Optimization proposal for an inner city intersection of main streets with special consideration for public transport, pedestrian and cyclist traffic – Case study of the Herzogsplatz intersection in Wiesbaden, Germany

Marinić, Marko

Master's thesis / Diplomski rad

2019

Degree Grantor / Ustanova koja je dodijelila akademski / stručni stupanj: **University of Rijeka, Faculty of Civil Engineering / Sveučilište u Rijeci, Građevinski fakultet**

Permanent link / Trajna poveznica: https://urn.nsk.hr/urn:nbn:hr:157:794895

UNIVERSITY OF RIJEKA
FACULTY OF CIVIL ENGINEERING

Marko Marinić

PRIJEDLOG OPTIMIZACIJE URBANOG RASKRIŽJA GLAVNIH CESTA S POSEBNIM NAGLASKOM NA JAVNI PRIJEVOZ, PJEŠAČKI I BICIKLISTIČKI PROMET – STUDIJA SLUČAJA RASKRIŽJA HERZOGSPLATZ U WIESBADENU, NJEMAČKOJ

OPTIMISATION PROPOSAL FOR AN INNER CITY INTERSECTION OF MAIN STREETS WITH SPECIAL CONSIDERATION FOR PUBLIC TRANSPORT, PEDESTRIAN AND CYCLIST TRAFFIC – CASE STUDY OF THE HERZOGSPLATZ INTERSECTION IN WIESBADEN, GERMANY

Master thesis

Rijeka, 2019.

UNIVERSITY OF RIJEKA
FACULTY OF CIVIL ENGINEERING
University Graduate Study Programme
Urban engineering
Urban traffic

Marko Marinić

JMBAG: 0114025189

Prijedlog optimizacije urbanog raskrižja glavnih cesta s posebnim naglaskom na javni prijevoz, pješački i biciklistički promet – Studija slučaja raskrižja Herzogsplatz u Wiesbadenu, Njemačkoj

Optimization proposal for an inner city intersection of main streets with special consideration for public transport, pedestrian and cyclist traffic – Case study of the Herzogsplatz intersection in Wiesbaden, Germany

Master thesis

Rijeka, October 2019

IZJAVA

Diplomski rad izradio sam samostalno, u suradnji s mentorom/mentoricom i uz poštivanje pozitivnih građevinskih propisa i znanstvenih dostignuća iz područja građevinarstva. Građevinski fakultet u Rijeci je nositelj prava intelektualnog vlasništva u odnosu na ovaj rad.

Marko Marinić

U Rijeci, 19. listopad 2019.

SAŽETAK

Naslov rada: Prijedlog optimizacije urbanog raskrižja glavnih cesta s posebnim naglaskom na javni prijevoz, pješački i biciklistički promet – Primjer raskrižja Herzogsplatz u Wiesbadenu, Njemačkoj

Student: Marko Marinić

Mentori: Prof. Dr.-Ing. André Bruns
doc.dr.sc. Sanja Šurdonja

Studij: Diplomski sveučilišni studij, Građevinarstvo

Koelgij: Promet u gradovima

Pod osnovnim načelima održive mobilnosti i prometa, grad Wiesbaden trenutno implementira širok skup mjera usmjerenih prema povećanju udjela javnog prijevoza, kao i pješačkog i biciklističkog prometa. Jedna od glavnih mjera je uvođenje novog tramvajskog sistema CityBahn, zbog kojeg se javlja potreba da se kompletno preoblikuju veliki dijelovi ulica unutar trase. Osim implementacije tramvajskog sistema, cilj je također i poboljšati uslužnost za nemotorizirani promet. Budući da se istovremeno kapacitet raskrižja sa prometnog stajališta ne može značajno smanjiti, zadatak preoblikovanja raskrižja rezultira različitim kompromisima koji se moraju riješiti tijekom procesa planiranja. Glavna točka ovog zahtjevnog zadatka bilo je raskrižje Herzogsplatz u četvrti Biebrich. U uvodnom dijelu obrazložena je pozadina projekta CityBahn i povezana je s konceptom održive mobilnosti. U drugom poglavlju zadatak je bio analizirati trenutnu prometnu situaciju i oblikovanje ulica koje formiraju raskrižje. Karakteristike prometa pješaka i biciklista opisane su u zasebnom potpoglavlju. U trećem poglavlju, cilj je bio opisati mikrosimulacijski model koji je izrađen pomoću softvera PTV VISSIM. Rezultati simulacije prometa sažeti su prema načinima prometa i prikazani na kraju poglavlja. U četvrtom poglavlju cilj je bio dizajnirati izgled preuređenog raskrižja. U postupku oblikovanja konzultirane su njemačke smjernice za promet i osmišljen je pripadajući mikrosimulacijski model. U petom poglavlju ustanovljena je i provedena višekriterijska analiza za usporedbu rezultata predloženog dizajna i trenutnog stanja. Rezultati su sažeti, a konačna evaluacija i rasprava nalaze se u šestom poglavlju. U posljednjem poglavlju predstavljeni su utvrđene spoznaje i zaključci rada.

Ključne riječi: urbani promet, raskrižje, Wiesbaden, CityBahn, pješački promet, biciklistički promet, mikrosimulacija, VISSIM

ABSTRACT

Thesis title: Optimization proposal for an inner city intersection of main streets with special consideration for public transport, pedestrian and cyclist traffic – Case study of the Herzogsplatz intersection in Wiesbaden, Germany

Student: Marko Marinić

Mentor: Prof. Dr.-Ing. André Bruns
doc.dr.sc. Sanja Šurdonja

Study: University Graduate Study Programme, Civil Engineering

Course: Urban traffic

Under the main goals of sustainable mobility and traffic, the city of Wiesbaden is currently implementing a broad set of measures aiming at the increase of the public transport as well as pedestrian and cyclist traffic. One core measure is the introduction of a new light rail system, the CityBahn, which entails the need to completely redesign large parts of the affected streets. Besides integrating the light rail infrastructure the objective is also to improve the level of service for the non-motorized traffic. Because at the same time the capacity for traffic from a system point of view may not be reduced massively, the task of the redesign results in various tradeoffs that had to be solved during the planning process. One focal point of this challenging task was the intersection Herzogsplatz in the neighborhood of Biebrich. In the introduction part, the background of the CityBahn project was explained and linked to the concept of sustainable mobility. In the second chapter the task was to analyze the current traffic and street space situation in the affected streets and at the intersection. Pedestrian and cyclist traffic characteristics were described in a separate subchapter. In the third chapter, the aim was to describe a microscopic simulation model which was created by means of the software PTV VISSIM. The results of the traffic simulation were summarized by traffic modes and shown at the end of the chapter. In the fourth chapter the aim was to design a layout for the remodelled intersection. The German traffic guidelines were consulted in the process of the redesign and a corresponding microscopic model was designed. In the fifth chapter, a multiple criteria assessment procedure was created to compare the results from the proposed layout to the results of the current layout. These were summed up and a final assessment and discussion was done in the sixth chapter. Lastly, the findings and conclusions of the thesis were presented.

Key words: urban traffic, intersection, Wiesbaden, CityBahn, pedestrian traffic, cyclist traffic, microscopic simulation, VISSIM

Table of contents

List of figures

List of tables

1. INTRODUCTION

This chapter will provide insight into the main ideas and goals of the thesis. These are going to be linked with the concept of sustainable mobility, which is covered in the second subchapter. Furthermore, the background of the CityBahn project is going to be made clear to provide context and explain which measures are prioritised. Along with that, an overview of the proposed layout is going to be depicted, to display the extent of the project. Lastly, the scope of the thesis, the location of the Herzogsplatz intersection is going to be shown. Its position within the city is going to be conveyed and described in detail to make sense of the current state of traffic and street space there.

1.1. Main goals of the thesis

Under the main goals of sustainable mobility and the integrated urban development concept [1], the city of Wiesbaden is currently introducing a broad set of measures aimed at increasing the share of the so-called "Umweltverbund" (non-motorised traffic) in the modal split. Public transportation, pedestrian and cyclist traffic are some of the focal points and because of that, one key measure is to introduce a new light rail system, the CityBahn, which will promote the switch from personal cars to public transportation systems. Because of the CityBahn project, large parts of the affected streets face a complete redesign.

This thesis will cover and explain the whole thinking process and try to achieve these main goals:

- 1. Integration of the CityBahn in the area of the Herzogsplatz intersection
- 2. Improvement of the level of service (LOS) for pedestrians and cyclists

As stated in Highway Capacity Manual 2010 (HCM), LOS is a qualitative measure to describe service measures such as, speed and travel time, freedom of manoeuvre, traffic interruptions, as well as comfort and convenience. It is measured on an A-F scale, where LOS A represents the best operating conditions for the user and LOS F the worst.

1.2. Sustainable mobility

One of the key concepts of transport innovation and traffic planning altogether, sustainable mobility has proven to be not only a desirable, but also an integral part of how modern societies approach and adapt to increasing social, economic and ecological challenges. Within growing cities, motorized transport remains the prevailing choice for meeting the demands of individual mobility and movement of goods within densely populated areas, as well as rural parts. Keeping in mind it´s reduced energy-efficiency and negative environmental and health effects (noise and air pollution and traffic-related accidents), high volumes of cars and trucks worsen the burden of traffic and cause congestions in the traffic network. [2] Because of that, the city of Wiesbaden is currently implementing a broad set of measures, aiming at increasing the share of public transport as well as pedestrian and cyclist traffic.

1.3. CityBahn project

The CityBahn project is part of a joint effort, put in by the City of Mainz, the City of Wiesbaden and the Rheingau-Taunus circle, to make the use of public transport more attractive.

Nowadays, the main challenges of these regions include:

1. Constant population growth of the capitals, Mainz and Wiesbaden
2. Traffic jams in the whole region
3. Alarming air and noise pollution
4. Performance of the bus network at its limit

The six main measures, which are shown on Figure 1, serve to promote the switch from using personal cars, to using other ways of transport. They represent a common vision of the partaking sides, which promote modern and sustainable mobility and focus on the cleanliness of the region, as well as quality of life altogether. [7]

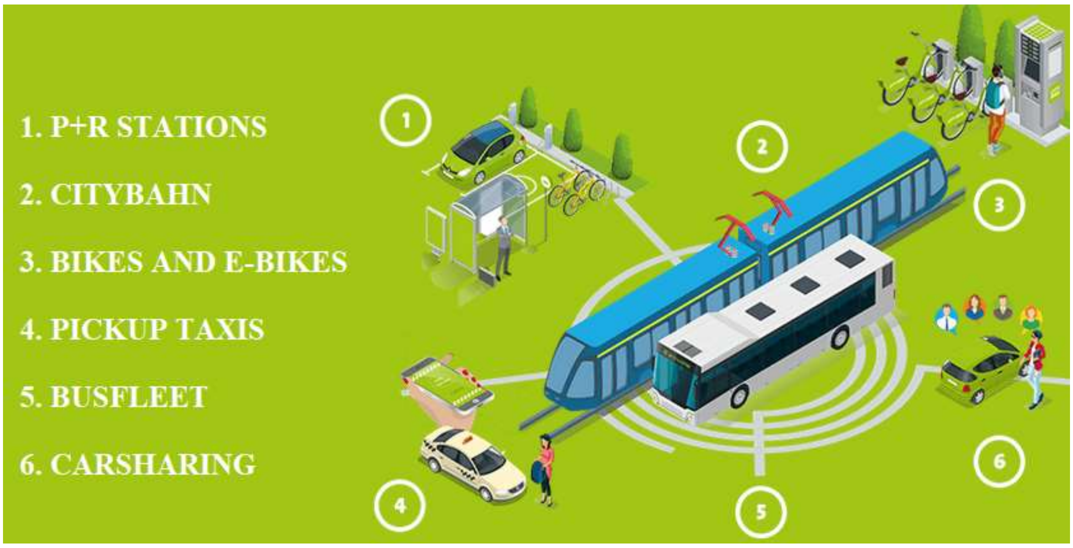


Figure 1: Main measures of the sustainable mobility vision [7]

The proposed layout of the CityBahn rail system (Figure 2), which is thought of being the most feasible option, should connect one of the main study facilities in Wiesbaden (Hochschule RheinMain) and the central train station in Mainz (Mainz Hauptbahnhof). By 2022, the expectation is that it could accommodate up to 100.000 passengers daily [7]. Moreover, the rail system is planned to be expanded to reach the city Bad Schwalbach, passing also through the city Taunusstein. That way, commuters from the Rheingau-Taunus circle could easily park their cars outside of Wiesbaden and continue to the city centre with the CityBahn, negating the impact of a lot of unnecessary car rides.

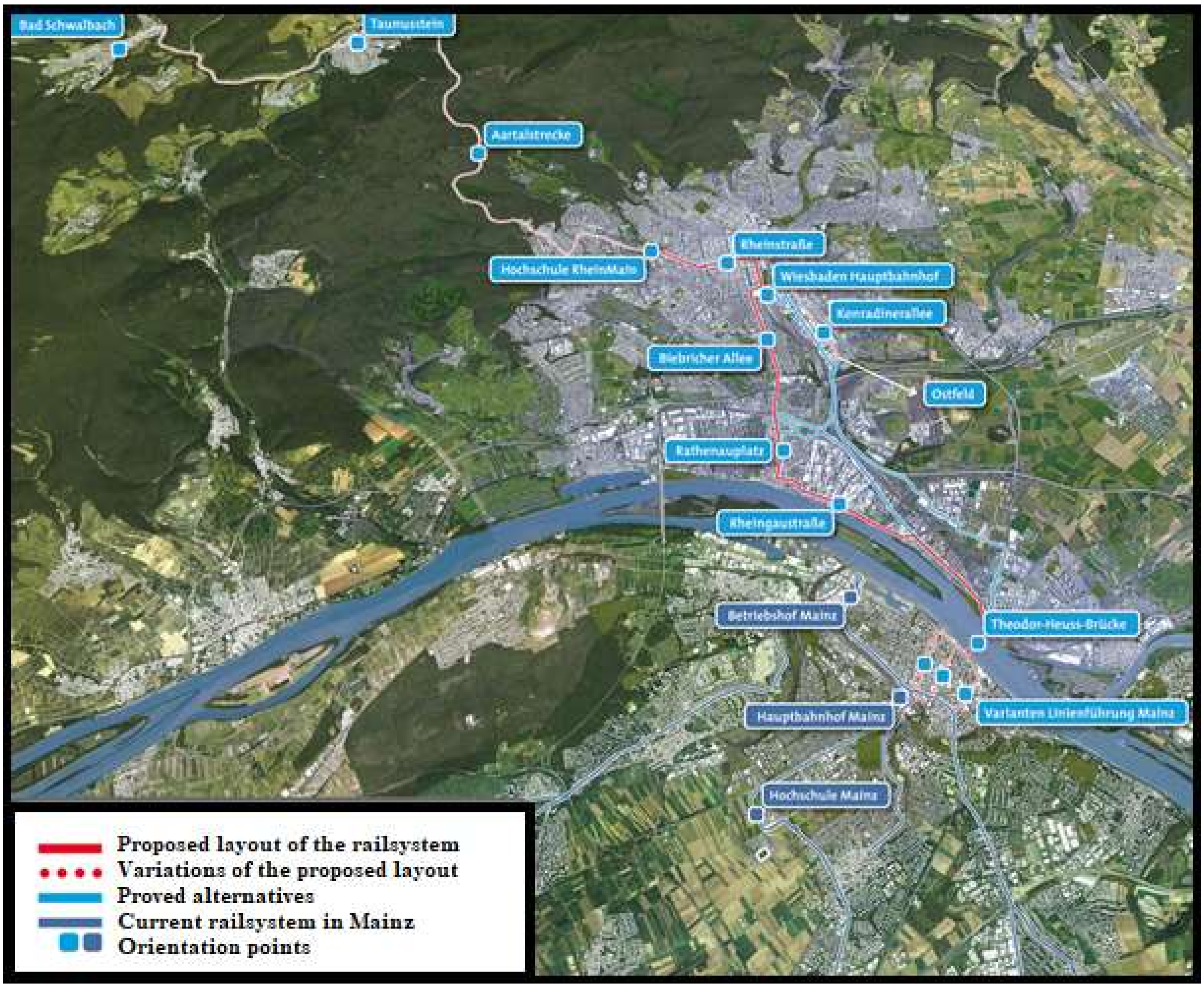


Figure 2: Proposed layout of the CityBahn rail system

Looking at the inner-city segments of the layout, one section of the proposed route encompasses the Biebricher Alle and Straße der Republik, passing through the focal point of this thesis, the Herzogsplatz intersection (Figure 3). [6]

Figure 3: Location of the Herzogsplatz intersection [6]

1.4. Scope of the thesis: Herzogsplatz Wiesbaden

Herzogsplatz (Figure 4), a very important inner city intersection, is located in Wiesbaden, in the neighbourhood of Biebrich, and formed as a junction of main streets, which have different properties. It's very interesting from a traffic planning standpoint because it's an intersection where many means of transportation already coexist and with the introduction of the CityBahn, the complexity of this inner-city junction raises.

Figure 4: The Herzogsplatz intersection [3]

2. ANALYSIS OF THE CURRENT SITUATION

2.1. Cross sections

The analysis of the current situation starts with examining the cross sections of the four streets that form the Herzogsplatz intersection (Figures 5-8). The cross sections represent widths of the street space in the intersection area but differ from the characteristic cross section further from the intersection area.

Biebricher Allee

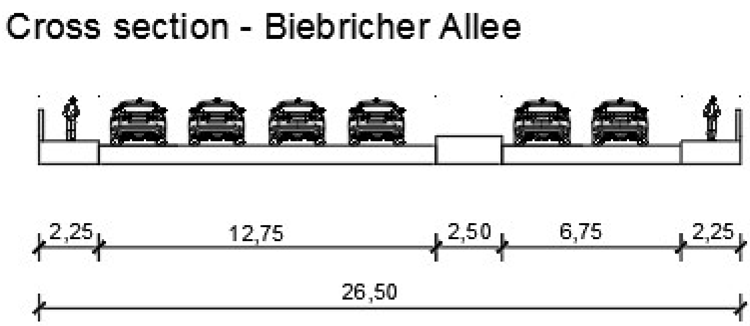


Figure 5: Cross section (Biebricher Allee)

Kasteler Straße

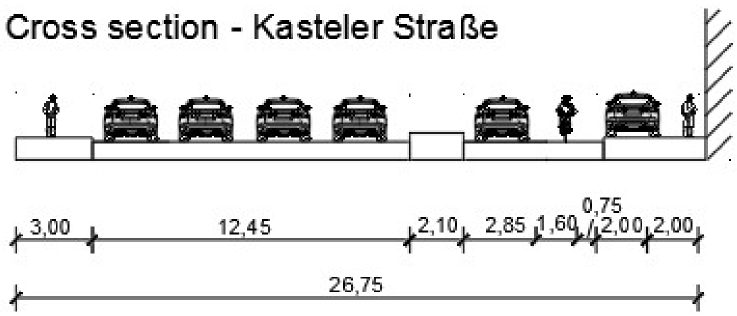


Figure 6: Cross section (Kasteler Straße)

Straße der Republik

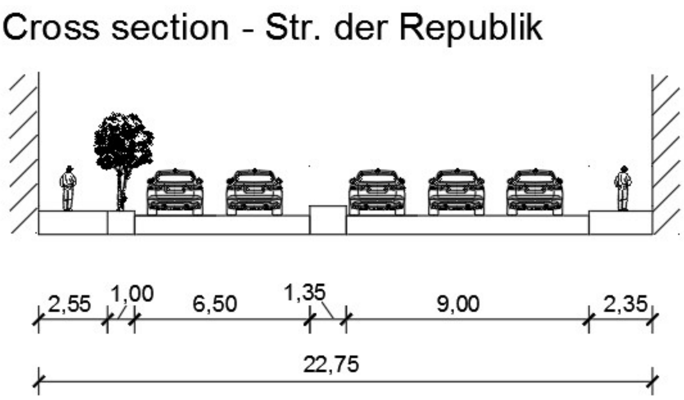


Figure 7: Cross section (Straße der Republik)

Äppelallee

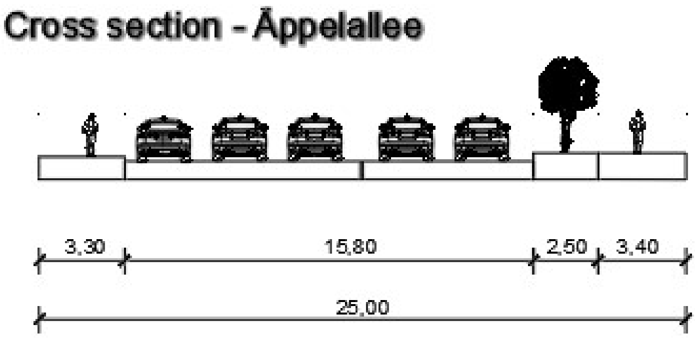


Figure 8: Cross section (Äppelallee)

2.2. Road classification features

As stated in RASt 06, in urban roads classification, there are two key categories of features to consider:

- traffic features
- urban design characteristics

These are then later divided into smaller subcategories, as pictured on Figure 9.

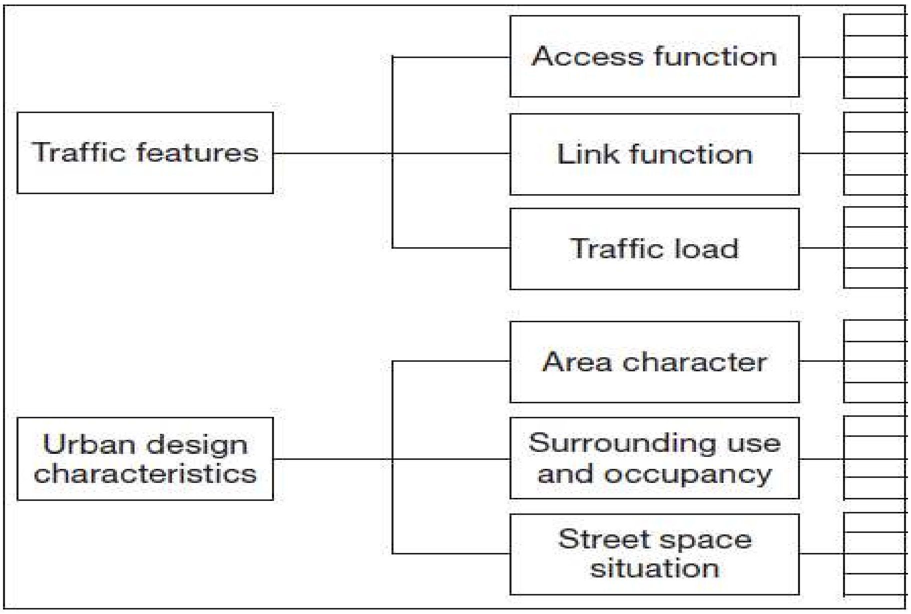


Figure 9: Categorisation of urban road classification features [10]

The link between traffic features and urban design features is very important, especially for main arterial roads, which have to fulfil a broader set of functions. These are for instance:

- ➢ wider-area functions – connected to the need to link urban and suburban areas, as well as insuring a communication between towns

- local functions – connected to the type and uses of the adjacent buildings, with respect to environmental qualities and urban context

2.3. Traffic features

When thinking about traffic features of an urban road, we can picture them as a result of urban and traffic planning. Traffic features describe the significance of a road in the traffic network and are subdivided into three parts:

- access function
- link function
- traffic load

2.3.1. Access function

The access function of urban roads is dictated by the characteristics of the surrounding environment and the resulting number of routes for persons using all means of transport, as well as frequency and duration of loading operations.

2.3.2. Link function

The link function of urban roads is connected to the importance of the locations being linked and their distance, as well as the intensity of the respecting traffic links. It is measured by the quality of traffic flows. An assessment of the link function should always be made for every means of transport independently, because a road with a major link function for public transport could have a lesser significance for other types of transport (for example cycle traffic).

The link function of the respective streets is as follows:

- Biebricher Allee → link between the city centre and south districts
  → entry point to the highway
  → scheduled bus lines
- Kasteler Straße → access point for the industrial areas, highway
  → scheduled bus line
- Straße der Republik → link to the city centre
  → scheduled bus lines
- Äppelallee → access point for the industrial areas, highway
  → scheduled bus line

2.3.3. Traffic load

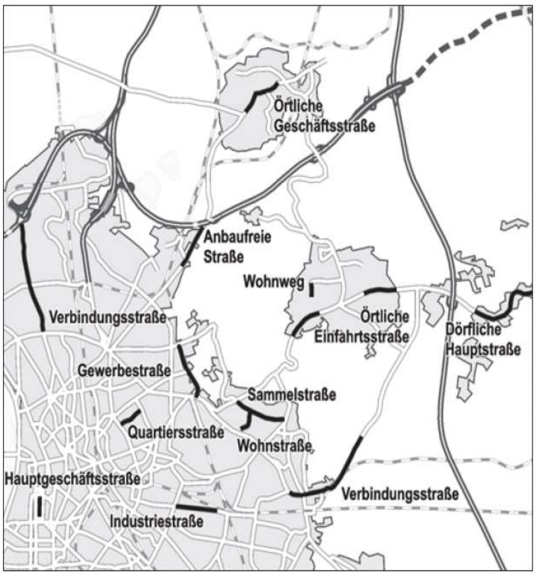
The traffic load function consists of incoming and outgoing traffic and can widely vary depending on the type of urban road. Therefore, traffic load is a very important distinguishing aspect for road classification.

The traffic function of the respective streets is as follows:

- Biebricher Allee → high traffic load
- Kasteler Straße → moderate traffic load
- Straße der Republik → high traffic load
- Äppelallee → high traffic load

2.4. Determined road classification

Included in RASt 06, there are possible typical design situations which the user can consult (Figure 10). Furthermore, each type of road has a dedicated chapter with representative details.



Typical design situations	Road categories
Residential lane	ES V
Residential street	ES V
Collector road	ES IV
City neighbourhood street	ES IV, HS IV
Village main street	HS IV, ES IV
Urban main road	HS III, HS IV
Local main street	HS IV, ES IV
Main shopping street	HS IV, ES IV
Roads in commercial areas	ES IV, ES V, (HS IV)
Industrial Estate road	ES IV, ES V, (HS IV)
Link road	HS III, HS IV
No frontage access road	VS II, VS III

Figure 10: Typical design situations used for determining the road classification [10]

The output of the road classification process is a short and indicative overview of two things:

1. Characteristics
2. Typical conditions and requirements

After taking into fact all considerations, the following classification were determined in the next subchapters.

2.4.1. Biebricher Allee

The Biebricher Allee, which is shown on Figure 11, is the main connecting axis between Wiesbaden's city centre and its largest district Biebrich.

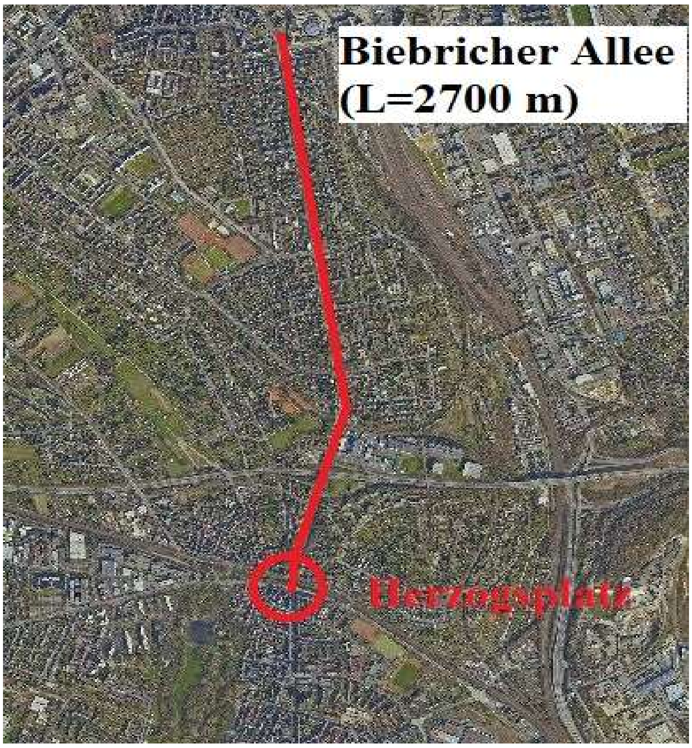


Figure 11: Biebricher Allee (aerial image) [4]

It can be described as a link road and possesses these features:

<u>Characteristics:</u>

- Main arterial road (HS III, HS IV)
- Varying sections with different characteristics
- Residential and commercial uses
- Length of 2700 m
- Traffic volume of over 2,800 vehicles per hour (morning peak hour)
- Special requirements for cycle traffic and public transport

<u>Typical conditions and requirements:</u>

- Cycle traffic on separated facilities

2.4.2. Kasteler Straße

The Kasteler Straße, which is shown on Figure 12 is a long street that connects industrial areas to the highway. It features also an advisory lane for cyclists.

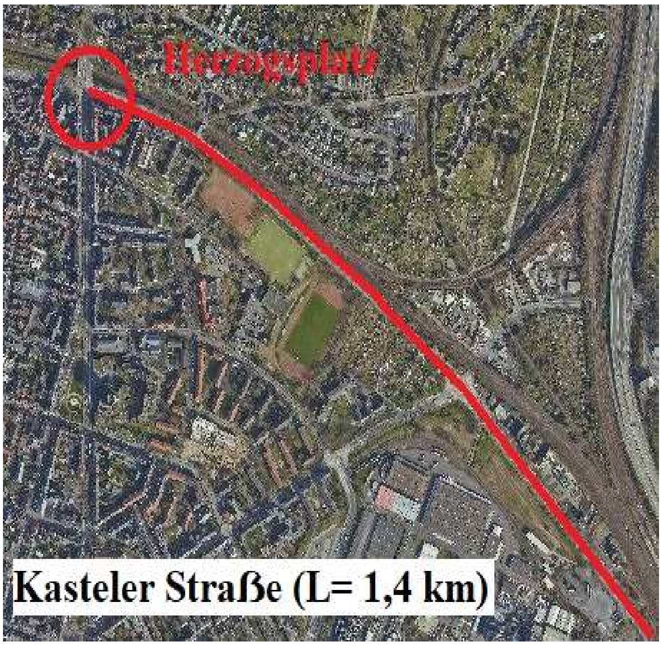


Figure 12: Kasteler Straße (Aerial image) [4]

It can be described as a link road and possesses these features:

Characteristics:

- Main arterial road (HS III, HS IV)
- Varying sections with different characteristics
- Residential and industrial uses
- Length of 1,4 km
- Traffic volume of over around 900 vehicles per hour (morning peak hour)
- Special requirements for cycle traffic and public transport

Typical conditions and requirements:

- Cycle traffic on separated facilities

2.4.3. *Straße der Republik*

Straße der Republik, which is shown on Figure 13 is a main street in the neighbourhood of Biebrich.

Figure 13: Straße der Republik (Aerial image) [4]

It can be described as a local main street and possesses these features:

<u>Characteristics:</u>

- Access road/main arterial road (ES IV, HS IV)
- Located in the heart of the district Biebrich
- Continuous frontage (residential and business uses)
- Varying sections with different characteristics
- Residential and commercial uses
- Length of 700 m
- Traffic volume of around 1500 vehicles per hour (peak hour)
- Special requirements for pedestrian areas and crossings, parking and delivery services
- Special requirements for public transport

<u>Typical conditions and requirements:</u>

- Incorporation of adequate pedestrian walkways and crossing points
- Speeds of motorized traffic and visual contact between pedestrians and vehicles

2.4.4. *Äppelallee*

Äppelallee, which is shown on Figure 14 is a long street that connects industrial areas to the highway.

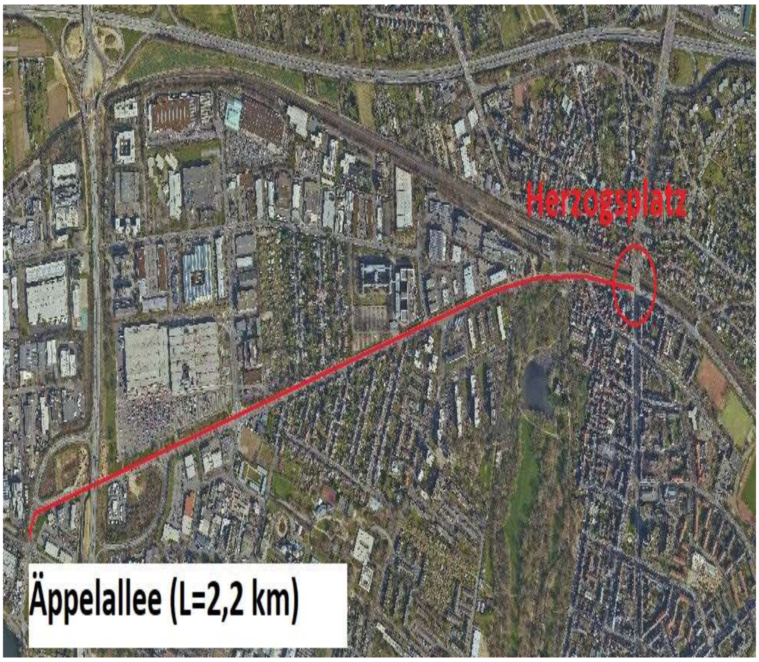


Figure 14: Äppelallee (Aerial image) [4]

It can be described as a link road and possesses these features:

<u>Characteristics:</u>

- Main arterial road (HS III, HS IV)
- Varying sections with different characteristics
- Residential and industrial uses
- Length of 2,2 km
- Traffic volume of over around 2000 vehicles per hour (morning peak hour)
- Special requirements for cycle traffic and public transport

<u>Typical conditions and requirements:</u>

- Cycle traffic on separated facilities

2.5. Non-motorized traffic

2.5.1. Cyclist traffic

The promotion of cycling is widely seen as a way through which cities can become healthier and more attractive to live in. The amount of cyclist in urban areas is influenced by many factors but the most positive precondition should be a safe, well thought out and connected cyclist infrastructure. Wiesbaden does not yet meet these criteria, but it is taking constant steps and measures to improve the cycling conditions. The existing cyclist infrastructure varies widely in quality and features gaps, which leaves the traffic and urban planners thinking how to connect and expand it. The city recognised all four streets forming the Herzogsplatz intersection as important corridors of future cyclist traffic. They were included in the projection of the basic cyclist network map of Wiesbaden in 2020 (Figure 15). Depicted in blue, were measures that need to be taken until 2020 (new build or revaluation), some of which already happened. In December 2018, a 2.3 kilometers long cycle route between Herzogsplatz and the motorway access Kasteler Straße - Äppelallee was completed. All of these measures serve the creation of a gap-free basic cyclist network 2020 in cyclist traffic infrastructure, derived from the 2030 target network of the cyclist transport concept. Their objective is to enhance the share of cyclist traffic in the modal split from 5.7 %, to more than 10 %. [5]

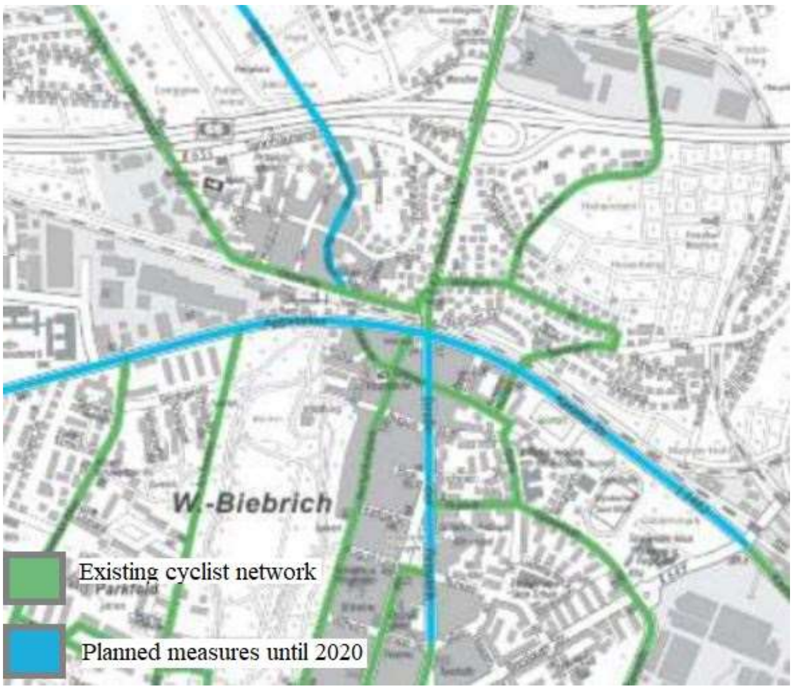


Figure 15: Basic cyclist network map 2020 - Cycling infrastructure network around the Herzogsplatz intersection (Wiesbaden) [5]

The current layout of the intersection incorporates only an advisory lane, starting in the intersection area and continuing through Kasteler Straße (Figure 16).

Figure 16: Start and continuation of the advisory lane

Other than that, there is only a cyclist crossing from the Kasteler Straße to Äppelallee, adjacent to the pedestrian crossing (Figure 17). The overview of the positions can be seen on the layout of the intersection in the attached drafts.

Figure 17: Cyclist crossing adjacent to the pedestrian crossing

2.5.2. Pedestrian traffic

Pedestrian traffic features four pedestrian crossing points. These four points were named with letters A – D, which will be relevant in the following chapters. Each crossing point includes a central reservation. The current situation of the pedestrian infrastructure can be seen on Figures 18 and 19.

Figure 18: Pedestrian crossing

Figure 19: Central pedestrian island

3. MICROSCOPIC SIMULATION OF THE CURRENT LAYOUT

3.1. Microscopic simulation in general

According to Barceló et al. (1998) [11], a microscopic simulation model is a result of a process, which consist of building a model that suitably represents a given system with its belonging characteristics (input). Based on the input, a simulation can be used to answer a series of "what if" questions that help the system designer to both understand the current state of the system, and assess the impact of changes on an already existing system.

A microscopic traffic simulation is built on a detailed representation of the behaviour (movement) of individual vehicles composing a traffic flow. It can be distinguished from a macroscopic traffic simulation in which traffic flows are regarded in an aggregated way, without considering the individual movement of vehicles, according to Barceló et al. (1998) [11]. Macroscopic variables are for instance traffic density and traffic volume, whereas microscopic can be acceleration and response of a vehicle following another vehicle (i.e. car-following models).

In the next subchapters, a brief overview of the modelling procedure is going to be shown.

3.2. PTV VISSIM Software

Simulation software is increasingly applied to the study of traffic and transportation systems. The traffic simulation has been done by utilizing the software PTV VISSIM 20, licensed by the PTV Group.

It is one of the most renowned software used for:

- microscopic traffic simulations of various junction geometries
- motorized and non-motorized traffic and modelling of their interaction (multimodal systems)
- simulation of public transport
- signal schemes and etc.

3.3. Modelling of the network

Modelling of the Herzogsplatz intersection was done in many steps, first of which is to define the model as a network (Figure 20). VISSIM offers a possibility of modelling in 2D or 3D, of which the former option was chosen. To make the model look as real as possible, an aerial image of the intersection was inserted as a background layer.

Figure 20: Herzogsplatz intersection shown as a VISSIM network

3.4. Network objects

In this subchapter, an overview of the objects in a VISSIM network will be given. Insights about important elements such as links and connectors, as well as pedestrian areas will be provided. Afterwards, there is going to be talk about the data input. Finally, the modelling of underlying traffic features such as routing decisions, conflict areas and speed restriction areas is going to be described.

3.4.1. Links and connectors

Links and connectors are the main elements that compose a VISSIM network. A link represents a road, which can have one or multiple lanes, depending on the layout. All links are independent of each other, which means that vehicles, cyclists or pedestrians will move on the link from start to finish. Elements that connect links are called connectors, and they make it possible to cross from one link to another and continue movement (i.e. simulate turning movements). Links (blue) and connectors (purple) can be shown with a centreline in wireframe mode (Figure 21a) or without wireframe mode (Figure 21b).

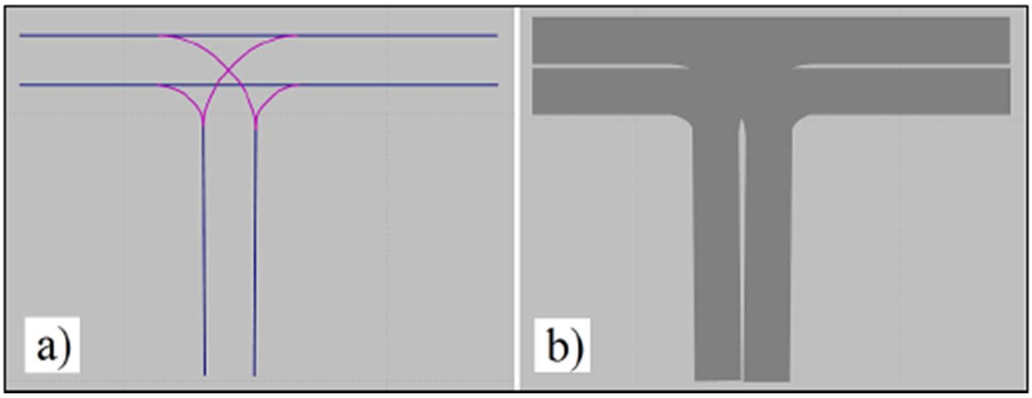


Figure 21: Links and connectors in wireframe mode (a) and without wireframe mode (b) [15]

3.4.2. Pedestrian links and areas

Links can be specifically made for pedestrians, which allows them to follow the direction of the link, what would otherwise not be possible with normal links. However, there is a simplification for the links as they cannot possess middle points and must be drawn as straight lines. Pedestrians also need start and destination areas (Figure 22), and routing decisions (from area to area). Areas allow for free movement in the direction of the link with pedestrian interaction which imitates reality, where pedestrians also have the ability to move sideways.

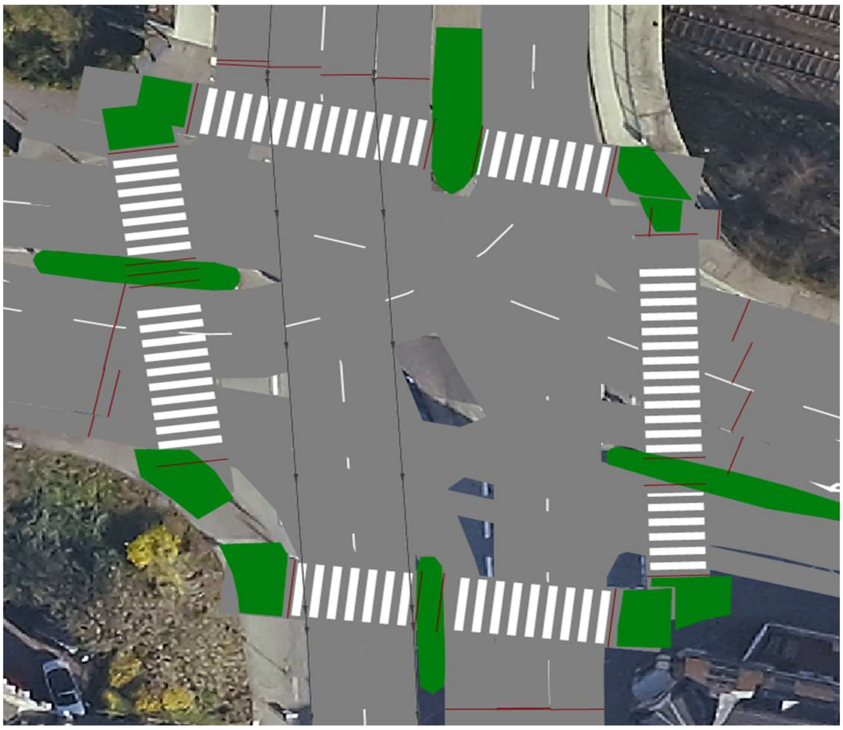


Figure 22: Pedestrian surfaces (green)

3.4.3. Vehicle, cyclist and pedestrian inputs

Vehicle inputs

Available data was issued from the traffic planning department of the city Wiesbaden. The data was collected in December 2018 and shows the traffic flows from the morning peak hour (7:30 – 8:30). The measuring unit is vehicles/hour and all numbers are absolute, with the number in the bracket referring to the number of trucks and heavy vehicles. A graphical display of the vehicle traffic flows is given on Figure 23.

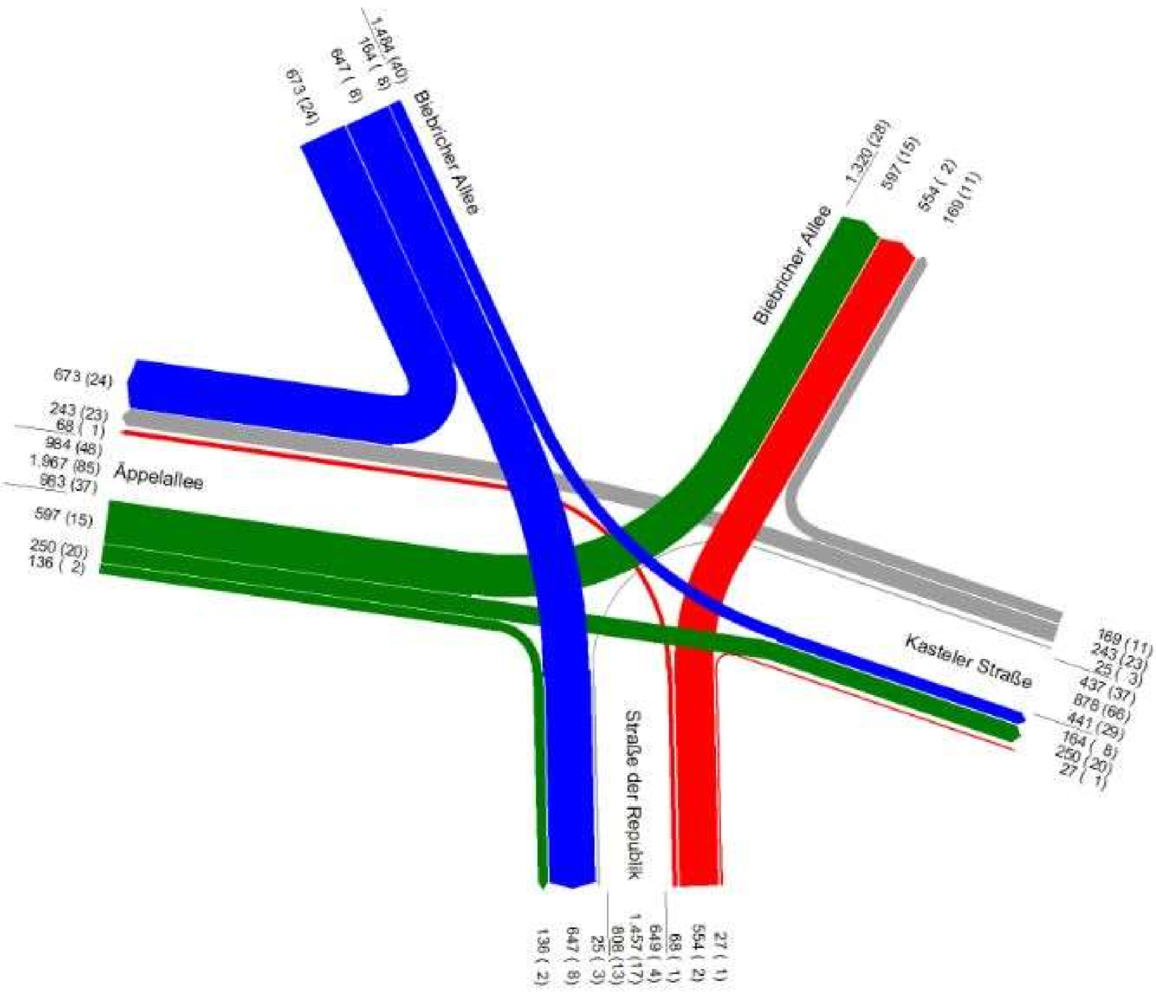


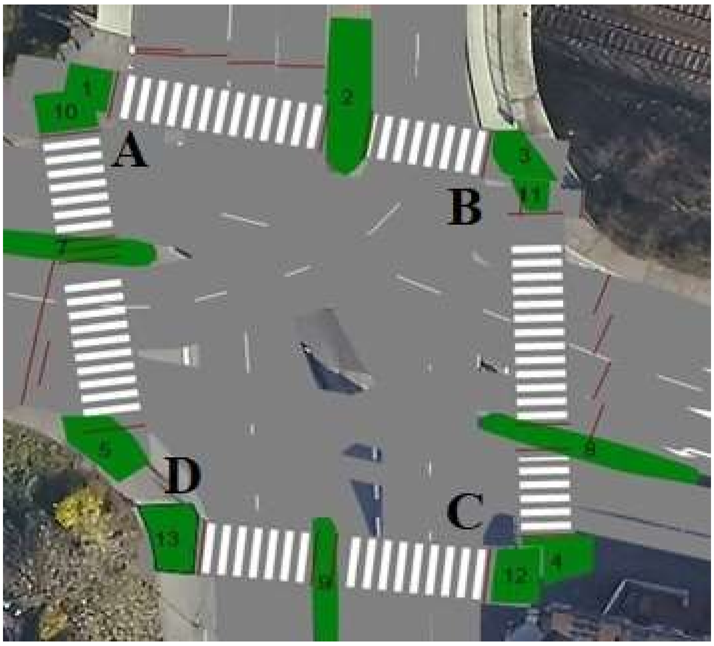
Figure 23: Graphical display of vehicle traffic flows from the morning peak hour

Cyclist input

Cyclist data wasn't available so it was taken empirically. Cyclist traffic enters the network in four points. The chosen number of cyclists per entry point was 60, adding up to 240 cyclists in one hour. Relative flows were distributed equally because of the lack of data.

Pedestrian input

Pedestrian data wasn't available so it was taken empirically. Pedestrians enter the network in eight pedestrian areas (Figure 24), with the other four areas being central pedestrian islands. The chosen number of pedestrians per area was 50, adding up to 400 pedestrians in one hour. Relative flows were distributed equally because of the lack of data. Pedestrian points were named with the letters A, B, C and D and the pedestrian routes in the simulation results sections (3.7. and 4.7.) were referenced in the same manner.



Anzahl: 8	Nr	Name	Fläche	Belas(0)	FgZusSetz(0)
1	1		1	50,0	1: Pedestrians
2	2		3	50,0	1: Pedestrians
3	3		4	50,0	1: Pedestrians
4	4		5	50,0	1: Pedestrians
5	5		10	50,0	1: Pedestrians
6	6		11	50,0	1: Pedestrians
7	7		12	50,0	1: Pedestrians
8	8		13	50,0	1: Pedestrians

Figure 24: Pedestrian areas with inputs

3.4.4. Routing decisions

Vehicles

After all inputs are made, vehicle routing decisions need to be assigned. Each vehicle routing decision is drawn from a starting point of a link to the end of the links that are connected to it (Figure 25). The vehicle, which starts on the position of the vehicle input, will follow one of the routes depending on the relative flow parameter. Each movement (TM - through movement, LT – left turn, RT - right turn) has a corresponding relative flow, which can be viewed as a percentage of the vehicles taking the mentioned route. The larger the relative flow, the larger is the number of vehicles on the particular route. The sum of all relative flows is typically one.

Count: 3	VehRoutDec	No	Name	Formula	DestLink	DestPos	RelFlow(0)
1	1	1	Äppelallee LT		4: Str. de Republik	360,663	0,600
2	1	2	Äppelallee TM		8: Äppelallee	294,795	0,260
3	1	3	Äppelallee RT		7: Biebricher Allee	363,536	0,140

Figure 25: Example of vehicle routing decisions (Äppelallee)

<u>Cyclists</u>

Cyclists were routed on the available cyclist infrastructure (advisory lane and cyclist crossing).

<u>Pedestrians</u>

Pedestrians were routed on the pedestrian crossings with links in each direction, leading to pedestrian areas. The routes which connect the areas were named in the previous subchapter.

3.4.5. Conflict areas

In VISSIM, conflict areas are generated automatically and can either be:

- passive (yellow)
- active permissive (green)
- active preventive (red)

The automatic state is passive and the user can select a conflict area from a list and manually change it. A passive state indicates that the two selected links have a conflict area, which is not significant and does not affect the movement of the vehicles in the network. This state is present where the links, which cross each other, have no vehicle interference because of the signal schemes. If the passive state is deselected, one of the links has to be chosen to have the active permissive state, while the other takes the active preventive. The link with the active permissive state (green) therefore has the right of way. These conflicts areas (Figure 26) are important for managing the left and right turn conflicts with through movements of vehicles, cyclists and pedestrians.

Figure 26: Conflict areas – Herzogsplatz (current situation)

3.4.6. Speed restriction areas

Speed restriction areas (Figure 27) were added to the intersection to try to model the behaviour of drivers, which should in theory adjust (lower) their speed while approaching/entering the intersection. For through movements, the desired speed was lowered from 50 km/h to 40 km/h. The same was done for the left turn from Äppelallee to Biebricher Alee where the signal phasing does not allow for conflicts between the turning vehicles and pedestrians. All other turning vehicles had their speed reduced to 20 or 30 km/h because of the need to adjust the approach speed to the conflict areas with cyclists and pedestrians.

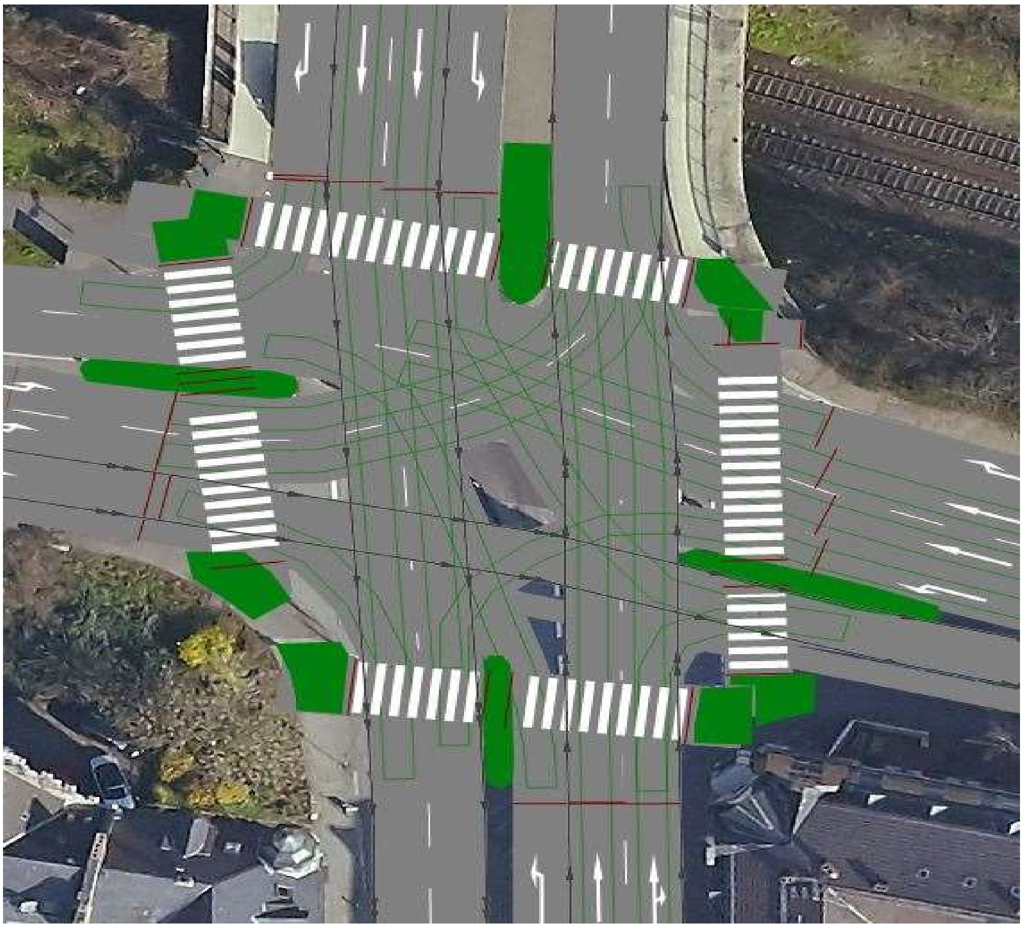


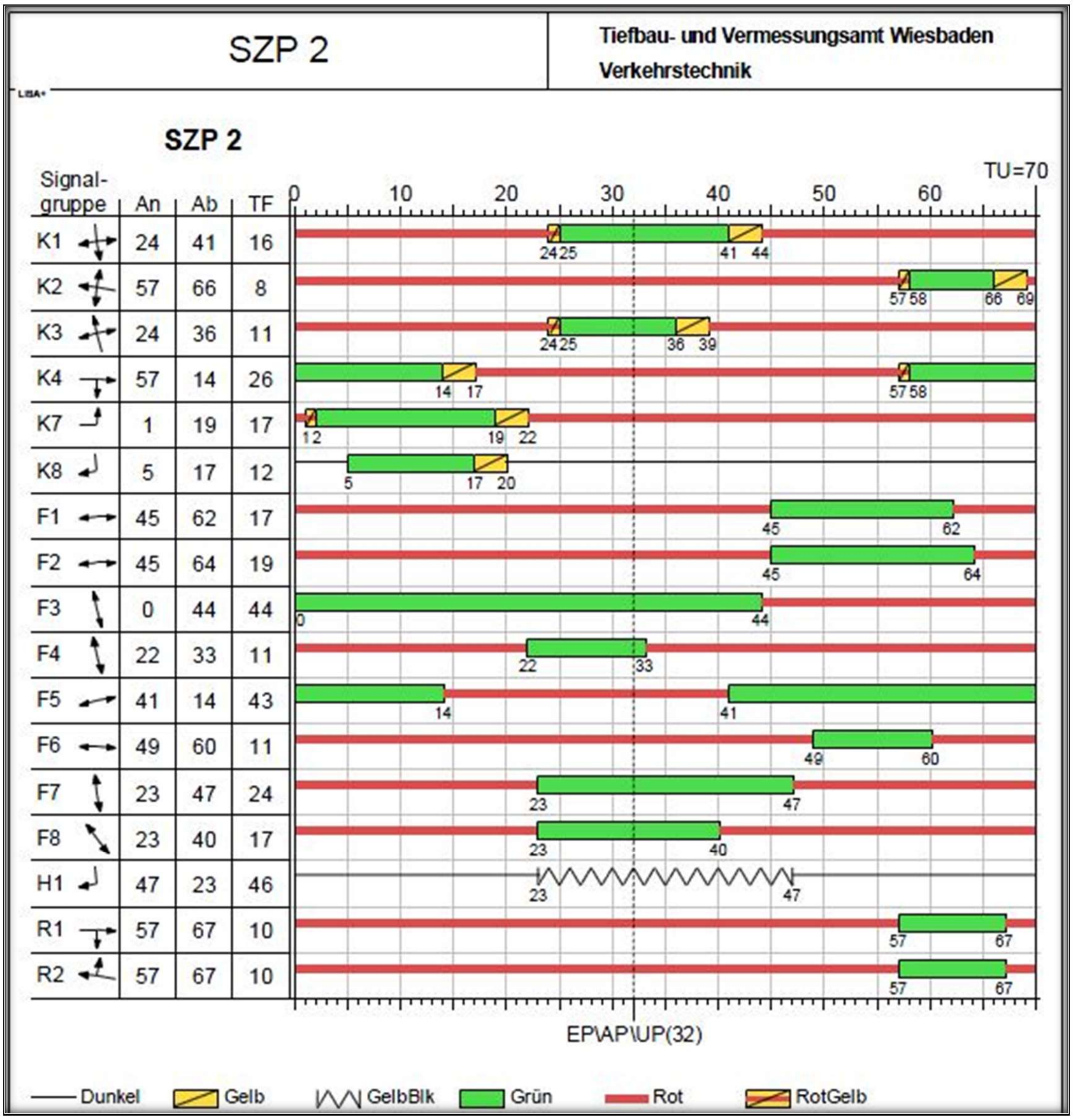
Figure 27: Speed restriction areas in VISSIM

3.5 Traffic signal control

The signal controller SZP 2 (Figure 28) was used for this intersection. It consists out of 17 signal groups with these abbreviations:

- K1 – K4, K7 - K8 → signal groups for vehicles

- F1 – F8 → signals groups for pedestrians ; in this case mixed with cyclists which use some of the crossings
- R1 – R2 → signals groups for cyclists
- H1 → additional signals



Signal-gruppe	An	Ab	TF
K1	24	41	16
K2	57	66	8
K3	24	36	11
K4	57	14	26
K7	1	19	17
K8	5	17	12
F1	45	62	17
F2	45	64	19
F3	0	44	44
F4	22	33	11
F5	41	14	43
F6	49	60	11
F7	23	47	24
F8	23	40	17
H1	47	23	46
R1	57	67	10
R2	57	67	10

Figure 28: Signal controller SZP 2 – Morning peak hour

The signal groups were organised into a phasing scheme with three stages (Figure 29). For reference, the who signalization plan for the intersection can be seen in the signal layout plan (Figure 30).

	1: Stage 1	2: Stage 2	3: Stage 3
▶1: K1	✗	✓	✗
2: K2	✗	✗	✓
3: K3	✗	✓	✗
4: K4	✓	✗	✓
5: K7	✓	✗	✗
6: K8	✓	✓	✗
7: F1	✗	✗	✓
8: F2	✗	✗	✓
9: F3	✓	✓	✗
10: F4	✗	✓	✗
11: F5	✓	✗	✓
12: F6	✗	✗	✓
13: F7	✗	✓	✗
14: F8	✗	✓	✗
15: H1	✗	✓	✗
16: R1	✗	✗	✓
17: R2	✗	✗	✓

Figure 29: Phasing scheme (current situation)

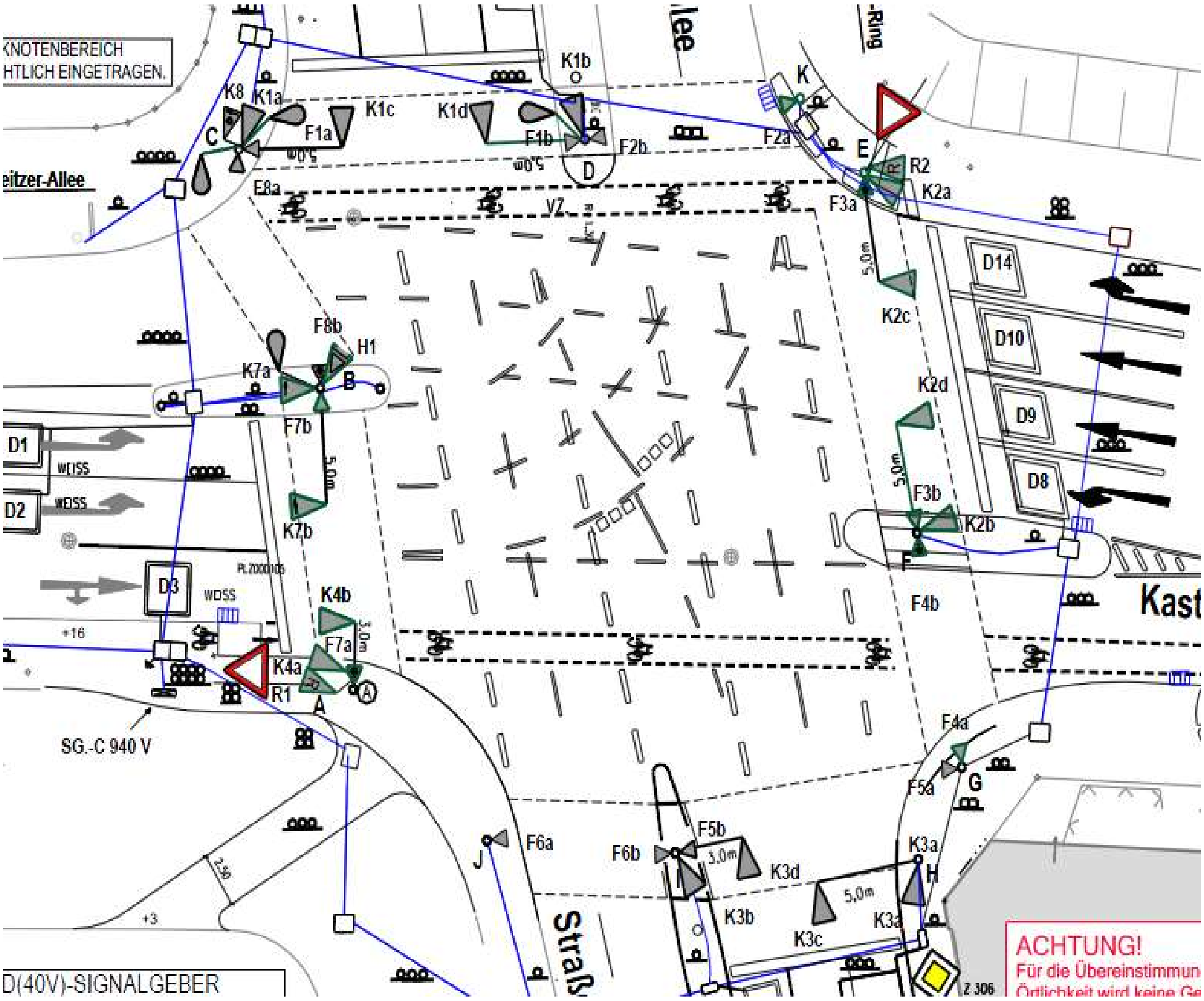


Figure 30: Signal infrastructure layout of the Herzogsplatz intersection

3.6. Microscopic simulation of the current layout

3.6.1. Simulation parameters

<u>The simulation parameters where as follows:</u>

Period → T=3600 s (1 hour)

Number of runs → 5

Random seed increment → 1

Simulation resolution → 10

3.6.2. Node evaluation parameters

VISSIM offers an option to draw an evaluation node (Figure 31), which measures the selected parameters inside the node area.

Figure 31: Evaluation node – Simulation of the current situation

When analysing the traffic performance of an intersection the user can choose many approaches such as node evaluations, link evaluation etc. In this thesis, these node evaluation parameters where selected (Table 1).

Table 1: Node evaluation parameters [15]

Parameter	**Definition**	**Unit**
Average queue length	An average of all the queue lengths on the specific movement	[m]
Delay time	(Actual travel time) – (optimal travel time when travelling at the desired speed)	[s]
Max queue length	The maximum length of the queue at any time during the simulation	[m]
Stopped delay	Average time spent at a standstill per vehicle	[s]
Stops	Average number of stops per vehicle	[stops]

For vehicular traffic, queue lengths are good indicators of the network functionality. In each time step, the current queue length is measured and an average queue length is calculated for every time interval. Maximal queue lengths are also a key factor for evaluating the effect of the peak hour queues on the adjacent intersections. Moreover, measuring of average vehicle delays and stops is a reliable way for indicating why they happen, which vehicle routes are problematic and whether these delays can be minimised.

3.7. Simulation results

3.7.1. Vehicles

					QLen(avg) [m]	QLenMax [m]	Σ (Vehs)	LOS (avg)	VehDelay(avg) [s]	StopDelay(avg) [s]	Stop(avg)
1-5	0-3600	2: Kasteler Straße	4: Str. de Republik	Kasteler Straße RT	28,21	60,19	857	LOS_E	82,77	71,20	2
1-5	0-3600	3: Äppelallee	7: Biebricher Allee	Äppelallee LT	14,03	52,57	2821	LOS_C	25,78	19,66	1
1-5	0-3600	4: Str. de Republik	4: Str. de Republik	Str. der Republik TM	17,68	57,19	2607	LOS_C	33,04	25,31	1
1-5	0-3600	4: Str. de Republik	9: Kasteler Straße	Str. der Republik RT	17,68	57,19	145	LOS_C	30,59	22,20	1
1-5	0-3600	5: Str. de Republik	8: Äppelallee	Str. der Republik LT	3,06	19,91	471	LOS_D	40,07	30,29	4
1-5	0-3600	6: Biebricher Allee	8: Äppelallee	Biebricher Allee LT	19,67	54,25	714	LOS_F	81,48	59,45	3
1-5	0-3600	7: Biebricher Allee	7: Biebricher Allee	Biebricher Allee TM	14,04	66,04	2802	LOS_C	24,50	17,02	1
1-5	0-3600	8: Äppelallee	4: Str. de Republik	Äppelallee RT	13,24	67,61	631	LOS_C	23,08	15,12	1
1-5	0-3600	8: Äppelallee	8: Äppelallee	Äppelallee TM	13,38	67,30	1263	LOS_B	21,12	12,51	1
1-5	0-3600	9: Kasteler Straße	9: Kasteler Straße	Kasteler Straße TM	8,51	29,75	1255	LOS_C	33,59	25,34	1
1-5	0-3600	10: Kasteler Straße	4: Str. de Republik	Kasteler Straße LT	0,00	0,30	105	LOS_C	0,00	0,00	1
1-5	0-3600	11: Biebricher Allee	8: Äppelallee	Biebricher Allee RT	51,55	82,85	2941	LOS_C	68,87	40,46	1
1-5	0-3600	38: CycLan	38: CycLan	Cyclist lane TM	1,59	10,94	288	LOS_C	32,72	29,17	1
1-5	0-3600	Average of all simulation runs - Intersection (Time interval 0-3600 s)			15,59	48,16	16900	LOS_C	38,28	28,29	1

Table 2: Averages of five node evaluation results for all vehicle routes

The node evaluation results of five simulation runs were collected and an average for every vehicle route was calculated. On Table 2 the final results for the morning peak hour (7:30 – 8:30) are shown. The vehicle routes were named after the starting link (street) and these suffixes:

TM – through movement

RT – right turn

LT – left turn

For each of these routes, queue lengths were tracked with the results being the average and maximum queue lengths for every route. The next parameter was the number of vehicles that entered and exited the node. Additionally, average vehicle delays and stop delays were tracked. These results were linked with the average number of stops a vehicle had to make. That data was then used to evaluate the LOS for every route. According to the level of service criterion for signalized intersections from HCM 2010 (Table 3), the LOS for every vehicle route was graded.

Table 3: Level of service criterion for signalized intersections (HCM 2010) [16]

Level of Service	Average Control Delay (seconds/vehicle)	General Description
A	≤10	Free Flow
B	>10 – 20	Stable Flow (slight delays)
C	>20 – 35	Stable flow (acceptable delays)
D	>35 – 55	Approaching unstable flow (tolerable delay, occasionally wait through more than one signal cycle before proceeding)
E	>55 – 80	Unstable flow (intolerable delay)
F[1]	>80	Forced flow (congested and queues fail to clear)

The simulation parameter VehDelay(avg), which shows the average delay per vehicle (seconds/vehicle) was compared to the values from the table. The summed up resulting LOS scheme can be seen on Figure 32.

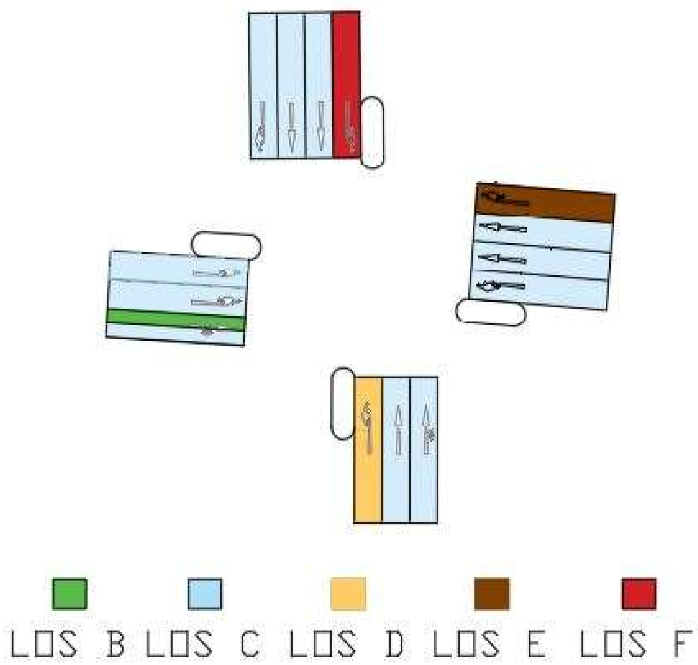


Figure 32: Vehicle LOS scheme from the simulation results

3.7.2. Cyclists

As for the cyclist simulation of the current situation model, only the advisory lane was tracked and had an average LOS C. The result is shown in the previous subchapter as the last entry (CycLane).

3.7.3. Pedestrians

The results of five simulation runs were turned into an average and this yielded four types of parameters for pedestrians: 1. journey time, 2. loss time, 3. relative loss time and 4.volume. Pedestrian routes were named with letters A – D and linked with areas that they connect. The results are shown on Tables 4 - 7.

Table 4: Pedestrian journey time results (Current situation)

PEDESTRIAN JOURNEY TIME (0-3600 s)				
From area	To area	Route	Measurement	Unit
1	3	A - B	67.3	[s]
3	1	B - A	47.2	[s]
11	4	B - C	41.8	[s]
4	11	C - B	53.4	[s]
12	13	C - D	43.2	[s]
13	12	D - C	52.6	[s]
5	10	D - A	38.9	[s]
10	5	A - D	57.3	[s]

Table 5: Pedestrian loss time results (Current situation)

PEDESTRIAN LOSS TIME (0-3600 s)				
From area	To area	Route	Measurement	Unit
1	3	A - B	41.1	[s]
3	1	B - A	43.7	[s]
11	4	B - C	43.5	[s]
4	11	C - B	43.7	[s]
12	13	C - D	43.7	[s]
13	12	D - C	31.2	[s]
5	10	D - A	43.6	[s]
10	5	A - D	34.1	[s]

Table 6: Pedestrian relative loss time results (Current situation)

PEDESTRIAN RELATIVE LOSS TIME (0-3600 s)				
From area	To area	Route	Measurement	Unit
1	3	A - B	0.5	[s]
3	1	B - A	0.4	[s]
11	4	B - C	0.4	[s]
4	11	C - B	0.5	[s]
12	13	C - D	0.5	[s]
13	12	D - C	0.5	[s]
5	10	D - A	0.4	[s]
10	5	A - D	0.6	[s]

Table 7: Pedestrian volume results (Current situation)

PEDESTRIAN VOLUME (0-3600 s)				
From area	To area	Route	Measurement	Unit
1	3	A - B	48	[ped/hour]
3	1	B - A	42	[ped/hour]
11	4	B - C	42	[ped/hour]
4	11	C - B	66	[ped/hour]
12	13	C - D	36	[ped/hour]
13	12	D - C	42	[ped/hour]
5	10	D - A	30	[ped/hour]
10	5	A - D	48	[ped/hour]

Additionally, the performance of the pedestrian network was tested. All of the tracked parameters and their explanations are shown on Table 8.

Table 8: Pedestrian network performance evaluation (Current situation)

PEDESTRIAN NETWORK PERFORMANCE EVALUATION		UNIT	EXPLANATION
SimRun	1		Simulation run
TimeInt	0-3600	[s]	Time interval
PedEnt(All)	384		Pedestrians (entered) = Number of pedestrians in the network
DensAvg(All)	0.01	[ped/m2]	Average pedestrian density = Ratio of pedestrians in the network to walkable areas
SpeedAvg(All)	1.69	[km/h]	Average pedestrian speed
FlowAvg(All)	0.01	[ped/m s]	Flow (average) = Product of current speed, averaged over all pedestrians and the current density
TravTmAvg(All)	51.35	[s]	Average travel time
StopsAvg(All)	0		Average number of stops per pedestrian
StopTmAvg(All)	0	[s]	Average stop time
NormSpeedAvg(All)	0.47		Ratio of actual speed over desired speed, averaged over pedestrians and time steps

Pedestrian level of service was evaluated using the average pedestrian density. The result was compared to the table values [13], where LOS A represents a free flowing pedestrian traffic, while LOS F represents congestions that results in walking difficulties (Table 9). With the average density of only 0.01 pedestrians per squared meter, this intersection fits in the LOS class A.

Table 9: Pedestrian level of service criterion [14]

Level of Service	Flow Rate *(pedestrian/minute/meter)*	Density *(pedestrian per squared meter)*
A	≤ 7	≤ 0.08
B	7 - 23	0.08 - 0.27
C	23 - 33	0.27 - 0.45
D	33 - 49	0.45 - 0.69
E	49 - 82	0.69 - 1.66
F	≥ 82	≥ 1.66

4. REMODELLING OF THE HERZOGSPLATZ

4.1. Design tasks

As pointed out in the introduction chapter, the main objective of the thesis was to propose a layout for the Herzogsplatz intersection, which will accommodate the CityBahn, as well as improve the level of service (LOS) for non-motorized transport modes. After analysing the current state of the intersection, the aim was to design a new layout, which would be the most beneficial in terms of solving the interaction of existing traffic modes with the addition of the CityBahn. For this task, planning data concerning the CityBahn and other geographical data was made available. The result of the redesign had to be a layout which would need to have the same measurable criterion, which would be evaluated and compared in search of concise answers to specific traffic planning questions.

4.2. Design methodology

RASt proposes a design flowchart with a detailed overview of the street space design procedure, which is shown on Figure 33. It´s goal is to ensure the most optimal design solution, which is derived from an iterative approach and multiple assessments and evaluations during the design process.

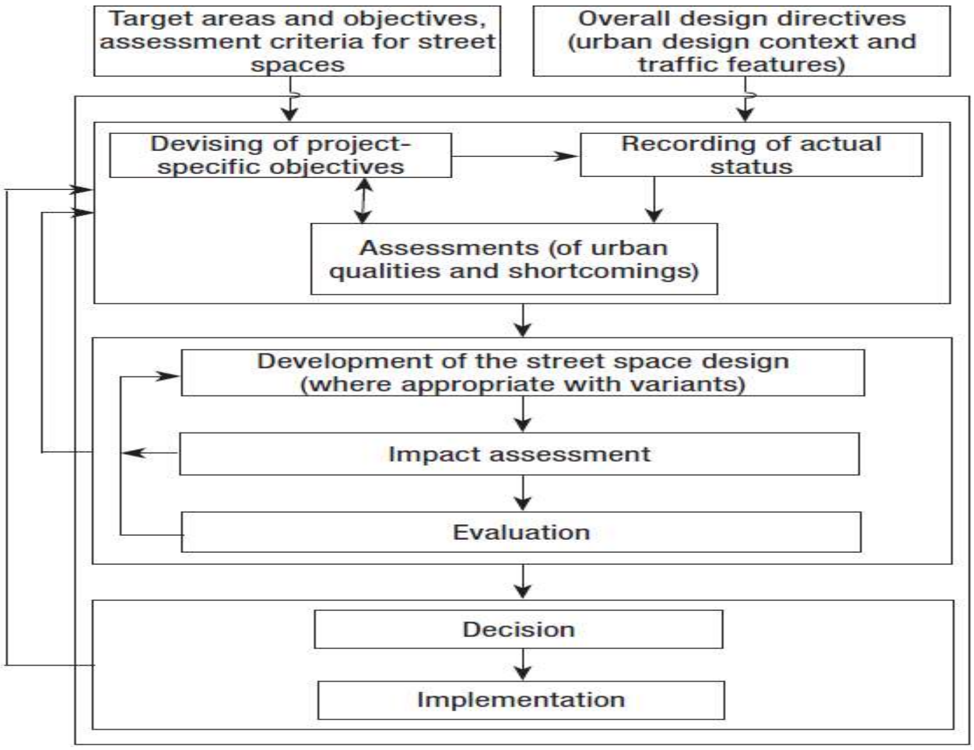


Figure 33: Street space design procedure [10]

Especially in urban areas, street space design has to take into account local space demands and available space related to adjacent buildings or other physical constrains. The need to balance space demands for motorized and non-motorized users influences the final width of the carriageway/footway, resulting in various trade-offs which the planner has to solve (Figure 34).

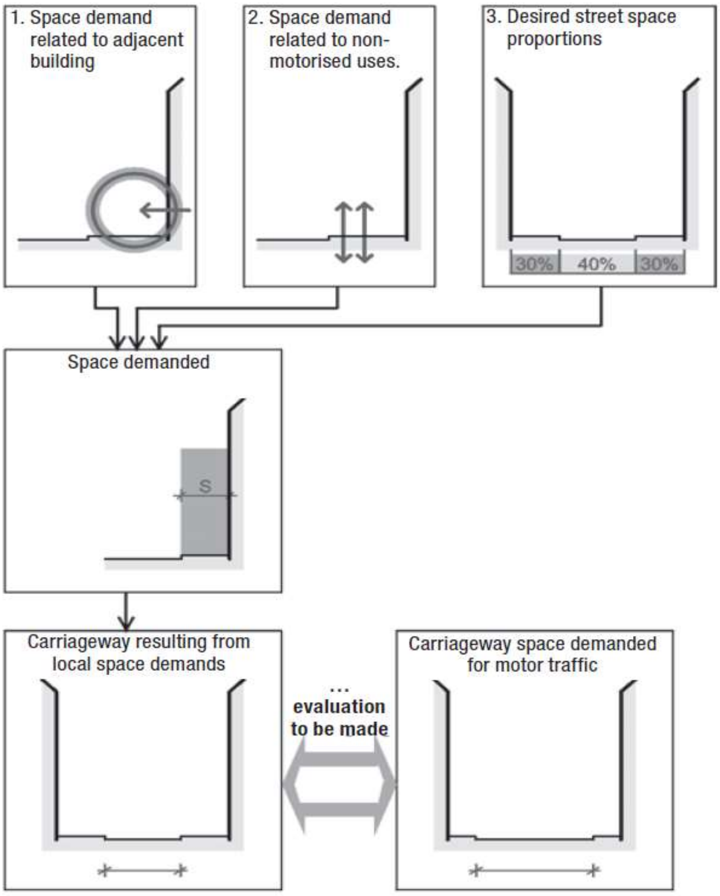


Figure 34: Balancing the space demands for motorized and non-motorized users [10]

Objectively, the process of designing urban street spaces should start from the edges and continue inwards. This presumption is based on three important factors:

- A space between the footway and the building facades should be allowed for various reasons (commercial uses, comfort space, etc.); i.e. important for Straße der Republik
- Reasonable space for pedestrians must be provided, sometimes in interaction with cyclists traffic (according to the situation)
- Footway widths must ensure ease and comfort for pedestrians, and the side of the street needs to be relative to the width of carriageway

According to RASt, the consensus is the ratio should be around 30:40:30. However, it is always a question of how appropriate such a ratio is, because different priorities result in different layouts depending on the needs in focus. Some of the priorities include:

- user and access-friendliness of the street space
- indicating crossing points of pedestrians and insuring central reservations (i.e. pedestrian islands) or at least reasonable visual contact with drivers (by inserting breaks between parking bays)
- layouts that force drivers to adjust their speed
- overall road safety
- traffic flow management
- cost/benefit studies etc.

4.3. Recommended solutions for typical design situations

According to RASt06, for each determined road classification there are recommended design solutions. These are depicted as a series of overview sheets from which the user can choose a preferable cross section. The sheets contain a step-by-step procedure with special consideration for constrains that are taken from design demands (Figure 35).

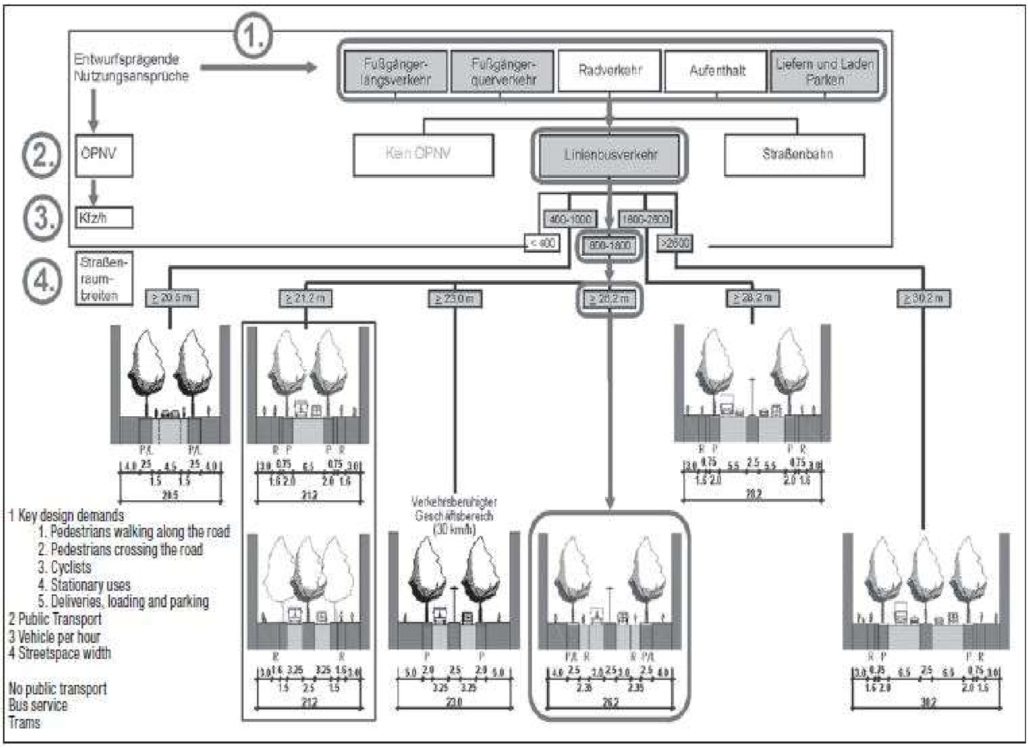


Figure 35: Step-by-step procedure for the selection of a recommended cross section [10]

The steps are as follows:

Step 1. Check if there are specific (unordinary) demands for pedestrian and cyclist traffic, as well as parking provision

Step 2. Define the demands of local public transport (choice between: no public transport, scheduled bus lines and/or trams)

Step 3. Define the volumes of motorized traffic (vehicles per hour) in the peak hour - may refer to current or forecasted numbers (depending on the purpose of the design)

Step 4. Check available or planned street space – for urban spaces usually the width between buildings

Design demands depend on the importance of the street for pedestrian and cycle traffic, public transport and vehicle traffic volume overall (vehicles per hour). Moreover, the user suits the recommended cross section depending on the available street width. The typical design situations cover the majority of practical design problems, but often need to be adjusted for number of lanes and other case specific factors. The specified street space widths from the cross sections indicate the minimum for applying the given cross section. If more space is available, then it should be assigned to pedestrians traffic or, where appropriate, cyclist traffic. However, if less space is available, a potential omission of a cross section element (i.e. parking bays) can be investigated. Reducing the dimension of any element is not appropriate and should be avoided altogether. Keeping all of this in mind, and following the before mentioned steps, these new cross sections were proposed (Figures 36-39).

4.4. Remodelled cross sections

Biebricher Allee

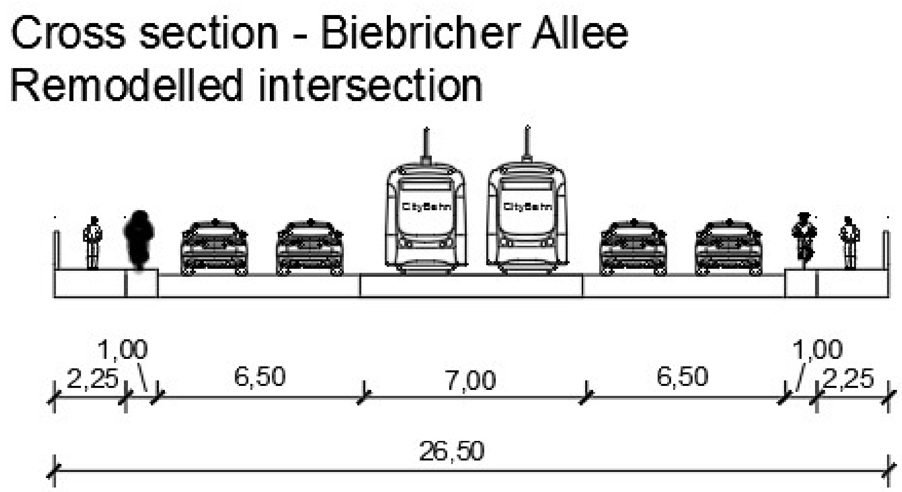


Figure 36: Cross section of the Biebricher Allee (remodelled intersection)

Kasteler Straße

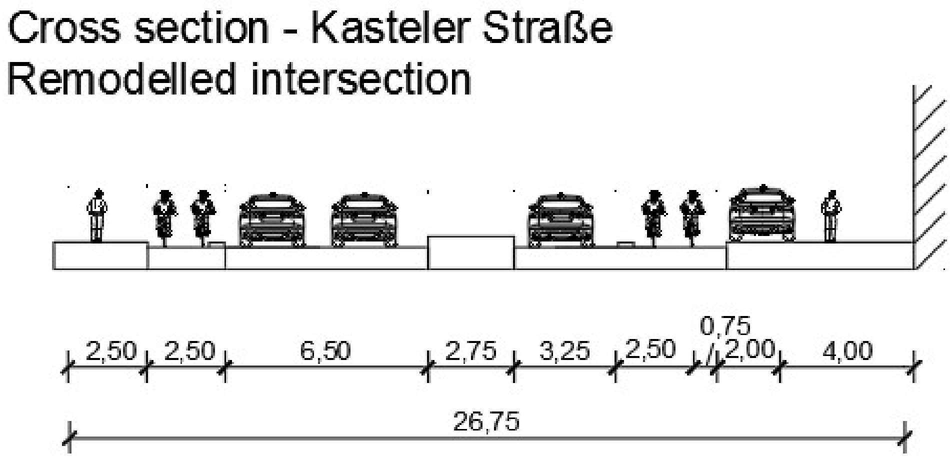


Figure 37: Cross section of the Kasteler Straße (remodelled intersection)

Straße der Republik

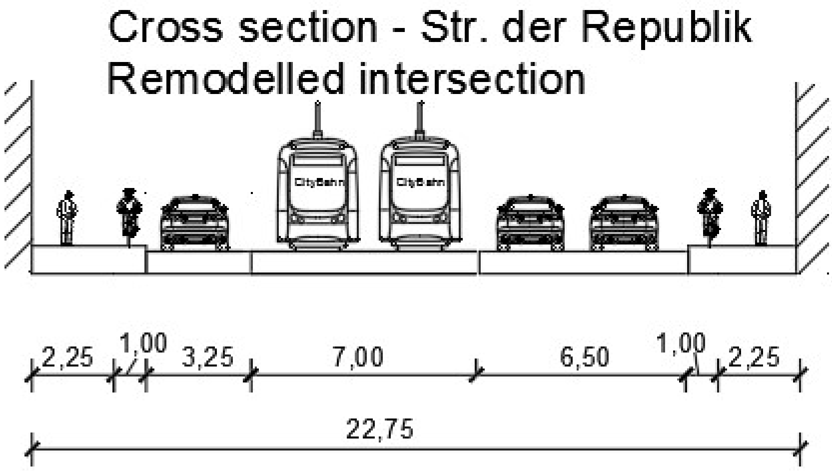


Figure 38: Cross section of the Straße der Republik (remodelled intersection)

Äppelallee

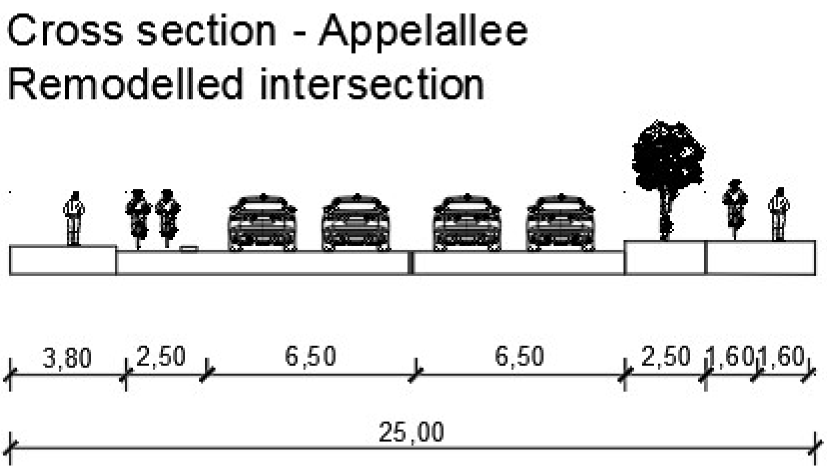


Figure 39: Cross section of the Äppelallee (remodelled intersection)

4.5. New layout – Protected intersection

After a detailed analysis of the intersection, a possible way to improve the conditions for non-motorized traffic was looked upon. According to ERA (2010) [9], the graph on Figure 40 shows a correlation between volume of motor vehicles and the operating speed of motorized vehicles on the desired road. Within the chart, in the areas I and II, the guidance of the cyclist traffic on the carriageway is justifiable. In the area III it's possible to separate cyclist traffic from motorized traffic out of safety reasons. All four streets that form the intersection are either on the border of the areas II and III or just inside the area III. Keeping in mind that the borders on the chart aren't strict, it's reasonable to suggest implementing the physical separation of the cyclist traffic to improve the overall safety of the intersection.

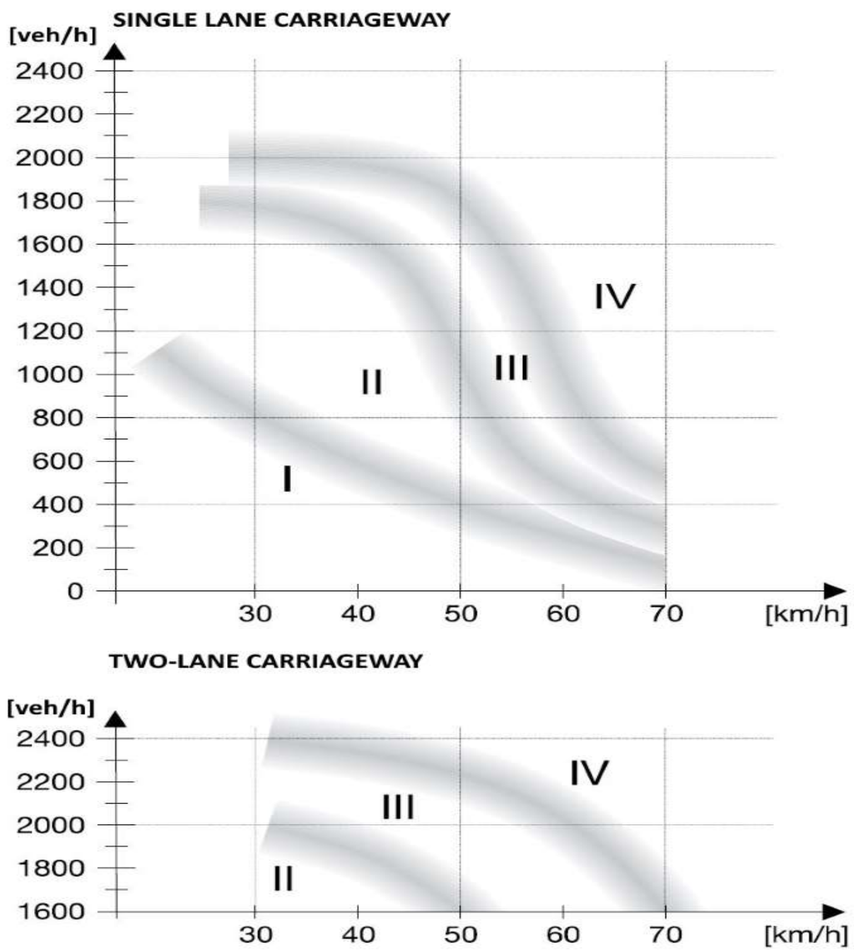


Figure 40: Cyclist facilities based on traffic load and operating speeds of motorized vehicles on single and two-lane carriageways on urban roads [9]

Based on the current state of the intersection, the choice for an improvement was to implement either separated cycle paths or cycle lanes. Because cycle paths tend to need more space and the lack of space is already an issue (i.e. Straße der Republik), the choice went to the cycle lanes. A special kind of cycle lane called protected cycle lane was the role model. More talk about the characteristics of these lanes is going to appear in the next subchapter.

4.5.1. Protected cycle lanes

As stated in RASt, cycle lanes on the carriageway are visually separated from vehicles by a solid broad line, which is 0.25 m wide. The dimensions of a cycle lane are given on Figure 41a and b.

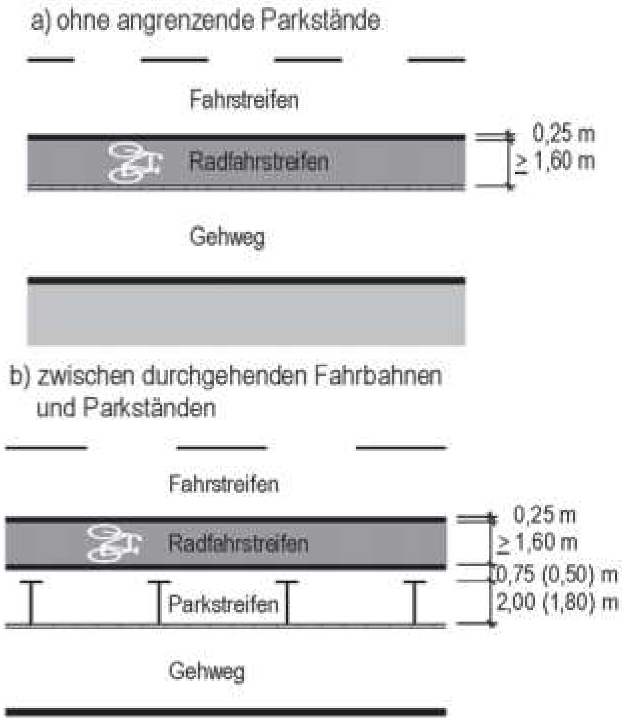


Figure 41: Dimensions of a cycle lane without (a) and with (b) and adjacent parking bay [10]

The protected cycle lane adopts these dimensions but uses a buffer space in place of the solid line. Curbs, and protective barriers can be installed and in that way cyclist are separated from the adjacent motorized traffic. This can be done either with an elevated cycle lane that is in the sidewalk level (Figure 42) or in the same level as the carriageway (Figure 43).

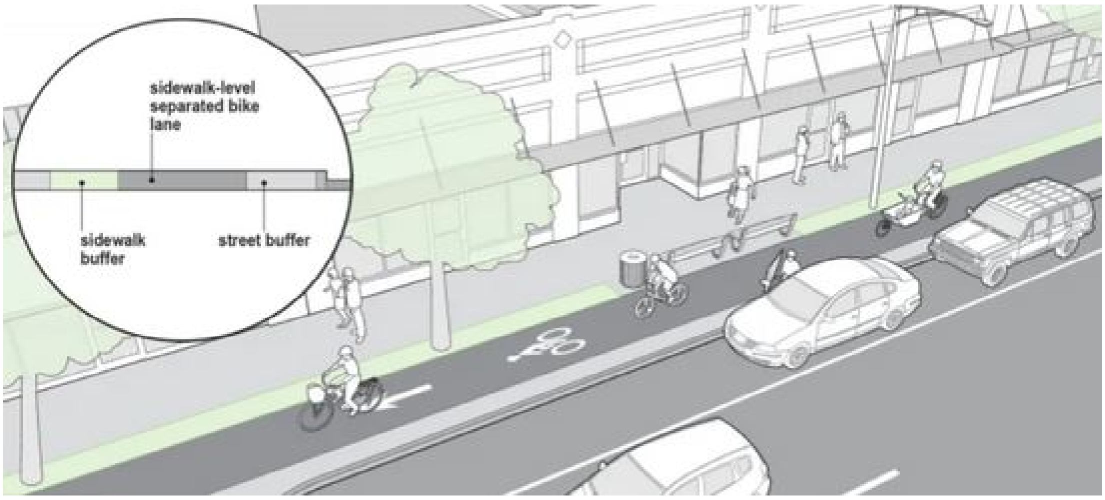


Figure 42: Sidewalk level protected cycle lane [8]

Figure 43: Protected cycle lane in the carriageway level [13]

A study from Portland, US [12] suggests that the implementation of protected bike lanes increased the number of bicycle rides and found out that 96% of the cyclist felt safer because of that change. The interference of 16 000 cyclists and nearly 20 000 vehicles was observed and not a single accident happened. Moreover, interviewed drivers stated that the protected lanes made traffic more predictable. All of these findings suggest that there are indeed large benefits of inserting barriers between motorized traffic and cyclist and that significant improvement can be achieved often with small and uncostly solutions. A solution such as on Figure 44 could possibly fit in the Kasteler Straße where there are parking bays adjacent to the advisory cycle lane.

Figure 44: Carriageway level protected cycle lane adjacent to a parking bay [12]

Other options (Figure 45) of protected lanes can also be considered and implemented depending on the available street space and the needs of the situation.

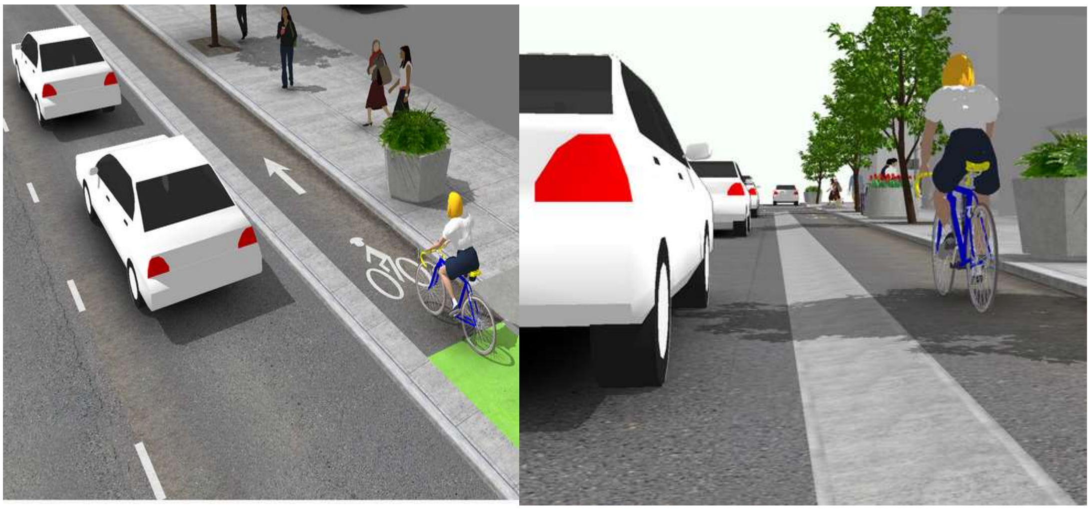


Figure 45: Examples of an elevated protected cyclist lane [12]

4.5.2. Characteristics of the protected intersection

The idea was to introduce a new layout which replaces the advisory lane with a protected separated lane and to introduce these lanes in the other streets to form a consistent solution for the intersection.

The proposed layout was inspired by the concept of a "protected intersection". A protected intersection is a road junction where cyclist and pedestrians are physically separated from motorized traffic. It´s design can consist of many elements that provide increased reaction time for drivers turning right and better visibility of crossing cyclists and pedestrians, which in turn raises the overall security of the intersection.

This proposal emphasizes the need to improve the level of service (LOS) for non-motorized traffic. A protected intersection would also significantly improve the safety of cyclists because of the physically separated lanes, which don´t allow contact with adjacent motorized traffic. From the comfort and convenience standpoint, using the cycling facilities would become more enjoyable and attractive, which moreover promotes cycling and should therefore result in a greater number of cyclists overall.

In regards to the design of the protected intersection, there are multiple features (Figure 46), which serve to create safe and comfortable conditions for cyclists. Not all of them need to be used in all situations, but they represent a typical layout of a protected intersection.

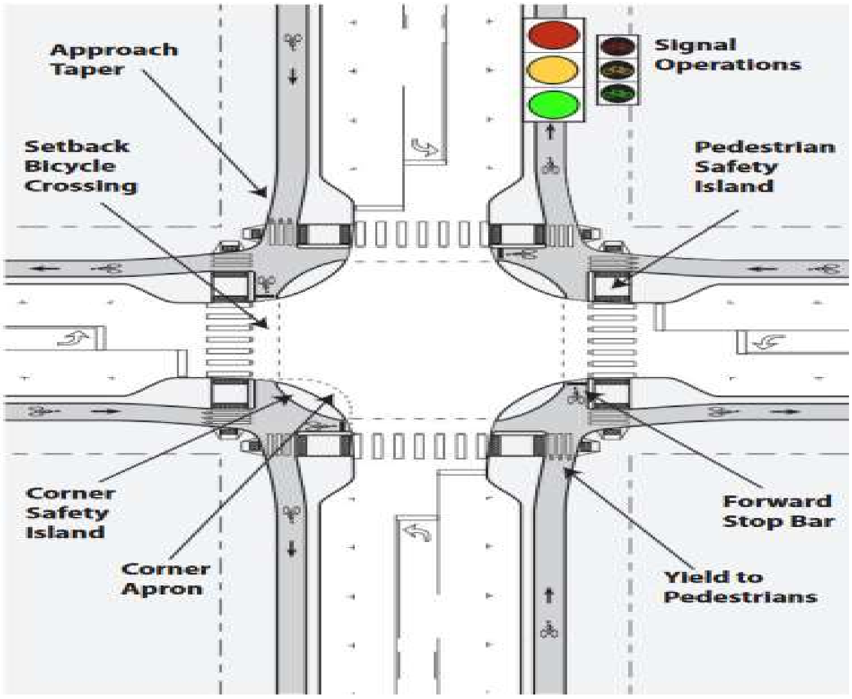


Figure 46: Key features of the protected intersection [17]

A special feature of the layout is the design of the corner safety island. If the design vehicle for the intersection entails a wide corner radius, problems with passenger cars could arise because of them turning at excessive speed. Because vehicle speed can directly be correlated with yielding reactions and probabilities of an accident, a wider corner radius is somewhat undesirable. However, if a wider corner radius can´t be avoided, a mountable corner apron (Figure 47) with a secondary radius should be included in the design.

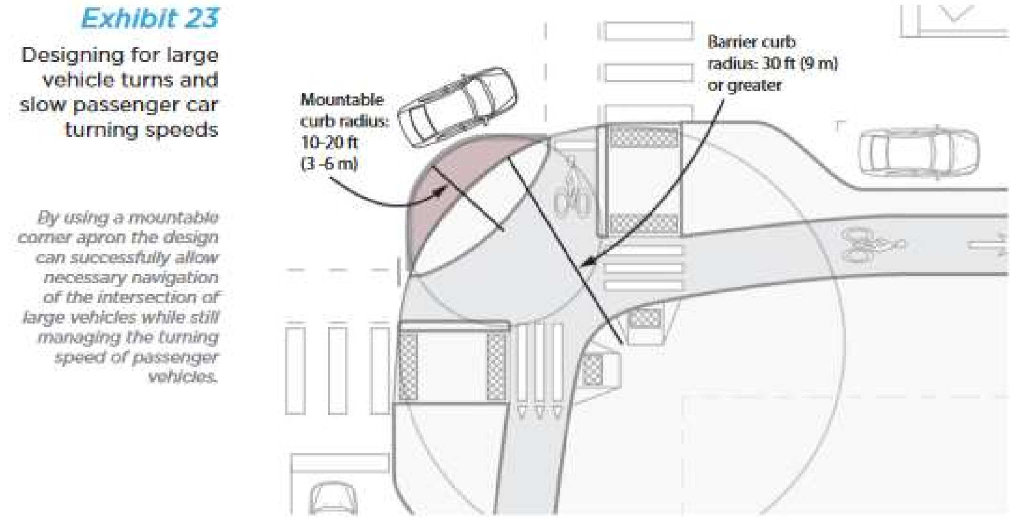


Figure 47: Design of the corner safety island featuring a mountable corner apron [17]

The apron should be visually different from both the roadway and the protective island (Figure 48). A different colour and material texture would further discourage passenger cars of making fast turns.

Figure 48: Example of a mountable corner apron [17]

Overall, the implementation of a protected intersection offers several benefits but also needs to answer multiple challenges. These are summarized by points of concern and shown on Figure 49.

Benefits	Challenges
Pedestrians	
Shortened roadway crossing distance. Slower driver speed reduce collision severity and increases yielding to crossing pedestrians.	Reliance on bicyclists yielding to pedestrians with right of way.
Safety	
Provide more reaction time for all users to detect and correct for mistakes due to lower vehicle speed.	May increase difficulties for individuals with vision disabilities due to the potential for pedestrian path deflection and challenges in detecting adjacent moving bicyclists.
Operations	
Shorter bicycle and pedestrian crossing distance created by the forward stop bar and pedestrian safety island allow these users to clear the intersection in less time.	If right-turn-on red is prohibited, it may negatively impact capacity. If exclusive bicycle signal phase or leading pedestrian/bicycle intervals are used, may negatively impact intersection capacity.
Space	
May not require additional right-of-way on streets configured with on-street parking and wide sidewalks. Many intersections could be reconfigured to be protected intersections within the existing footprint.	Certain signal phasing schemes may require an exclusive left and right turn lane, potentially increasing the physical size of the intersection. Achieving the desired crossing setback distance from the roadway may require right-of-way acquisition at corner locations.

Figure 49: Benefits and challenges of implementing a protected intersection [17]

The benefits all point to the enhanced safety of cyclists and pedestrians, which is achieved by shortening the roadway crossing distance, physical protection by the protective island and slowing down of the driver speed in the intersection. However, these benefits also result in some drawbacks, which are mainly connected to the possible lower capacity of the intersection as a result of the implemented measures. Moreover, phasing schemes have to be adjusted to accommodate the new arrangement of the intersection, bearing in mind the conflict points between motorized and non-motorized traffic.

4.6. Microscopic simulation of the protected intersection

The simulation of the layout was done with the same simulation parameters. Node evaluations were also used for the extraction of the intersection data (Figure 50). The protected intersection model featured more pedestrian areas because of the central and protective islands that are used in the layout. These new areas in the model are just schematically placed to illustrate the movement of cyclist through the intersection area. The real position of the elements can be seen in the attached drafts, where the layout of the protected intersection is depicted. Also, the tram lanes were drawn as four parallel links, two on which the trams travel (in the middle) and two elements on the left and right side, where there is no vehicle movement. These were inserted to depict the 7.0 meters, which is the clearance dimension for the two direction tram lane.

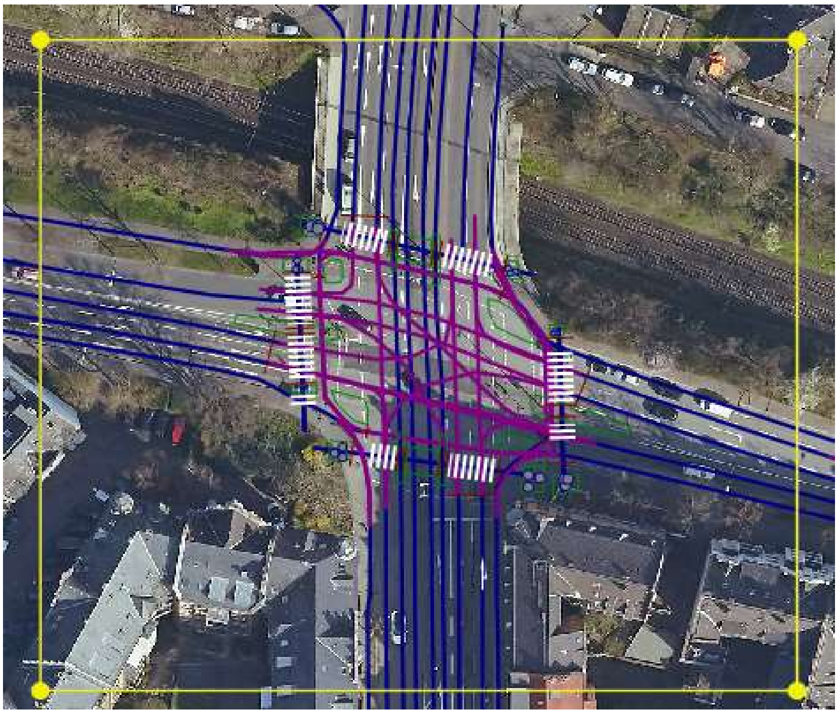


Figure 50: Evaluation node – Remodelled intersection

4.7. Simulation results

4.7.1. Vehicles

					QLen(avg) [m]	QLenMax [m]	Σ (Vehs)	VehDelay(avg) [s]	LOS(avg)	StopDelay(avg) [s]
1-5	0-3600	CityBahn N-S	CityBahn N-S	CityBahn N-S	0,00	0,00	6	0,00	LOS_A	0,00
1-5	0-3600	Äppelallee	Biebricher Allee	Äppelallee LT	106,40	143,60	378	124,32	LOS_F	102,53
1-5	0-3600	Str. de Republik	Kasteler Straße	Str. der Republik RT	1,92	38,41	26	24,99	LOS_C	17,49
1-5	0-3600	Str. de Republik	Äppelallee	Str. der Republik LT	0,02	2,64	258	2,92	LOS_A	1,28
1-5	0-3600	CityBahn S-N	CityBahn S-N	CityBahn S-N	0,00	0,00	6	0,00	LOS_A	0,00
1-5	0-3600	Kasteler Straße	Biebricher Allee	Kasteler Straße RT	0,85	12,69	28	33,92	LOS_C	31,01
1-5	0-3600	Kasteler Straße	Str. de Republik	Kasteler Straße LT	0,75	8,60	28	34,07	LOS_C	30,83
1-5	0-3600	Biebricher Allee	Str. de Republik	Biebricher Allee TM	0,00	0,00	20	0,59	LOS_A	0,06
1-5	0-3600	Biebricher Allee	Äppelallee	Biebricher Allee LT	6,26	34,47	122	32,60	LOS_C	25,11
1-5	0-3600	Äppelallee	Str. de Republik	Äppelallee RT	6,26	34,47	24	36,01	LOS_C	26,41
1-5	0-3600	Äppelallee	Kasteler Straße	Äppelallee TM	118,46	186,71	662	49,84	LOS_D	36,88
1-5	0-3600	Kasteler Straße	Äppelallee	Kasteler Straße TM	116,85	177,41	142	51,89	LOS_D	37,78
1-5	0-3600	Str. de Republik	Biebricher Allee	Str. der Republik TM	0,02	8,45	26	4,20	LOS_A	3,64
1-5	0-3600	Biebricher Allee	Kasteler Straße	Biebricher Allee LT	1,65	11,15	36	56,43	LOS_D	49,96
1-5	0-3600	Motorized traffic - Average of all simulation runs - Intersection (Time interval 0-3600 s)			25,67	47,04	3260	32,27	LOS_C	25,93

Table 10: Simulation results for vehicle traffic

The node evaluation results of five simulation runs were collected and an average for every vehicle route was calculated. Except cars, the evaluation covered also the two direction tram lanes (shown in orange colour). On Table 10, the final results for the morning peak hour (7:30 – 8:30) are shown. The vehicle routes were named after the starting link (street) and these suffixes:

TM – through movement

RT – right turn

LT – left turn

N-S – direction north to south

S-N – direction south to north

The same parameters as in chapter 3.7. were tracked.

4.7.2. Cyclists

The same parameters for vehicles were also tracked for cyclists (Table 11).

The cyclist routes were named with these suffixes:

N – north

E – east

S – south

W – west

The starting link is named after the side of world from which the cyclist is entering the evaluation node, i.e. the route "Cyclist S-N" would lead to a through movement of the cyclist starting from Straße der Republik and continuing to the Biebricher Allee. With the same logic, a right turn by a cyclist entering through Straße der Republik and going to Kasteler Straße would be named „Cyclist S-E".

From the results we can see that the intersection has an average cyclist LOS class C.

					QLen(avg) [m]	QLenMax [m]	Σ (Cyclists)	CycDelay(avg) [s]	LOS(avg)	StopDelay(avg) [s]
1-5	0-3600	Cyclist S	Cyclist E	Cyclist S-E	0,85	12,69	28	33,92	LOS_D	31,01
1-5	0-3600	Cyclist S	Cyclist N	Cyclist S-N	0,75	8,60	28	34,07	LOS_D	30,83
1-5	0-3600	Cyclist S	Cyclist W	Cyclist S-W	0,00	0,00	20	0,59	LOS_A	0,06
1-5	0-3600	Cyclist N	Cyclist W	Cyclist N-W	0,41	13,06	26	4,20	LOS_A	3,64
1-5	0-3600	Cyclist N	Cyclist E	Cyclist N-E	0,93	9,28	36	56,43	LOS_E	49,96
1-5	0-3600	Cyclist N	Cyclist S	Cyclist N-S	0,59	5,27	32	20,38	LOS_C	18,06
1-5	0-3600	Cyclist E	Cyclist N	Cyclist E-N	1,31	13,58	20	35,71	LOS_D	32,78
1-5	0-3600	Cyclist E	Cyclist S	Cyclist E-S	0,00	0,00	22	6,83	LOS_B	6,21
1-5	0-3600	Cyclist E	Cyclist W	Cyclist E-W	1,06	20,49	46	28,23	LOS_D	24,37
1-5	0-3600	Cyclist W	Cyclist E	Cyclist W-E	0,00	0,00	32	4,19	LOS_A	3,11
1-5	0-3600	Cyclist W	Cyclist N	Cyclist W-N	0,00	0,00	30	19,04	LOS_C	16,50
1-5	0-3600	Cyclist W	Cyclist S	Cyclist W-S	1,30	0,00	30	4,96	LOS_A	4,14
1-5	**0-3600**	**Cyclist traffic - Average of all simulation runs - Intersection (Time interval 0-3600 s)**			**0,60**	**6,91**	**350**	**20,71**	**LOS_C**	**18,39**

Table 11: Simulation results for cyclists

4.7.3. Pedestrians

The same process as in chapter 3.7.3. was repeated. The results of the simulation are given in the Tables 12-15.

Table 12: Pedestrian journey time results (remodelled intersection)

PEDESTRIAN JOURNEY TIME (0-3600 s)				
From area	To area	Route	Measurement	Unit
1	3	A - B	67,0	[s]
3	1	B - A	54,1	[s]
11	4	B - C	34,2	[s]
4	11	C - B	51,6	[s]
12	13	C - D	38,4	[s]
13	12	D - C	53,2	[s]
5	10	D - A	20,2	[s]
10	5	A - D	43,7	[s]

Table 13: Pedestrian loss time results (remodelled intersection)

PEDESTRIAN LOSS TIME (0-3600 s)				
From area	To area	Route	Measurement	Unit
1	3	A - B	38,9	[s]
3	1	B - A	28,0	[s]
11	4	B - C	13,7	[s]
4	11	C - B	29,7	[s]
12	13	C - D	14,3	[s]
13	12	D - C	27,3	[s]
5	10	D - A	5,4	[s]
10	5	A - D	24,6	[s]

Table 14: Pedestrian relative loss time results (remodelled intersection)

PEDESTRIAN RELATIVE LOSS TIME (0-3600 s)				
From area	To area	Route	Measurement	Unit
1	3	A - B	0,5	[s]
3	1	B - A	0,5	[s]
11	4	B - C	0,4	[s]
4	11	C - B	0,5	[s]
12	13	C - D	0,3	[s]
13	12	D - C	0,5	[s]
5	10	D - A	0,2	[s]
10	5	A - D	0,5	[s]

Table 15: Pedestrian volume results (remodelled intersection)

PEDESTRIAN VOLUME (0-3600 s)				
From area	To area	Route	Measurement	Unit
1	3	A - B	42	[ped/hour]
3	1	B - A	42	[ped/hour]
11	4	B - C	42	[ped/hour]
4	11	C - B	72	[ped/hour]
12	13	C - D	36	[ped/hour]
13	12	D - C	42	[ped/hour]
5	10	D - A	40	[ped/hour]
10	5	A - D	48	[ped/hour]

Additionally, the pedestrian network performance for the remodelled layout was evaluated. The results can be seen on Table 16.

Table 16: Pedestrian network performance evaluation (remodelled intersection)

PEDESTRIAN NETWORK		UNIT	EXPLANATION
SimRun	1		Simulation run
TimeInt	0-3600	[s]	Time interval
PedEnt(All)	384		Pedestrians (entered) = Number of pedestrians in the network
DensAvg(All)	0,01	[ped/m2]	Average pedestrian density = Ratio of pedestrians in the network to walkable areas
SpeedAvg(All)	1,77	[km/h]	Average pedestrian speed
FlowAvg(All)	0,01	[ped/m s]	Flow (average) = Product of current speed, averaged over all pedestrians and the current density
TravTmAvg(All)	46,78	[s]	Average travel time
StopsAvg(All)	0		Average number of stops per pedestrian
StopTmAvg(All)	0	[s]	Average stop time
NormSpeedAvg(All)	0,49		Ratio of actual speed over desired speed, averaged over pedestrians and time steps

With the average pedestrian density of only 0.01 pedestrians per squared meter, this intersection fits in the LOS class A.

5. COMPARATIVE ASSESMENT

5.1. Development of a multiple criterion assessment procedure

After obtaining the results, it was important to come up with a multiple criterion assessment procedure that would display them in a concise and comprehensible way.

The six chosen criterion are:

- functionality criterion
- urban space criterion
- traffic criterion
- traffic safety criterion
- level of service criterion
- environmental criterion

In the evaluation process, a cross-modal approach was taken. The aim of the comparison was to answer some questions that also appeared throughout the whole design process:

1. What kind of functionality will the new layout have if it hinders the amount of lanes for motorized traffic?
2. What is the future urban development plan for the Biebrich district and the city of Wiesbaden?
3. What can be done to improve the conditions for the most vulnerable traffic participants (cyclists and pedestrians)?
4. Which advantages/drawbacks will the implementation of the CityBahn have?
5. Will the long term benefits outweigh some of the short term problems?

5.2. Comparison: Current situation vs. Remodelled intersection

The current situation was compared with the remodelled layout, side to side for each of the criteria. The results of this evaluation are summarized and presented with an evaluation matrix for the intersection.

5.2.1. Functionality criterion

The current functionality of the intersection in terms of the role in the network is relatively good (Table 17). However, the intersection in the remodelled would open up better possibilities for public transport and non-motorized traffic. At the same time, that would produce kind of a drawback for the functionality of vehicle traffic, which is not that bad in itself but has to be taken into consideration. The overall assessment is that the role of the intersection would stay roughly the same.

Table 17: Functional criterion

	CURRENT SITUATION	REMODELLED INTERSECTION
1 - Role of the intersection	4/5	4/5
FUNCTIONAL CRITERON:	4/5	4/5

5.2.2. Urban space criterion

The current influence on the adjacent urban space is not negative but it could offer many potential possibilities (Table 18). With the implementation of the CityBahn, more pedestrians could be expected in the vicinity of the intersection, depending on where the tram stops are located. The protected intersection would definitely attract more cyclists, which would surely benefit businesses along the Straße der Republik and the Biebrich area. Moreover, the buffer zone between cyclists and motorized traffic could be decorated with greening, which would overall be more pleasant for users. The overall assessment is that the urban space criterion is significantly in favour of the remodelled intersection.

Table 18: Urban space criterion

	CURRENT SITUATION	REMODELLED INTERSECTION
2 - Influence on the adjacent urban space	3/5	5/5
URBAN SPACE CRITERON:	3/5	5/5

5.2.3. Traffic loads criterion

In the current situation, the traffic loads of motorized traffic are relatively high (Table 19). The remodelled intersection was graded better in this regard because the design is aimed to ensure better possibilities for non-motorized traffic, as well as give room to the public transport. This would in turn, theoretically inspire more vehicle users to switch to alternative transport modes and reduce the traffic loads of motorized traffic. As for the non-motorized traffic, the expectation is that the loads are going to slightly increase in time, but the intersection has enough capacity to ensure a decent cyclist and pedestrian level of service. The overall assessment is that the traffic load criterion is a bit more favourable for the remodelled intersection.

Table 19: Traffic loads criterion

	CURRENT SITUATION	REMODELLED INTERSECTION
3A - Traffic loads of motorized traffic	3/5	4/5
3B - Traffic loads of non-motorized traffic	3/5	3/5
TRAFFIC LOADS CRITERON:	6/10	7/10

5.2.4. Traffic safety criterion

The traffic safety in the current situation is not negative but could be improved (Table 20). Motorized traffic would definitely be a bit slowed down in the remodelled intersection and the fewer amount of car lanes is also beneficial. As for non-motorized traffic, the current layout does not really support a great cyclist infrastructure and also leaves some possibilities for the improvement of pedestrian safety. The protected intersection is exactly aimed at that cause and offers a great and cheap solution. The overall assessment is that the traffic safety would significantly improve in the remodelled intersection.

Table 20: Traffic safety criterion

	CURRENT SITUATION	REMODELLED INTERSECTION
4A - Traffic safety of motorized traffic	3/5	3/5
4B - Traffic safety of cyclists	3/5	5/5
4C - Traffic safety of pedestrians	3/5	4/5
TRAFFIC SAFETY CRITERON:	9/15	11/15

5.2.5. Level of service criterion

The current level of service for vehicles is not ideal, but given the role of this intersection and the high traffic loads, the vehicle LOS is tolerable (Table 21). However, in the remodelled intersection, one of the biggest trade-offs is that the vehicle LOS would drop significantly and could lead to large congestions in the peak hour. This could then have a bad effect on the adjacent intersections, which could overload the existing infrastructure. Some of the possible measures to minimise that effect will be discussed in the next subchapters.

Table 21: Level of service criterion

	CURRENT SITUATION	REMODELLED INTERSECTION
5A - LOS for vehicles	3/5	2/5
5B - LOS for cyclists	3/5	5/5
5C - LOS for pedestrians	3/5	5/5
LEVEL OF SERVICE CRITERON:	10/15	13/15

5.2.6. Environmental criterion

The emissions of air pollutants because of the large amounts of motorized traffic inside the urban areas is a big problem not only for Wiesbaden, but in the whole world. Intersections like Herzogsplatz, with a relative high amount of motorized traffic have large emissions of air pollution because of more frequent stops and longer waiting times. With the promotion for a switch to public transport and cycling/walking, some of that negative output would be reduced. The addition of the CityBahn as an alternative option for transport is really promising in terms of the air pollution reduction so the remodelled intersection got a significantly better grade (Table 22)

As for traffic noise, the reduction of vehicle number will be beneficial. In comparison to the noise output from cars, the CityBahn is very silent and is better suitable for residential and business spaces. Because all of these reasons, the remodelled intersection has a significantly better grade.

Table 22: Environmental criterion

	CURRENT SITUATION	REMODELLED INTERSECTION
6A - Emissions of air pollutants	2/5	4/5
6B - Traffic noise	2/5	4/5
ENVIRONMENTAL CRITERON:	4/10	8/10

5.2.7. Evaluation matrix

The evaluation matrix, which is shown on Table 23, is a cross-modal assessment which summarizes the six criteria which were described earlier. For each criteria and subcriteria, a number of points from 1 to 5 was awarded to the current situation layout and to the remodelled intersection. The sum of all grades was the final number of points, which was then compared. Out of the maximum 60 points, the remodelled intersection got 47 points in comparison to the 35 points for the current layout. Moreover, possible improvements in five of the six criteria were found, which explains the bigger difference in the final number of points.

:

Table 23: Evaluation matrix – Summary of all six criteria

Nr.	MAIN CRITERION	SUB-CRITERION	COMPARATIVE ASSESMENT	
			CURRENT SITUATION (points/max. points)	REMODELLED INTERSECTION (points/max. points)
1	FUNCTIONAL CRITERON	1 - Role of the intersection	4/5	4/5
2	URBAN SPACE CRITERON	2 - Influence on the adjacent urban space	3/5	5/5
3	TRAFFIC LOADS CRITERON	3A - Traffic loads of motorized traffic 3B - Traffic loads of non-motorized traffic	6/10	7/10
4	TRAFFIC SAFETY CRITERON	4A - Traffic safety of motorized traffic 4B - Traffic safety of cyclists 4C - Traffic safety of pedestrians	9/15	11/15
5	LEVEL OF SERVICE CRITERON	5A - LOS for vehicles 5B - LOS for cyclists 5C - LOS for pedestrians	9/15	12/15
6	ENVIRONMENTAL CRITERON	6A - Emissions of air pollutants 6B - Traffic noise	4/10	8/10
TOTAL NUMBER OF POINTS:			35/60	47/60

6. FINAL ASSESEMENT AND DISCUSSION

6.1. Final assessment and reasoning

After all results were summarized and compared through various points of concern, a final assessment had to be done to articulate the important findings, which led to some conclusions. The overall assessment is substantially in favour of the remodelled intersection, with the reasons elaborated in the fifth chapter. The implementation of the new layout would fit into the demands of the future sustainability but the whole aspect of this project has to be considered. This certainly opens a discussion, with many possible routes to achieve the overall aims that were set.

6.2. Discussion

Because traffic management is such a broad field of research, which deals with complex problems, often there are many conclusions to a problem, which cannot be seen on the surface. In this subchapter, some of the questions from the beginning of the thesis are going to be discussed about.

The subject of this thesis deals with multi modal traffic in an urban junction of main streets, where a high amount of traffic is present. The interaction between motorized and non-motorized traffic and the inclusion of the CityBahn made the future layout design a challenging task. Based on the fact that the city of Wiesbaden wants a better quality of life for its citizens, the switch to sustainable traffic modes is largely seen as a good idea. However, the CityBahn project has very polarising opinions, which is not unusual given the scale of the investment and the complexity of the project. These kind of infrastructural projects should always rest on the dialogue between the direct users of the intersection (citizens), and the decision makers (authorities).

The discussion points of this thesis were the result of the redesign process, which was done in accordance to the German guidelines. The fulfilment of the main aims of the thesis had to result in a number of trade-offs and the solutions that were found are in no way the only right solution for the given problems. The design process offers a lot of freedom within the boundaries of the guidelines and according to the given conditions, one concept was prioritised. The protected intersection, as a fairly new practical concept was chosen because it brings an innovation and fits the demands of the thesis well. The research about these kind of intersections gave insight into many positive experiences from successful implementations.

The microsimulation results, which were extracted with the help of VISSIM are also a point of discussion. Because the models are only models, the results have to be taken "with a grain of salt", meaning that VISSIM is only a tool to simulate complex problems and analytically assess the input from the user. In contrast of the analytical evaluation where the software gives as an output, the discussion always lies in the logical thought processes that a traffic and mobility planner has to use to interpret the results.

7. CONCLUSION

The topic of this thesis was the optimisation proposal for an inner city intersection Herzogsplatz, Wiesbaden. As a key measure of the city of Wiesbaden, the increase of the modal split in areas of public transport and non-motorized traffic (pedestrians and cyclists) is being prioritised and supported with a broad set of measures. One of the core measures is the planning of the future light rail infrastructure in Wiesbaden (CityBahn), which entails the need to completely redesign large parts of the affected streets. One focal point of that challenging task is the Herzogsplatz intersection.

The objective of this thesis was to come up with an optimisation/design proposal for a new layout of the intersection with special considerations for public transport, pedestrian and cyclist traffic. The aims were to increase the level of service for non-motorized traffic, while implementing the tram traffic and still keeping the functionality for the motorized traffic. This approach resulted in various trade-offs, which needed to be assessed. The task was to do an overall traffic analysis of current state of the intersection, which would serve as a background for redesign ideas. Consulting the German guidelines, the design of the new layout was carried out. The inputs were planning data concerning the CityBahn, measured traffic speed and volumes and aerial images, which all served the creation of two microsimulation models. The models, which were done in the software VISSIM yielded results that were compared with an cross-modal aspect. An evaluation matrix gave insight into the benefits/drawbacks brought by the new layout, which was inspired by the protected intersection concept. The findings of this thesis were, that it's very hard to balance the needs of motorized and non-motorized traffic in this intersection, but sustainable mobility projects like the CityBahn definitely offer a path that is not simple, but can result in many benefits. With the protected intersection design, an improvement of the cyclist infrastructure was stressed and should in future results with a higher amount of cyclists. The overall safety of pedestrians and cyclist was improved, which is always a welcoming aspect. The main drawbacks that the new layout caused were that some vehicle routes have shown the decrease of LOS, which was expected. With the same traffic loads as today, the intersection would have larger queues in the peak hour. Potential solutions with the traffic signals schemes should be investigated to cope with that. The problems that could arise, should be also viewed from an macroscopic standpoint, with the idea that the solutions in adjacent intersections could decrease the traffic burden on the Herzogsplatz. Moreover, the implementation of the CityBahn should result in the switch to using public transport, which would in the long run decrease some percentage of the traffic loads. The conclusion of the thesis is that the protected intersection is a feasible option for this case study. The fulfilment of the main aims of the thesis had to result in a number of trade-offs but the new layout will keep functionality. With the inclusion of the tram traffic, the urban potential of the area rises significantly and this aspect puts Wiesbaden in step with other modern cities in Europe.

In conclusion, the long-term advantages outweigh some of the short-term disadvantages and these kind of projects/interventions should be supported, as they are very beneficial for the community.

References

[1] Wiesbaden 2030+, Integriertes Stadtentwicklungskonzept https://www.wiesbaden2030.de/sites/default/files/downloads/integriertes_stadtentwicklungskonzept_wiesbaden_2030_online_0.pdf , accessed on 15.6.2019

[2] https://www.german-sustainable-mobility.de/wp-content/uploads/2014/10/Imagebroschuere_GPSM_Okt_20141.pdf , accessed on 13.5.2019

[3] https://www.openstreetmap.org , accessed on 14.5.2019

[4] https://geoportal.wiesbaden.de/kartenwerk/application/luftbilder, accessed on 15.5.2019

[5] https://www1.wiesbaden.de/microsites/radbuero/radinfrastruktur/grundnetz-2020.php , accessed on 13.5.2019

[6] https://www.echo-online.de/lokales/rhein-main/city-bahn-neue-variante-der-streckenfuhrung-nimmt-vorschlage-der-wiesbadener-burger-auf_18651378# , accessed on 1.6.2019

[7] https://www.citybahn-verbindet.de/die-vision/ , accessed on 1.6.2019

[8] https://usa.streetsblog.org/2018/09/21/key-street-design-guide-to-finally-include-protected-bike-lanes/ , accessed on 17.10.2019

[9] ERA - Empfehlungen für Radverkehrsanlagen [FGSV-Nr. 284], Forschungsgesellschaft für Straßen- und Verkehrswesen (FGSV), Köln, 2010.

[10] Richtlinien für die Anlage von Stadtstraßen: RASt - Edition 2006 / Translation 2012: Englische Übersetzung (PDF), Forschungsgesellschaft für Straßen- und Verkehrswesen (FGSV), Köln, 2012.

[11] Barceló, J. R. Hoyos et al., "Microscopic traffic simulation for ATT systems analysis a parallel computing version", 1998.

[12] https://nacto.org/publication/urban-bikeway-design-guide/cycle-tracks/one-way-protected-cycle-tracks/, accesed on 17.10.2019

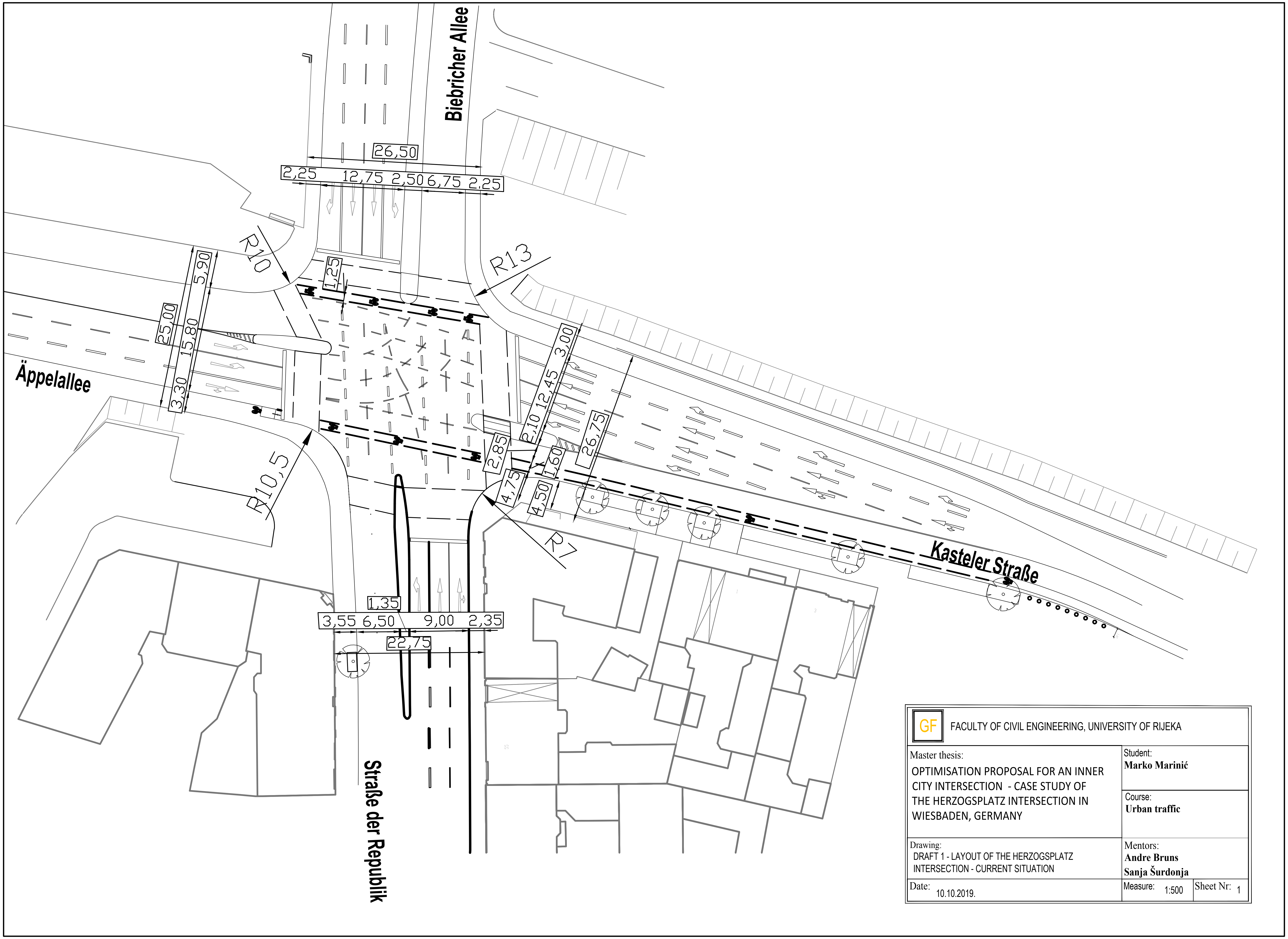
[13]https://www.secondwavemedia.com/concentrate/features/protectedbikelanesannarbor0290.aspx, accesed on 17.10.2019

[14] J.J. Fruin, "Pedestrian planning and design", Metropolitan Association of Urban Designers and Environmental Planners, 1971.

[15] PTV VISSIM 5.30 – 05 User manual , PTV AG, Karlsruhe, 2011.

[16] Manual, H.C.: HCM 2010. Transportation Research Board, National Research Council, Washington, DC 2010.

[17] Presentation - Evolution of the Protected intersection, Alta planning+design, 2015.



GF FACULTY OF CIVIL ENGINEERING, UNIVERSITY OF RIJEKA

Master thesis:
OPTIMISATION PROPOSAL FOR AN INNER CITY INTERSECTION - CASE STUDY OF THE HERZOGSPLATZ INTERSECTION IN WIESBADEN, GERMANY

Student: Marko Marinić

Course: Urban traffic

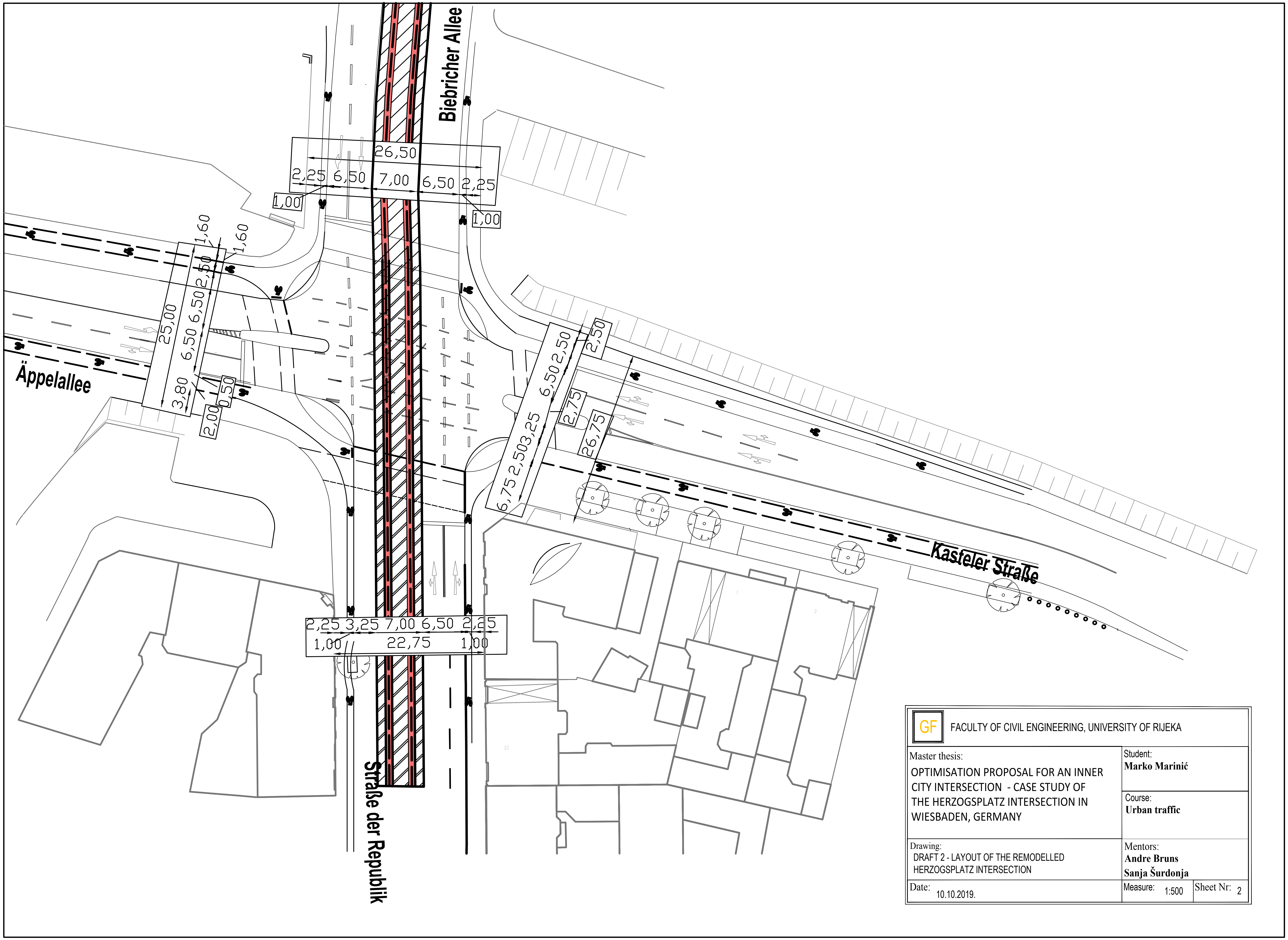
Drawing:
DRAFT 1 - LAYOUT OF THE HERZOGSPLATZ INTERSECTION - CURRENT SITUATION

Mentors:
Andre Bruns
Sanja Šurdonja

Date: 10.10.2019.

Measure: 1:500

Sheet Nr: 1



GF FACULTY OF CIVIL ENGINEERING, UNIVERSITY OF RIJEKA

Master thesis: OPTIMISATION PROPOSAL FOR AN INNER CITY INTERSECTION - CASE STUDY OF THE HERZOGSPLATZ INTERSECTION IN WIESBADEN, GERMANY	Student: **Marko Marinić**
	Course: **Urban traffic**
Drawing: DRAFT 2 - LAYOUT OF THE REMODELLED HERZOGSPLATZ INTERSECTION	Mentors: **Andre Bruns** **Sanja Šurdonja**
Date: 10.10.2019.	Measure: 1:500 — Sheet Nr: 2