These five queue length values are averaged to give one calculated queue length. Depicted is the average of this calculated queue length over the five replications of each scenario. Looking at the same scenario that was just analysed, it can be seen that the queue length in the future situation is only about a quarter of the queue length in the current situation. The same goes for the other scenarios.

Figure 8-7: Average queue length of five longest queues – comparison current and future.

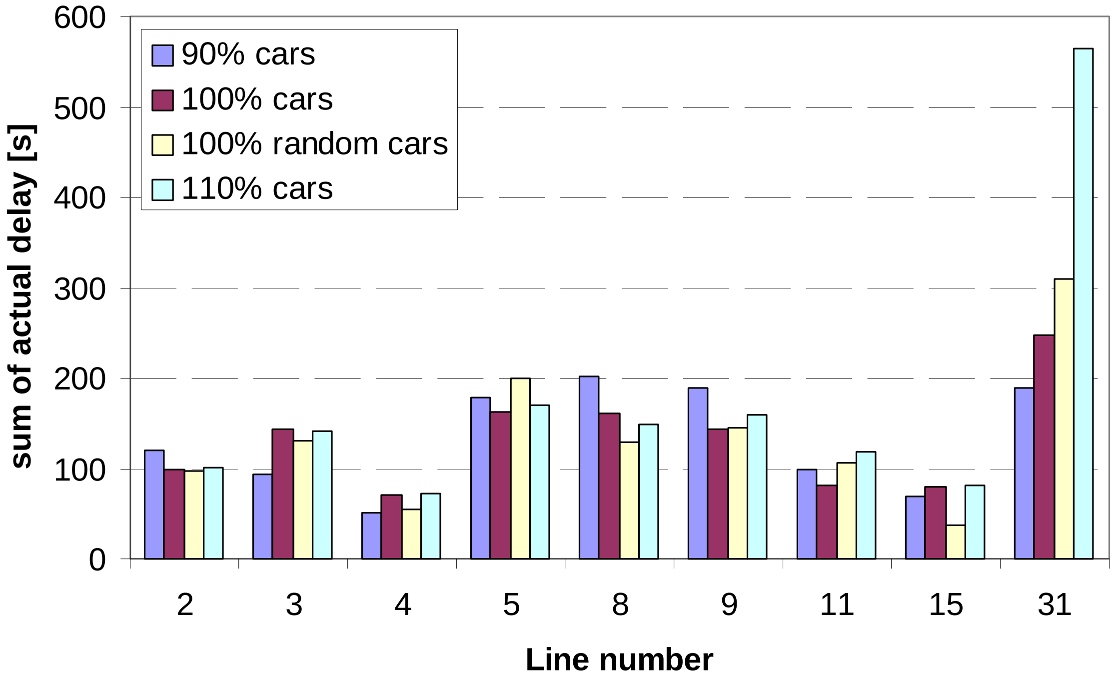


8.4 Public transport stops

The public transport has in the modelled network a substantial share of exclusive right-of-ways and can thus go unhindered by the other traffic. Nevertheless, some conflict points are unavoidable as well as some waiting time at traffic lights, though this time is minimised by the control logic of the signals. An exception to this is the bus line 31 which has to go on ordinary streets for a significant part of its way.

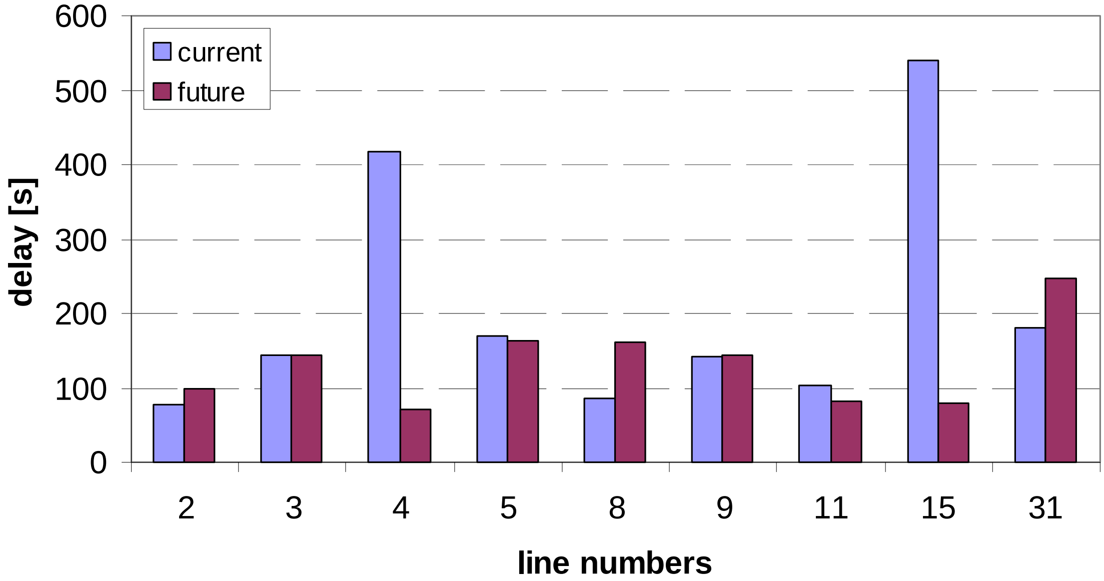
Figure 8-8 shows the actual delay times of the public transport lines, meaning the sum of all forced stops (averaged over both directions of the line) minus the uncongested delay measured in a network without any non public transport vehicles. The values are averaged over all five replications for each of the different scenarios and only the lines with significant stop times (delays) are shown, e.g. line 6 just enters and leaves the network at Central, so has only one stop in the modelled area and there is not much possibility where it could be forced to stop on its way. The figure depicts the future situation (the chart for the current situation looks similar) and it is easily visible that for all scenarios and each line the delay times are approximately constant, meaning that the public transport can go freely, no matter how many other vehicles are in the area. However, the one exception to this is the bus line 31 that has to share its way with the private vehicle traffic at the beginning of its routes in both directions, once at Central and once coming from Zeltweg and going through Heimplatz. These parts of the route have a significant impact on its delay time and consequently it increases with the increasing number of cars. As a remark, it is not allowed to compare the values of different lines against each other, as the depicted values are sums over all vehicles going on that line. This number of vehicles is different, though, for separate lines due to slightly different intervals of these lines.

Figure 8-8: Actual public transport delay – future.



Comparing the delay times for the current and future situation (100% cars scenario), as shown in Figure 8-9, clear improvements are obvious for line 4 and 15. This is not surprising as they are using the Limmatquai between Central and Bellevueplatz which is freed of car traffic due to the closure, where the tram had to share the road with the private vehicle traffic. The delay time for the bus number 31 increases but it is not clear if this is because of the new sharing of a few meters of its lane with the individual traffic turning left at Central. The rest of the lines show both small increases and small decreases, approximately balancing each other.

Figure 8-9: Actual public transport delay – comparison current and future, 100% cars.



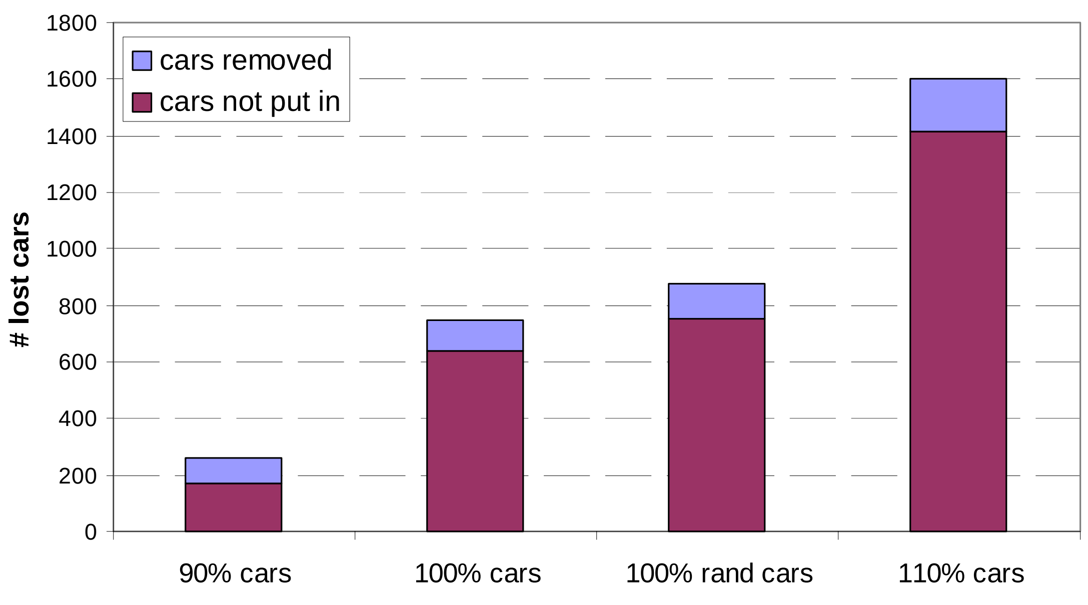
8.5 Car losses

During a simulation, in theory cars should not be lost. However in practice this cannot be completely avoided. Some streets where cars are input are not able to take all the cars that should be put in, resulting in 'lost' cars, meaning cars that should have been in the model but were not. On the other hand cars behaving not realistically have to be removed from the model in order not to disturb the rest of the simulation too much. Both these categories are counted as car losses and are described in more detail in chapter 5.3.

When looking at the current situation depicted in Figure 8-10, it is visible that the number of cars removed from the model during a simulation is much smaller than the number of cars that could not be entered. In general there is an increase in the car losses when the number of cars in the model increases. For the future situation (not shown) the overall lost number of cars is comparable to the one shown for the current situation. This is a bit surprising as the number of removed cars goes down in the future situation (see description below). This means that more cars could not be put into the model after the closure. The explanation for this could be that the input streets could no longer cope with the changed car volumes as a result of the changed traffic flow in the future situation. As different numbers of cars go on different routes the green phases at signal controlled junctions are no longer optimised to this traffic flow leading to less capacity on the necessary lanes. Therefore the number of cars not put in increases. From this, the need to adapt these green times to the new number of cars going through each lane can be derived.

However, when comparing the number of removed cars between current and future situation (see Figure 8-11), a heavy decrease in the number of removed cars is visible. As cars are removed when they are waiting too long for a lane change, these numbers point to an apparent problem with that in the current situation. When taking a closer look at this, a main problem area is located at Bellevueplatz, junction 602. From the south four lanes of cars are approaching the crossing of which two go straight on and two go to the right. The arriving cars however are not able to pick there correct lane early enough so that no lane changes are necessary just before the crossing. These lane changes decrease the number of cars that can get through a green phase of the traffic lights. Furthermore, if e.g. the two lanes going to the right are full with vehicles and a car wants to squeeze in from lane number three, it might not be able to accomplish that quickly enough – blocking in that way all the traffic behind it and being finally removed (see Figure 8-12 for a picture of a bad situation taken during a running simulation).

Figure 8-10: Car losses – current.



VISSIM allows to influence this lane changing behaviour with two parameters that each connector has, an emergency stop distance (default: 5m) and the normal lane change distance (default: 200m). A car approaching the connector (and having its route going over it) tries to change lane in order to be able to use the connector starting from the normal lane change distance away from the connector. If it is not able to get onto the desired lane, then it stops at the emergency distance away from the lane, waiting to be let onto the desired lane. However experimenting with these parameters did not improve the situation, so it was decided to accept this problem and leave these values at their default. Nevertheless it is proposed to do further analysis on the setting of these parameters to be able to avoid this capacity-decreasing problem.

Finally, after presenting the results of the different measurements it is possible to make conclusions and further recommendations together with giving an outlook on further research possibilities based on this work. This is done in the next and last chapter.

Figure 8-11: Removed cars from model – comparison current and future.

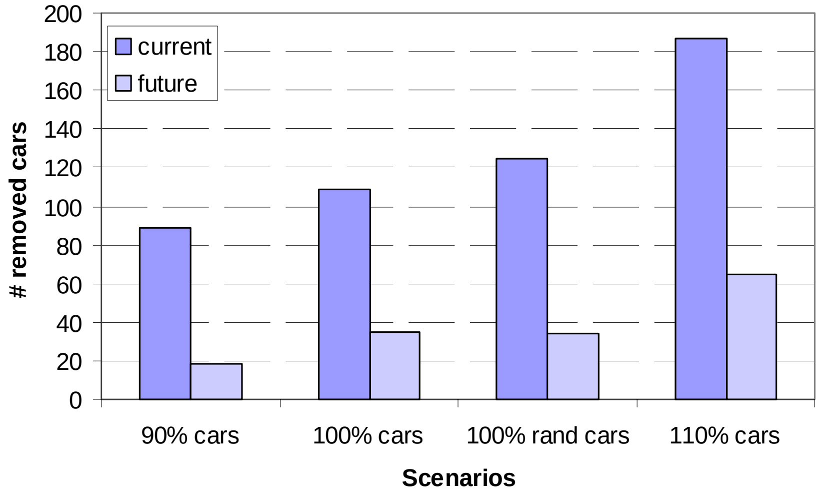


Figure 8-12: Lane change problem at Bellevueplatz.

9. Conclusions and recommendations

This chapter sums up the results presented in chapter 8 and draws from them advises where special attention has to be paid when implementing changes to the alternative routes as a result of the closure of the Limmatquai. Additionally, the future users and uses of the created VISSIM model are given in the context of suggestions for further research.

9.1 Conclusions

The main output variables looked at and compared for the current and future situation with the help of different scenarios were: travel and delay times on routes, total and delay time per car in the network, queue length, public transport delay and car losses.

To sum up, the travel and delay times on the measured routes are overall stable, some routes take longer, some routes take shorter time in the situation after the closure but only the directly effected routes have a considerable gain in the traffic time.

Overall delay and total time in the network decreases for all scenarios significantly in the future situation though part of that is caused by a different distribution of the cars on the routes going through the network and not based on an improved traffic situation.

The queues in the future situation are distinctively different in two aspects from the ones in the current situation. They are significantly shorter but also spread over more junctions.

The situation for the public transport after the closure naturally improves drastically for line 4 and 15 which are no longer slowed down by individual traffic on the closed part of the Limmatquai. For the other lines the differences are small and go in both directions, some have less forced stops and some have more.

The measured car losses allow some indirect conclusions about problems in the model. As the number of removed cars goes down significantly in the future situation it can be concluded that the traffic situation is less critical. Furthermore, as altogether approximately the same number of cars are lost in the current and the future situation, problems with the sub-optimal length of green phases at certain input streets are an explanation for this behaviour.

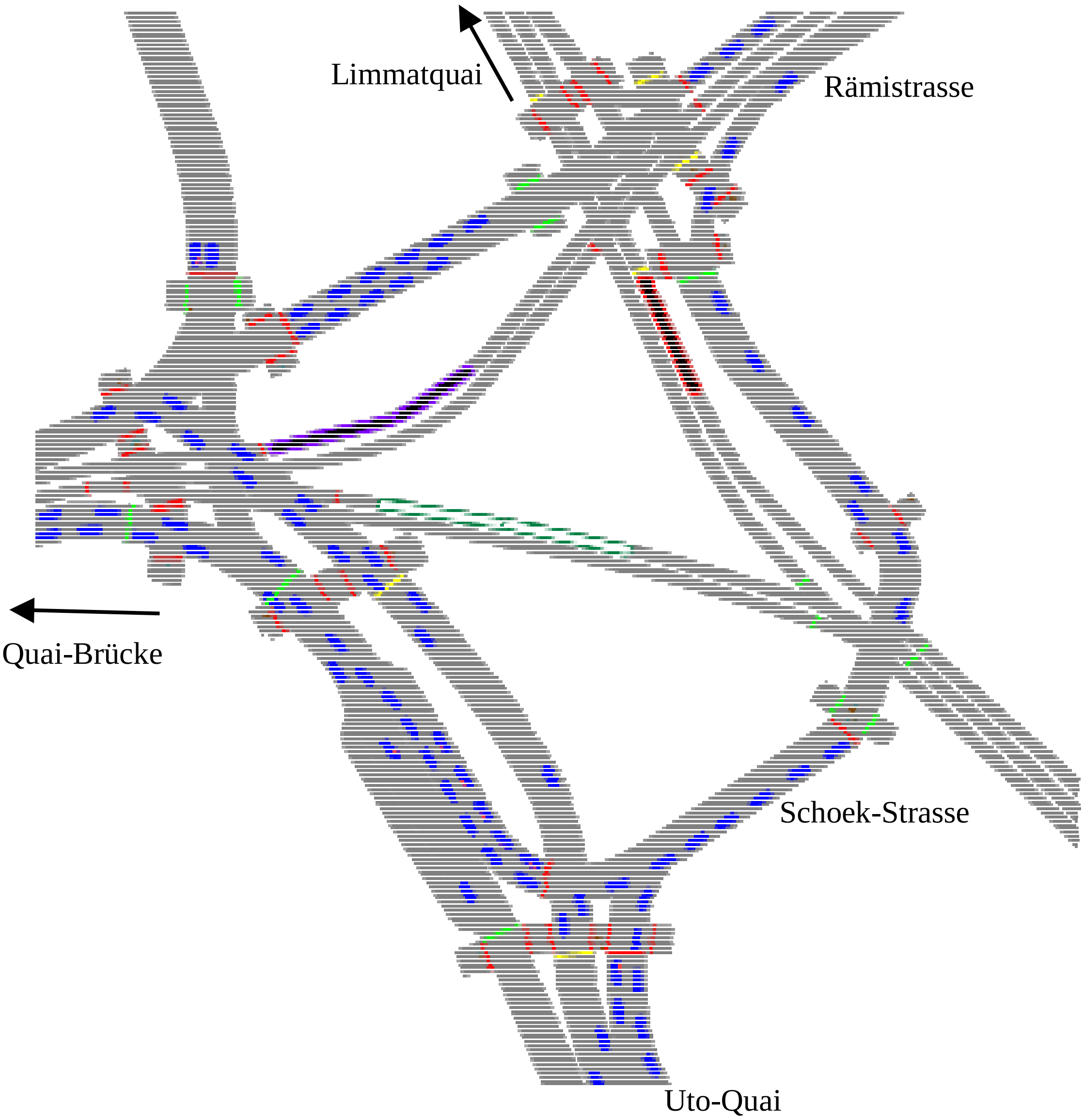
In a nutshell, no strong indications were found why the closure of a part of the Limmatquai should not be possible. From a viewpoint of the traffic situation of the modelled area, the alternative routes are able to handle the detoured traffic of the Limmatquai. For pedestrians the situation will improve as the closed part of the Limmatquai will be used as an additional pedestrian zone. This nice boulevard alongside the river Limmat will be a valuable addition to the living quality in Zürich and increase the attractiveness of the area for shop and restaurant owners as well as tourists. From the perspectives of the cantonal and city transport policies, the closure is a valuable addition and in good conformance with the set aims and goals.

However, it must be said that there are still some remaining problems with the model itself, problems which lead to a not optimal depiction of reality. The lane changing algorithm in VISSIM could be better, too many cars still have to be removed from the model which leads to a unnecessary blocking of a lane and in that way decreasing the capacity of the network. Another problem originates from the implementation of priority rules which are needed to avoid 'collisions' of cars which are not realistic and not good for the purpose of visualisation. On the other hand, having many priority rules leads to hard to predict (and to correct) situations of complete deadlock, where some queues of cars block each other and finally block the whole network. This behaviour is very unrealistic because intelligent human drivers are easily able to resolve situations like that or even prevent their creation as a result of which the traffic keeps flowing, even if that is very slow.

9.2 Recommendations

It was already mentioned beforehand that in general it is advisable to adjust and optimise the traffic light programs of the signal controlled junctions in the simulated area. This is especially important at Bellevueplatz where the right turn into Rämistrasse creates problems not occurring in the current situation. Due to the closure of the Limmatquai hardly any cars go straight into the Limmatquai at that junction, but instead go right which leads to the situation that nearly only the right lane is used in Othmar-Schoeck-Strasse by the cars coming on two lanes from Quai-Brücke as well as going right on two lanes from Uto-Quai (see Figure 9-1).

Figure 9-1: Bellevueplatz future situation, right turn into Rämistrasse.



The junction Limmatquai/Mühlegasse changes its character drastically after the closure. Due to the fact that the Limmatquai is closed, the traffic can no longer go in that direction. This leaves plenty of room for redesigning this crossing completely. It might e.g. be possible to add certain turning relations that were not allowed before. To check the effects of this on the traffic flow in the area would be an interesting future project. It might also be possible to remove the traffic lights altogether which was done in the model and did not cause additional problems. The possibility of turning the crossing into a roundabout could also be investigated, though the first thing to check there is if the available space is sufficient at all for such a change.

Not implementing the planned traffic light at Rämistrasse/Hirschengraben as it was done in the model did not cause additional delays for the public transport lines going up from Bellevueplatz to Heimplatz. In the light of that it might be interesting to do further research in this direction, especially as it is not yet know if putting the traffic lights improves the situation.

The number of pedestrians taken into account when modelling was chosen without actual counts performed as these are very time consuming (several pedestrian lanes for each junction would have to be counted). The duration of this project was too short to do exhaustive testing of the influence of different pedestrian volumes on the output parameters of the model. However it was argued that these volumes should not have too big an influence. Nevertheless it is recommended to do these experiments – or even better, perform the counts and use the correct number for each crossing.

9.3 Future users and uses

The City Police as well as the traffic planning section of the Department for City Engineering are possible future users of this model. It should be possible to test e.g. traffic light settings and coordination issues quickly in the created model so it might be a tool to implement the necessary adaptations to the signal controlled junctions. Furthermore, as the running simulation is a very good visual tool to give an impression of the traffic situation after the closure – also to a non-technical, broad audience – this work could be used for public relations as well.

Anybody wanting to use the VISSIM simulation software can benefit in two ways from this work. First, it offers an extended example with complex priority rules as well as signal controlled junctions and public transport lines to experiment, together with a description of the main features in chapter 4.1. Second, the gained experience during the work with the program put down in appendix A might help future users to assess and decide whether VISSIM is a good choice for their project at hand.

Other important points are the opportunities and possibilities this work together with the created model offers for future users, it is a good basis for further analysis as was already mentioned and suggested at various other points in this report.

This further analysis can use the data gathered during the executed simulations (available on the CD in folders ‘Evaluation/Detail …’) and extract different aspects and results not yet presented – with the sheer amount of data it was not possible to analyse everything in the scope of this work. After that additional runs with the existing model could be done in order to get better statistics for the output variables and in that way get smaller deviations on them. Then different alternatives, e.g. additional turning relationships or changed traffic light programs, could be implemented and tested for their effect and value by adapting the model. These are all relatively small projects that can be done within the time frame of a few weeks, once the user is confident with the used software and the model. This allows for further student projects in the form of semester or diploma works at IVT.

Very interesting possibilities are opened up if the model is extended to cover a larger area. At the moment the right hand side of the Limmat is covered but from calculations with the assignment model of Zürich and from the planning of the alternative routes it is known that the traffic will detour on both sides of the Limmat, the northbound traffic using mainly the right hand side while the southbound traffic will go on the streets left of the Limmat. Modelling these alternative routes west of the now modelled area would allow to better judge the traffic impacts of the closure of the Limmatquai. Furthermore, the extended area would provide for true alternative routes for the traffic wanting to go through this area from north to south and vice versa. This would allow to use the Dynamic Assignment module in VISSIM, creating the routes of the cars automatically based on an OD matrix. Furthermore this would give interesting possibilities to compare the results with the assignment created by VISUM.

Thinking even further into the future, if the streets on both sides of the upper lake Zürich were to be included as well, it would be possible to check the effects of a planned tunnel under the lake, designed to relieve the inner city area from traffic.

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Appendices

Appendices

List of appendix figures

A. Suggestions for improvement of VISSIM

When creating a complex model such as the one presented in this work, the user can come across problems that occur due to limitations of the software. Some of the problems encountered will be discussed here since they prevent or unnecessarily complicate the depicting of the real situation. Suggestions for changes to VISSIM are made for some points, which would make working with the program easier and better. The order of description in the following paragraphs goes from small to big changes required in the VISSIM software – this ordering might however not reflect the real effort necessary to implement these suggestions as it is in general hard to judge how big a change a certain feature requires in a software package.

Once a simulation is started it is no longer possible to check what measurements were turned on for a run. To check that, the simulation has to be stopped completely and has to be restarted, unnecessarily losing time due to this. Of course changing the settings during the run is not sensible but a possibility to examine which are turned on, should be added.

The possibility of selectively disabling programs for signal controlled junctions should be available. When starting a simulation all the signal programs for all the junctions are automatically loaded. First of all this is time consuming and in some cases when the user wants to look at some particular part of the network not all of the signal programs are needed. Especially during the testing phase this has to be done very often: start up the simulation, wait for all signal controllers to start up, watch one crossing and locate a problem, stop the simulation, fix the problem, retranslate from VisVAP to VAP and start the simulation again. Furthermore any error message displayed concerning problems with a signal control program does not specify at which junction (in which program) the problem is. Locating this would be easier with only one or a few of the controllers actually starting up. Therefore at the moment it is advisable to run a simulation after each new program has been created and at once correct all errors.

The link evaluation allows at the moment to watch the simulation with an alternate display. Instead of showing the single cars driving, the streets are coloured to encode information like density or average speed of the traffic on the corresponding piece of street. This naturally does not show instantaneous values but averaged values over an interval which can be set by the user. However this data is only available while the simulation is running, the graphical display of this information after the simulation is stopped is not possible, although the information can be written out to a file. But VISSIM is not able to do anything with this file later, like displaying the data in the same way as during a simulation run. It would help in the analysis of the data to be able to create figures later, after all simulations have been run.

When printing a network, VISSIM only prints the streets but none of the other elements that are currently displayed on the screen (like priority rules, detectors or the background). However during the running simulation it is possible to print the vehicles. For the purpose of analysing problems and documenting it would be very valuable to be able to print all the information that is displayed on the screen. In this way it is e.g. easier to give descriptions of how signal controlled junctions work in connection with their detectors. Furthermore the background map helps people not familiar with the model to orientate themselves which would be a helpful feature for a report like this. The alternative of making a screen shot is not desirable as the resolution of the output is relatively low.

Moving around in the modelled network is more difficult than it has to be. To go from one end of the network to another, at the moment it is best to zoom out and zoom in again, having to rescale the background twice which is time consuming and inconvenient. The scroll bars at the side of the screen do not help much either, as they allow only horizontal or vertical scrolling and are not good for long range movements. To solve this problem, a pan function like it is installed in graphic programs such as Adobe Photoshop, would be helpful. There a small image of the whole picture (network) is displayed together with a rectangular frame that shows the current position on the screen. By clicking on other positions in this small preview window it is possible to quickly navigate in the model while staying at the same zoom level.

The software does not provide the possibility of implementing inter-weaving (Reissverschlussverfahren). This technique is normally used when in a two lane street both lanes are merged into one. In VISSIM this situation can not be handled easily. If priority rules are used then one lane is always yielding for the other lane thus creating a totally unrealistic situation. If on the other hand no priority rules are used at all then the two cars from different lanes drive ‘into’ each other, forcing the one behind to do an emergency stop which creates the visual appearance of a crash and problems within the model. Although a merger of two lanes does not occur in the modelled area, this principle is useful in other situations as well, e.g. for ‘forcing’ the way from small streets into the flowing (or jammed) main traffic. Otherwise the drivers on the streets that have to give way would in many cases never be able to join the traffic which is not a realistic behaviour and creates queues in the yielding street – which in turn can cause a chain reaction and block further junctions. In reality drivers have ‘pity’ with the waiting cars and let them in – or the other way around, the waiting drivers are daring enough – especially in situations of slow and heavy traffic. There should be a possibility of defining two streets, where one has to give way to the other in such a way, that cars would be able to drive from both of them, e.g. in a ratio chosen by the user (always less cars from the street where drivers have to yield).

There is a very important VISSIM limitation when it comes to implementing routing decisions. At the moment VISSIM does not feature connectors (connecting streets/links) that can join streets on a different than a one to one basis. That means that it is possible to connect a two lane street with another two lane street (by a two lane connector), but if it is necessary to connect a one lane street with a two lane street it still has to be done with the help of two *separate* connectors. The problem occurs when a route goes over such a connector because it cannot go over more than one connector at the point the lanes are separated (or merged). As a consequence cars always take only one connector, the one that is part of the route, and thus all start on (or come from) the same lane. This does not allow to depict traffic flow realistically since in such a case the cars have to unnaturally change lane after (or before) the connector.

Additionally if there are many routing decisions using the same connector VISSIM automatically chooses those routes to go onto the same lane even if another connector would lead to a better lane for the current route. This, naturally, can create at some points traffic jams, because all the cars need to first go onto that lane before they change to a different one. Currently one way to deal with this problem is splitting the routes going over such connectors manually into several routes with identical origin and destination (with the relative flow divided proportionally between the split routes) using all the lanes available at the crucial connectors. Another way is to lead the car over the best fitting connector for its further route. It would be very helpful for the users if VISSIM would include connectors with different connecting ration than 1 to 1 (as described above). This would eliminate both problems and get rid of the need for tiresome changes in order to correct the routing decisions – provided that the cars then would automatically choose the correct lane on the one remaining connector.

During the creation of a model and its alternatives it is required to use a lot of dialog boxes. In some of them there is a possibility of using the keyboard to access the buttons for certain functions but in others this is not possible and the mouse has to be used. Furthermore the default button (the button that has the thick frame around it and is activated when pressing [Return]) is not set in a consistent way over all dialog boxes which further increases the trouble of inputting a lot of the data. Especially when doing a lot of changes it would greatly improve the speed of work if a keyboard shortcut existed for all buttons and if the behaviour of the dialog boxes was consistent within the whole software. Another possibility to solve this problem (in particular when doing changes) would be to have the functionality of importing and exporting the model (or parts of it) to a database or spreadsheet application – or with the help of saving the network in XML format (see below). With the help of tables a lot of the inputs could be greatly simplified as well as additional analysis and verification done. Questions like: ‘Are all pedestrian input numbers set to 200 pedestrians per hour?’ could be answered without having to click through all pedestrian inputs or having to go back to the saved network – which is done as a pure text file and thus possible to read by human beings. However, the manual specifically discourages changing anything in that file directly.

In the context of file formats another problem arises. Nearly all the output files that VISSIM produces are text files that are readable by human beings and relatively straight forward to import into Microsoft Excel or a similar spreadsheet software. However the output format is not consistent, sometimes a fixed width format was chosen (e.g. the public transport waiting times gathered in .ovw files) while other files use a semicolon delimited list of entries (e.g. the travel and delay time files, .rsz and .vlz). Furthermore they normally have a header part before the actual data starts. All this makes it harder to automatically post-process the data. A format that would fit the requirements perfectly is the XML standard (see [XML Standard, 2002] and [XML FAQ, 2002]). It is a human readable format for storing and exchanging structured data and has the big advantage that many standard tools are available for formatting, changing, importing and exporting this kind of data automatically. This would help a great deal in automating the necessary post-processing steps.

Another problem could be solved by switching to XML. As already mentioned earlier, the changing of input data can be very hard if done in the program. Editing the network file, VISSIM’s input file with the ending .inp, directly is possible and easier but explicitly discouraged in the manual as the file might become unreadable by VISSIM afterwards. The XML format would help here as well, the standard tools are able to do ‘mass’ changes (like decrease all car inputs by 10%) and the whole handling of the file would get much easier.

Along similar lines goes the – more general and harder to solve – problem of maintaining several alternative versions of basically the same network. VISSIM currently has no support for this problem so it is up to the user to deal with the arising problems. Every time anything is changed in the network, be it an input number for pedestrians or a signal head position, and the work is saved you get a new version of the file. Imagine working with four alternatives A to D where A and B are the same except for input numbers of cars. C and D have one signal controlled junction arranged differently than A and B. Between each other their input numbers differ but C’s input numbers correspond to A’s and D’s numbers to B’s. This is a simplified scenario but it is sufficient to show the arising problems. If you now discover an error in the input numbers of C you have to change that as well in A. If you discover a misplaced priority rule in the network, you have to change it in all files. The main problem is that data gets duplicated (or in this case quadruplicated!) so all the versions have to be kept up to date and, even more important, consistent. A solution – at least to part of the problems – would be to modularise the saving of networks so that the streets layout is saved separately from the input numbers for cars, etc. If there is only one place where the input numbers are stored, they only have to be changed once, no matter how many models are actually using them. Furthermore the possibility to create 'differences' between network files, i.e. to detect what changed from one version to another and visualise that, and to propagate changes automatically would help in maintaining consistency across different versions and alternatives. Again the XML format might be a part of the solution, as there exist tools to do e.g. differences between files.

VISSIM requires inputting the whole network structure manually. In order to make a junction all the streets have to be input separately. There are no standard blocks available that could be input directly and just altered to the user's needs. Especially for the priority rules - that at the moment have to be input explicitly everywhere – this would provide a big simplification. Being able to specify e.g. a normal four way crossing - a main street and two side streets which yield to the main street, allowing and preventing certain turning relationships – and just putting it into the place where it should go, having only to change the geometrical layout of the streets, would be ideal. Instead at the moment the user has to take care that the cars turning left and right wait for the appropriate lanes, adjust the headway and gap time manually, and make sure that in case of a traffic jam on the main street the side streets do not get blocked and can e.g. still cross the main street. This is very time consuming and could be improved by including such standard blocks for junctions that the user can then change and adapt to specific needs.

When creating the network it is often necessary to input streets that are overlapping each other (at all junctions). The software does not recognise that automatically and the vehicles at such points are freely driving over each other. Priority rules have to be implemented in order to deal with this problem. This however is very time consuming and problematic. On the other hand it is not clear that a general solution to this problem can be created, although it would greatly simplify the task at hand.

B. Figures of junction stages

Figure B-1: Stages for junction 323 – Mühlegasse/Seilergraben.

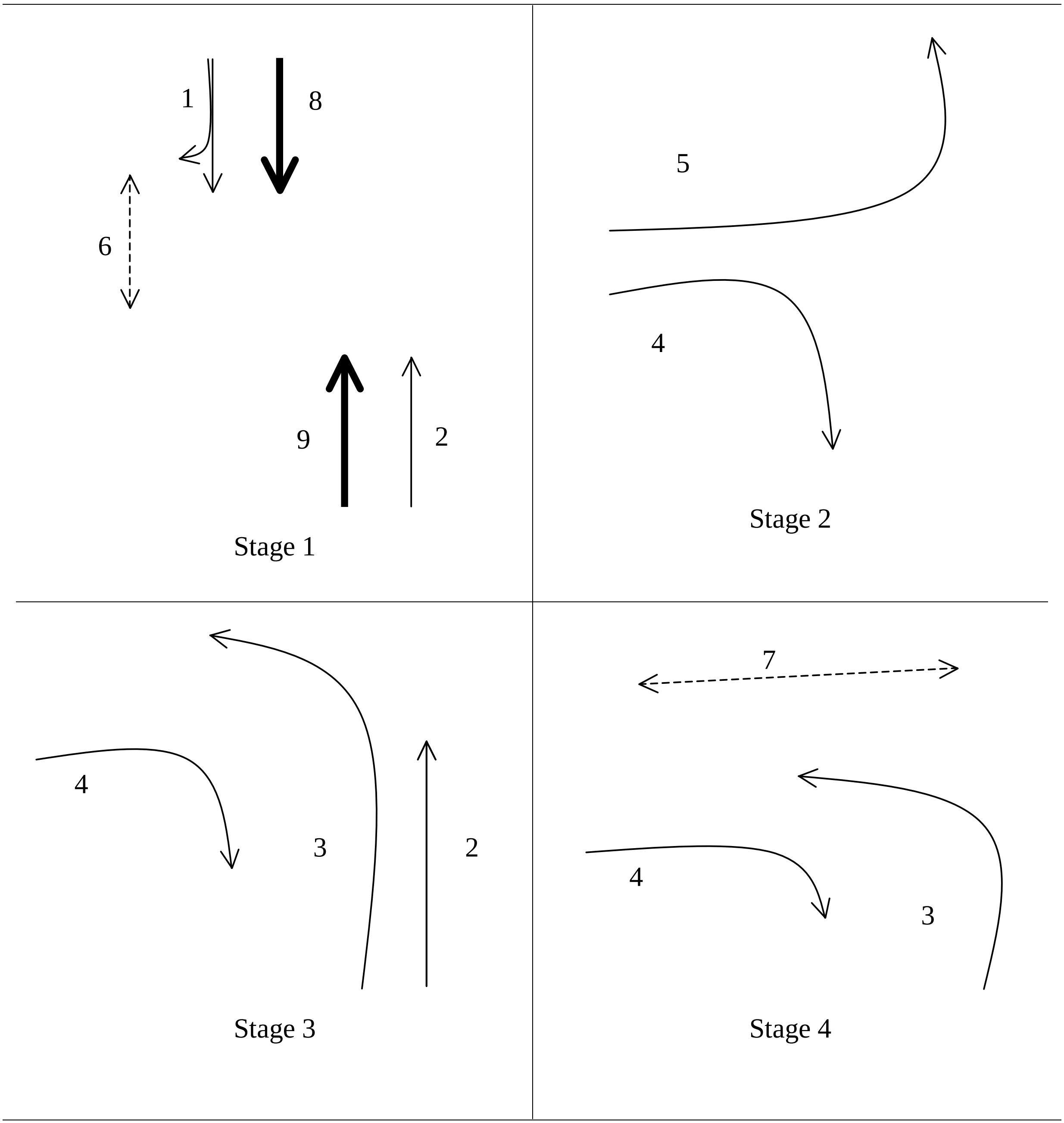

Figure B-2: Stages for junction 324 – Neumarkt/Seilergraben/Künstlergasse.

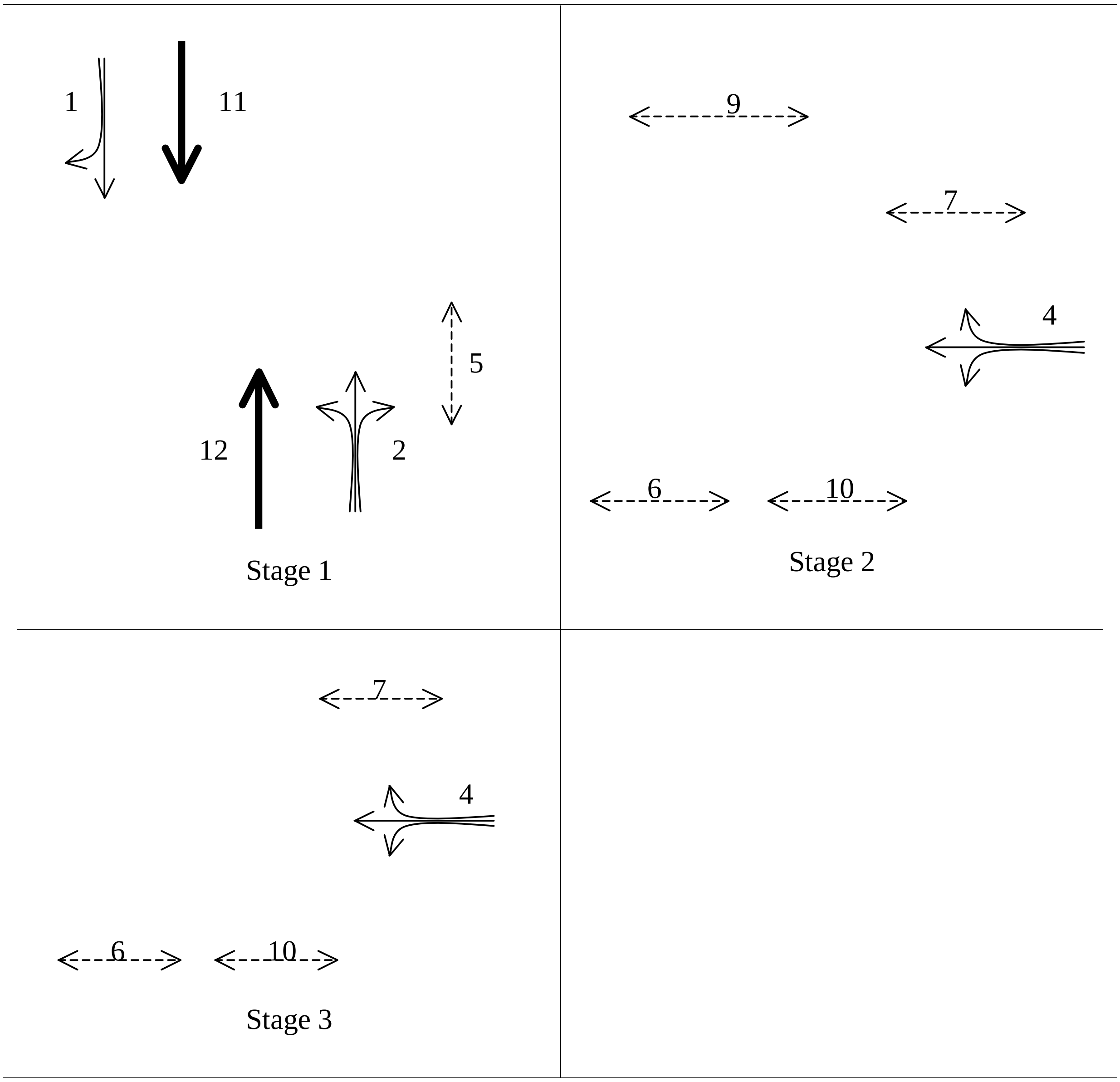

Figure B-3: Stages for junction 330 – Heimstrasse/Hirschengraben.

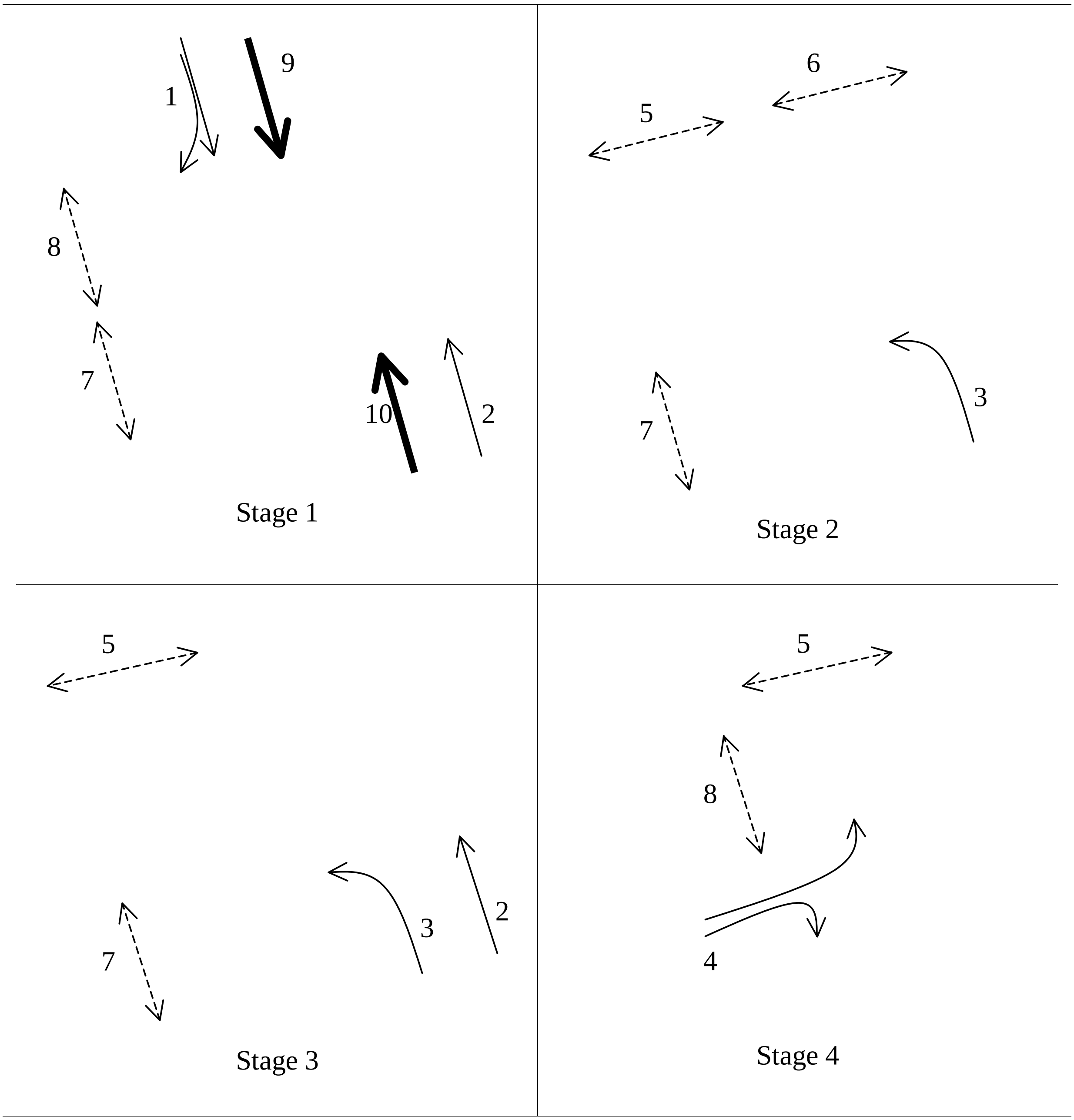

Figure B-4: Stages for junction 507 – Heimplatz/Hottinger/Rämistrasse.

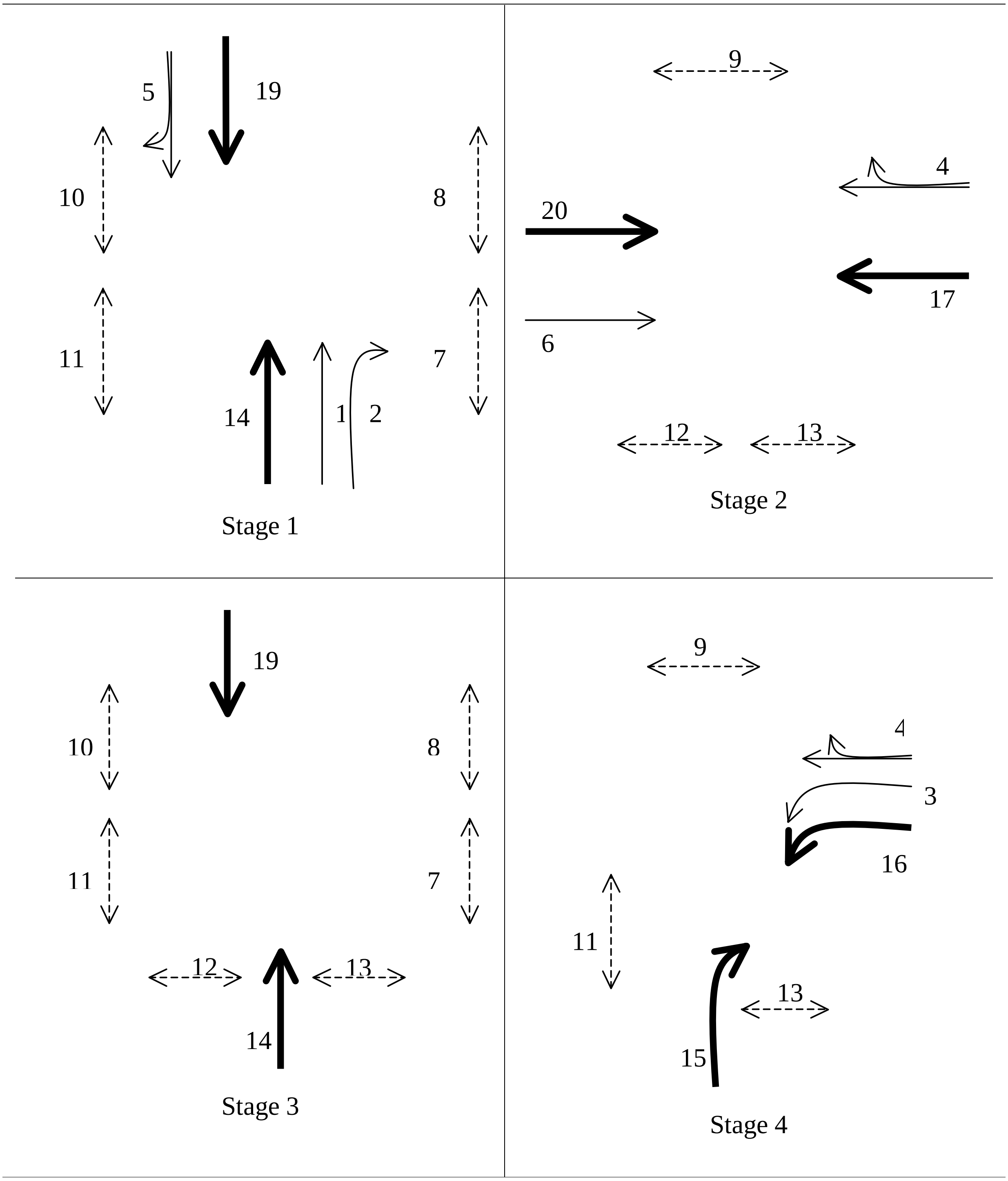

Figure B-5: Stages for junction 508 – Heimplatz/Rämistrasse/Zeltweg.