Dynamic Traffic Management System Concept For Messe Augsburg

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Abstract

Big national and international events —such as afa (Augsburger Frühjahrsausstellung) and GrindTec (International Trade Fair for Grinding Technology) — in Messe Augsburg result in high congestion levels, as induced traffic to Messe parking lots overloads the Messe intersection and spread into B17 Federal highway, which implies a need for modifications to the current traffic management system. This thesis tends to evaluate different traffic management strategies —including modifications to payment method at parking lots, travel demand management, and rerouting Messe visitors to an alternative route— based on their efficiency in reducing the average queue lengths.

To test the mentioned strategies, VISSIM traffic micro-simulation model of the study area was developed, and various strategies were formulated. The results showed decreasing the dwell time at the parking lots entrance for payment was associated with lower queue lengths. Moreover, a 30% reduction in Messe travels from B17 north-south cut the average queues effectively. Also, guiding the vehicles on B17 south-north heading to Messe parking lots through Forschungsallee smoothed the traffic flow on the road network around Messe, but diverted the traffic jam to the southern part of the network, which should be fixed via customizing signal program.

Finally, a basic concept for a rule-based dynamic traffic management at Messe Augsburg was developed. Please notice that this study was carried out about morning traffic on a Messe day.

Keywords: Event traffic management, traffic microsimulation, rule-based traffic management

Acknowledgment

Throughout the working on this project, I have received a great deal of support and assistance.

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Besides, I would like to thank my family for encouraging me. You are always there for me.

I tended to apply the “Agile Project Management” concept throughout my Master’s Thesis (1). Therefore, I defined 5 sprints before the colloquium due date. Each sprint was an approximate 5-week cycle of development. At the end of each sprint, I had a potentially deliverable solution, which was the basis of discussion with supervisors. Here is the estimated due date for each sprint:

Planned date	**Real delivery date**	**Deliverable**
Sprint 1: 27.04- 01.05	04.05.2020	deliverable: Thesis V1
Sprint 2: 01.06- 05.06	14.06.2020	deliverable: Thesis V2
Sprint 3: 06.07- 10.07	13.07.2020	deliverable: Thesis V3
Sprint 4: 10.08- 14.08	17.08.2020	deliverable: Thesis V4
Sprint 5: 14.09- 18.09	15.09.2020	deliverable: Thesis V5
Final deadline: 29.09	-	deliverable: Colloquium

Contents

Introduction

The city's main venues, where organized events are held in, attract a lot of visitors by different means of transportation, which cause disturbances to the normal use of a road by any road user. Thus, an event traffic management system should be used to regulate and guide visitors. Augsburg with almost 300,000 residents (2) is the third most populated city in the Free State of Bavaria. Its Messe hosts many national (e.g. afa[1], concerts in Schwabenhalle, etc.) and international (e.g. GrindTec[2]) events. Depending on the event, Augsburg Messe provides the visitors with different parking lots, including its own parking lot, a city-owned parking lot very near to Messe, and some other satellite lots. It is noticeable that, WWK-Arena -Augsburg soccer stadium- has been also located around 2 km south from Messe, which hosts a lot of matches yearly (e.g. FC Augsburg - FC Bayern Munich). One of the main access roads to both Messe and Arena is Federal highway B17. Unsurprisingly, Messe Augsburg attracts a lot of visitors. Therefore, in the time of events, induced traffic to Messe affects the traffic flow in the road network around Messe negatively. In fact, the modal split of visitors to Messe in Grindtec 2018 shows a dominant share of private motorized transport (92%) for visitors (3). Regarding the location of Arena, in case of parallel events (an exhibition in Messe and a match in Arena), the traffic conditions might become even worse. A smooth traffic flow around Messe during events is desirable. Thus, an efficient traffic management system is required.

There have been attempts to investigate the various traffic management strategies in the time of big events. On authorities level, the Department of transport and main roads in the State of Queensland has recently published a guideline about event traffic management, by which they attempt to provide a framework, so that the safety of road users on and around public roads to the venue can be ensured (4). On the dissertation level, a researcher has focused on the development of mathematical optimization models with real-world operational constraints to integrate various strategies for special event traffic management under different network configurations (5). Other researchers developed a traffic simulation model, using VISSIM to evaluate the impact of different traffic management strategies during a selected big event in India (6).

This research has tended to look at the study area as a complex whole on one example event day, to identify the system elements (including parking lots, traffic, road network, etc.), and their current features. Then, it has continued with manipulating some of the element features (including parking lot payment method, Messe travel demand, and changing the access roads

[1] Augsburger Frühjahrsausstellung
[2] International Trade Fair for Grinding Technology

to parking lots). This current study contributes to the traffic management body of knowledge for event traffic management.

Research Structure

This project starts with a literature review to identify relevant theories and methods in traffic control (see 1. Literature Review). Then it continues with problem analysis. In this step, system elements are determined and their condition (e.g.: features, problems, etc.) are examined (see 2. Problem Analysis). In the next step, the researcher asks questions based on found problems; the questions form the objectives of the project (see 3. Research Questions and Research Objectives). After these two steps, the researcher can design the methods and implementation techniques, that are required to find solutions to research questions (see 4. Methodology). The defined system of methods leads to a set of results. However, to find the best possible solutions the outputs should be interpreted and discussed (see 5. Results & Discussion). Finally, the researcher introduces a set of recommendations by reasoning (see 6. Conclusion). Figure 1 shows the structure that lies behind this project.

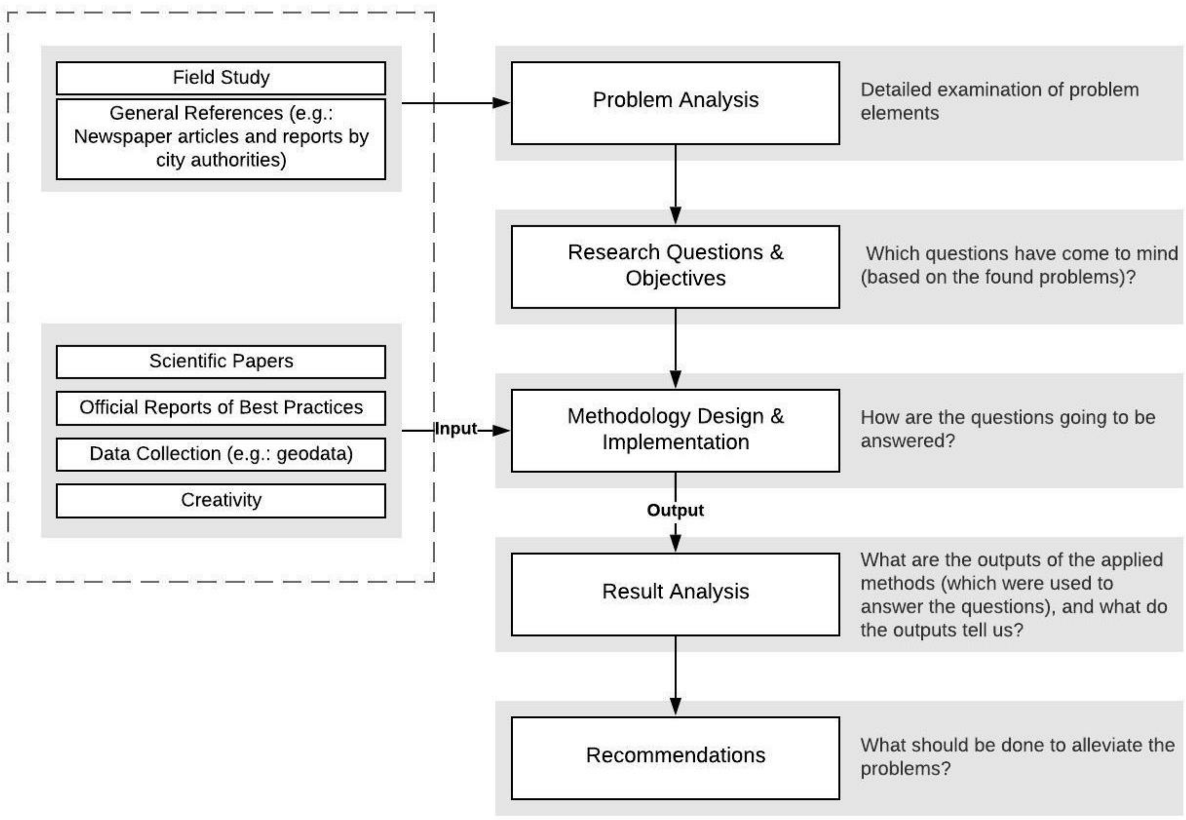


Figure 1: Research structure *(created by Author)*

1. Literature Review

This chapter provides a survey of the relevant literature to event traffic management and rule-based traffic management, that have been studied during this thesis project.

Although some studies argue that, car use among young adults in Germany has decreased since the turn of the millennium (7), and future transport infrastructure planning should concentrate on modification rather than on expansion because of the stagnation of overall per-capita travel demand in Germany since the mid-1990s (8), other studies((9) , (10)) insist that the country is still challenged by traffic congestion, which will bring about economic, environmental, and societal costs: “Full autobahns, kilometers of traffic jams and wasted time - this is more and more an everyday reality for drivers in Germany (10).”.

To achieve an acceptable congestion level, using the existing infrastructure more efficiently is desirable, and this cannot be achieved without traffic management and control methodologies, which prevent or reduce traffic jams. Traffic management starts with recording traffic data and continues with analyzing and evaluating the collected data. After taking the appropriate strategy, the traffic will be influenced, and the loop will be iterated(Figure 2) (11). The efficiency of such methodologies can be measured by indicators such as fuel consumption, air quality level, noise emission level, queue lengths, delays, etc (12). Depending on the traffic management application, the indicator and the required measurement techniques may vary. For example, the effectiveness of dynamic route and parking guidance, which is a traffic management application with the goal of congestion reduction by the distribution of shares of traffic from primary roads to alternative routes, can be measured by indicators such as traffic volume, queue lengths or the number of congestion occurrences, via inductive loop detectors and traffic models (12). Disregarding advances in Automated Vehicle technologies, currently implemented traffic management systems are based on roadside technologies, such as traffic signals, dynamic route information, and variable message signs, which may use collected data from roadside sensors and cameras and traffic management centers. One thesis project argues that each traffic management system should be (11):

- Up to date and dynamic.

- Flexible: adapts to different situations: normal rush hours, big events rush hours, etc. (Different control measures for different situations).

- Policy neutral: it should meet different transport policies.

- Reliable: reliable information will encourage the road users to follow the guidance

- Available to the public: information media should be available to most users; e.g. using signposts, radio announcements.

- Modular-structured: traffic management should be expandable and can be connected to other traffic components via interfaces.

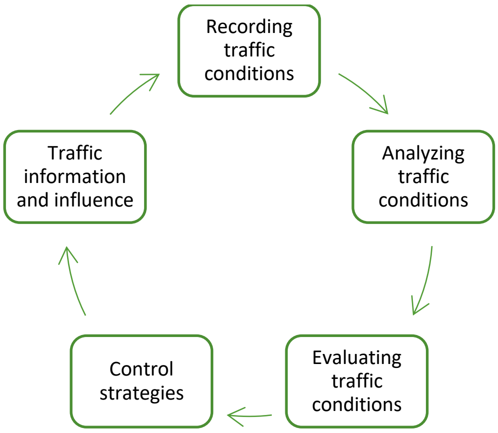


Figure 2: Traffic management loop *(Created by Author, using the information in* (11)*)*

Land uses for organized events, such as sports stadia and exhibition centers are dependent on the access of crowd from a wide urban catchment. In the past, a car-oriented city model based on urban motorways promoted car access to points of activity. By contrast, new urban developments of public venues, such as stadia, are more likely to be transit-oriented. These changes are represented in new stadiums such as Docklands in Melbourne and Lang Park in Brisbane, Australia (13) Therefore, as a preparatory step, developers implement extensive travel demand management measures and apply accessibility modeling to reduce car access and promote public transport use. For example, in 2009 Burke and Evans investigated proposed locations for a football stadium on Australia's Gold Coast, exploring its accessibility via the public transport system for city residents; travel time was chosen as cost. The results of the study gave an incisive view of the future stadium and football team viability (14). Unsurprisingly, the older developments, dating back to the car-oriented city model, are less likely to follow the same procedure. Regarding the modal split of trips to Messe Augsburg, one research claims that in one event, 92% of trips to Messe were done by car, which is a huge share, and implies that Messe Augsburg is preferred by visitors to be accessed by car (3).

However, the common goal of all these venues, either transit-oriented or car-oriented, is to attract as much crowd as possible. Therefore, it is desirable to integrate the induced traffic to the daily traffic on the road network near public venues smoothly, and at the same time manage the travel demand to these venues by promoting riding on public transport. One challenge for event traffic management is that, because special events, such as trade fair exhibitions, sports events, concerts, etc., are temporary, the cost-effectiveness of traffic management strategies is important to authorities.

1.1. Traffic management methodologies, AI, rule-based traffic management

Traffic control methodologies that are currently in use, can be placed in the following categories:

- Static feedback control,

- Optimal control and model predictive control, and

- Artificial Intelligence (AI) techniques.

The mentioned methods can be applied through measures such as ramp metering (at highway on-ramps), variable message signs, lane closure, hard shoulder opening, etc. (15).

Artificial intelligence techniques, which are used for decision making, work similarly to human intelligence: it starts with perceiving a situation, then thinking about that situation (based on our logic), and finally reacting to that. AI techniques can be classified as follows:

- Case-based reasoning,

- Fuzzy logic,

- Rule-based systems,

- Artificial neural networks, and

- Multi-agent systems (15).

Rule-based systems approach a situation using “if-then” rules, which are constructed by merging the knowledge of experts in the field. These systems have an inference[3] engine. These rules are saved in the inference engine. In fact, the engine always searches its memory to decide which rules fit the current situation (16). However, a rule-based system does not involve learning and self-improvement. It is noticeable that the scenarios of an AI-based controller are determined using simulation models, but the models are not directly incorporated in the controller (15).

Rule-based systems are very common in traffic control. Basically, switching recommendations (rules) can be determined by merging the knowledge from city and motorways authorities, police, event organizers, and parking lot managers to be stored in an inference engine (e.g.

[3] a conclusion reached on the basis of evidence and reasoning

Nuremberg dynamic traffic management system (17)). Figure 3 shows the simplified representation of the traffic management system in Nuremberg.

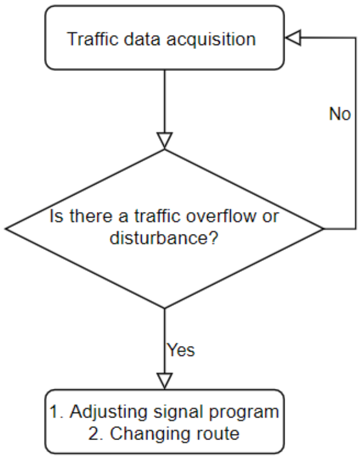


Figure 3: Schematic diagram of the traffic management system (*Created by Author, based on* (17))

These rules are to be kept as simple and easy to understand and to modify. In the Netherlands, a rule-based traffic management system has been implemented on the road network. It acquires real-time traffic information and has three simple rules. These three rules are applied to each link in the network. The first rule promotes the outbound traffic with longer green time when the road capacity gets satisfied. The second rule decreases the inbound traffic when congestion starts. Finally, the third rule reroutes traffic implementing a diversion route. In the future, this can also be communicated using in-car systems (18).

The recommended "if-then" scenarios can be tested by traffic simulation tools (6). During recent years simulation models have become easier to use. On one hand, these tools are effective approaches (moneywise and timewise) to compare and contrast the advantages and drawbacks of proposed scenarios. On the other hand, we should be skeptical about the output of the models, because of different types of errors, involved in the modeling process. Some attempts have tended to focus on comparing the performance of different models. For example, in a research project, the results from CORSIM and VISSIM (two different traffic flow simulation packages) have been compared (19); They argued that although the results were generally consistent, it is recommended to use more than one modeling tool before making a critical design decision. However, this is not the case regarding the time restraint of the Master's thesis project. Moreover, these complex models require tons of inputs including car-following and lane-changing coefficients, which are effective on simulation output. These coefficients should be specified in a way so that the simulation output reproduces numbers comparable to traffic measurements (20). Several studies including a 2018 study at the

University of Texas at Austin found Vissim a suitable tool for planning for active traffic management combining microsimulation and dynamic traffic assignment (21).

1.2. Best practices

Nuremberg

The city of Nuremberg has put a dynamic traffic management system for Messe/ Stadium/ ARENA into operation since 2004 with an investment of 26 million Euros, which is an example of a successful dynamic traffic management system (17) (22).

This example is worth reviewing, because similar to Messe Augsburg, which is very near to Augsburg Arena, in Nuremberg several public venues have been located around Dutzendteich public park, including Nuremberg Messe, Max-Morlock Stadium, and ARENA Nürnberger Versicherung, which can hold events with more than 100,000 visitors, and are occupied more than 300 days a year. Unsurprisingly, these large-scale events add an extra huge traffic flow for a short time to the road network. Therefore, parallel events have been the determining factor in the traffic management system design in Nuremberg.

The main objectives of this traffic management system are:

- Minimizing the negative effects of event traffic on urban traffic. (Traffic jams should be avoided, especially when there is a possibility that queues in urban streets enter motorways.)
- Providing easy access to event locations, parking spaces, and public transport hubs.
- Increasing the efficiency of the already existing road network (instead of expensive, time-taking, environmentally harmful road expansion)

To achieve these objectives, the Traffic Planning Office, Nuremberg Messe, Northern Bavarian Motorway Office, Police and the City of Nuremberg (traffic control and traffic management centers) worked together.

Here are the system features:

- Current traffic loads are counted by induction loops on access roads. Consequently, free capacity can be determined.
- There are about 150 dynamic variable message signs across 70 km motorway and 33 km urban streets.
- A control software is the backbone of the system (übergeordnete Steuerungrechner), that gives the operator recommendations.
- Concurrent events (three events) can be signposted separately.

- The traffic management system is connected to urban traffic counters, traffic data collection systems, and signal systems.
- Monitoring cameras are used by police and urban control centers.
- It complies with TLS (Technische Lieferbedingungen für Streckenstationen) and MARZ (Merkblatt für die Ausstattung von Verkehrsrechner- und Unterzentralen).

The control is possible via the following methods:

- Manual switches,
- Scenario switching with predefined routes for standard situations (e.g. large trade fairs, soccer matches, etc.),
- Traffic dependent switching (incident dependent).

Here are some of the methods that the traffic management system in Nuremberg uses:

- Depending on the traffic counts, the main route shown on the signposts may be replaced with an alternative route. *(in Augsburg case: guiding drivers to enter the Messe parking lots from Forschungsallee, if the traffic counts on B300 west-east reaches the limit, and the queues overflow to B17.)*
- In the case of parallel events, the vehicles can be guided to a satellite parking with shuttle bus facilities instead of guidance to the main parking lots. *(in Augsburg case: vehicles can be guided to a satellite parking like Sigma Park parking lot.)*
- The LED displays can guide different target groups. For example Messe visitors/ freight vehicles.
- Depending on the traffic situation, more lanes will be dedicated to turning. *(in Augsburg case: increasing the number of entrance gates to Messe parking lots.)*

It is noticeable that experience in Nuremberg has shown that drivers who are less familiar with the area, rely more on this traffic management system.

Munich

The traffic network control system in Munich is called VnetS[4] (23):

The VnetS consists of a control computer, a strategy computer (similar to an inference engine), and an incident detection computer, which exchange data via a central database server.

The first VnetS was set up in the course of the new construction of the Messe Munich in the Riem district in coordination with the highway guidance system and Messe parking system. Its main traffic engineering task is to maintain the maximum performance of the downstream network with its network control procedures during peak loads during trade fair operations - in

[4] Verkehrsnetz-Steuerungssystem

coordination with the traffic control system of the motorway and the parking guidance system of the trade fair center.

Munich uses VnetS to increase the performance of the road network, lower the waiting times, and improve utilization of infrastructure in the existing road network.

Florida, Fort Myers, sport events

A research empirically studied the traffic management strategies taken for sports events in Fort Myers, Florida, using data collected within five years on an arterial road. Basically, manual traffic control and signal retiming, applying variable message signs, and guiding to alternative routes have been the main strategies to approach this special traffic situation. According to travel time results from Bluetooth sensors, manual control was effective for one year; signal retiming smoothed the traffic entering games (40% reduction in travel times), but not for traffic exiting the games.; Variable Message signs did not considerably affect travel times; most of the drivers used the congested arterial, even though the alternative route was introduced (24).

To sum up, modifications to parking facilities (increasing the number of entrance/exit gates, showing the number of free spaces in different parking lots, etc.), rerouting traffic to alternative roads, and retiming traffic signals, are among the common practices that have been used in successful traffic management systems. However, other features of parking facilities, such as payment method, and observing the effect of sending a part of traffic out of network (to e.g. park and ride facilities) have been less discussed in the literature.

2. Problem Analysis

Assuming that the study area has been made up of a set of things working together as an interconnecting network (i.e. a system or a complex whole), we have to determine the system elements and examine their condition to find the problems in the study area. To do so, the researcher visited the study area once on Saturday 25.01.2020, during afa[5] 2020. Moreover, the existing background information has been studied through recent news and reports about Augsburg Messe.

2.1. System Elements

After examining the study area and general references, the following have been selected as system elements:

1. Events: A single event in Messe (or parallel ones -occurring at the same time with matches in Arena-) is the main factor, which attracts visitors to Messe Augsburg (i.e. extra traffic to the road network around Messe Augsburg).

2. Vehicles (traffic demand): The presence of daily traffic and induced traffic to Messe affect traffic conditions.

3. Road network: Different features of the road network (e.g.: design of the road, the access roads to venues, the traffic signal programs, the number of turning lanes to parking lots, etc.) can bring about traffic bottlenecks and affect traffic conditions.

4. Parking lots: The features of parking lots (e.g. number of parking spaces, payment method, layout, etc.) affect traffic conditions.

5. Traffic management system: An efficient traffic management system (including dynamic guidance system and parking management system) affect traffic conditions.

In fact, the big problem – i.e. complicated traffic conditions near Messe during the event(s)– is made up of smaller problems in system elements. Figure 4 shows the connections within this system. Although holding events induces extra traffic and put pressure on the road network and parking lots near Messe, an efficient traffic management system (including parking management system) balances the system partly (25).

[5] Augsburger Frühjahrsausstellung

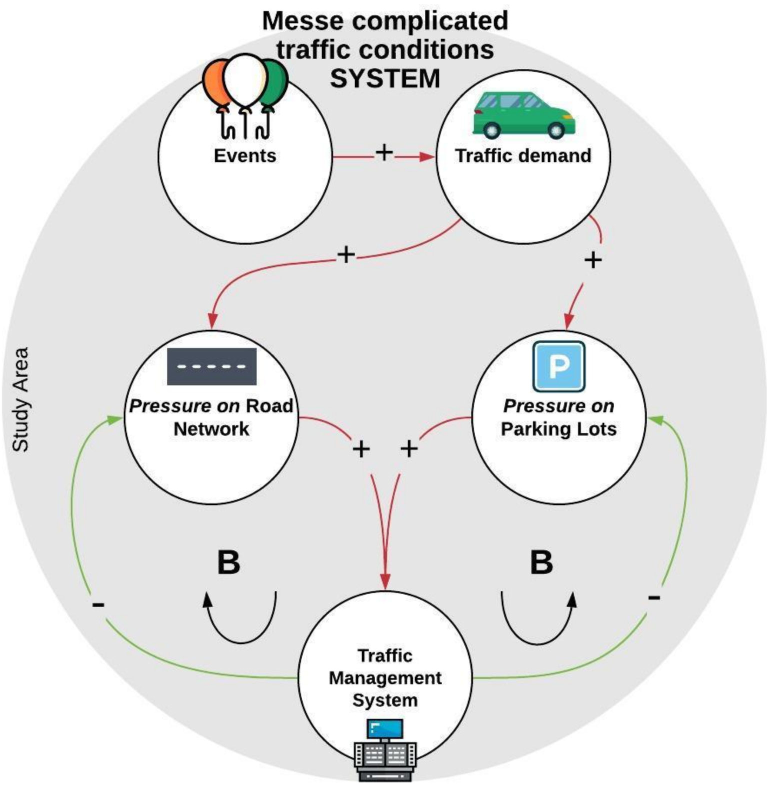


Figure 4: Systems thinking: how the system elements are connected; “+” shows reinforcing effect; “- “means weakening effect; “B” means balancing effect *(Created by Author)*

2.2. Focus Elements

Due to time restraints, it was not possible to go through all the system elements. However, this project has searched through modifications to parking lots, road network (accessibility to parking lots), and traffic demand.

Parking Lots

Two parking lots in the north and south of B300 Federal highway (also called Friedrich-Ebert-Straße) are generally used during Messe events (Figure 5).

The north parking lot is managed by Messe, and it is only used during Messe events, while the south parking lot is managed by the city of Augsburg.

Capacity: These lots provide around 2600 parking spaces. However, based on an email interview with the commercial manager[6] of Messe Augsburg, parking lot spaces are definitely **not** sufficient for exhibitors and visitors at large events (especially afa, JAGEN UND FISCHEN, Interlift, GrindTec, AMERICANA).

[6] Kaufmännischer Leiter

Figure 5: Messe Augsburg 3D plan *(Source: Messe Augsburg website, Edited by Author- red text-)*

Therefore, there have been plans for many years to expand the parking capacity in Messe Augsburg (26). Moreover, because of future urban developments in this area, it has been already discussed to increase the number of parking spaces to 3700 (27).

Satellite parking lots: Sometimes satellite parking lots (i.e. a parking lot away from Messe building) are in service (e.g.: Arena parking lot, SIGMA Technopark parking lot, Fujitsu parking lot, etc.) (28) (29) (30) (Figure 6). However, a shuttle bus service is **only** available between the WWK Arena and the Messe during AFAG events (26).

PCI parking lot is almost located in the Messe complex, and is sometimes used. The northern area of PCI parking lot, with approximately 100 parking spaces, has been rented by Messe from the Parks Department of the City of Augsburg[7], and is available for all events. If required, the project managers of the events rent the southern part on weekends from PCI (free of charge). The area is determined by PCI in each case. Parking spaces for PCI employees must be kept free (varies with the events). In total, up to 200 additional parking spaces are available on the PCI parking lot (26).

[7] Grünflächenamt der Stadt Augsburg

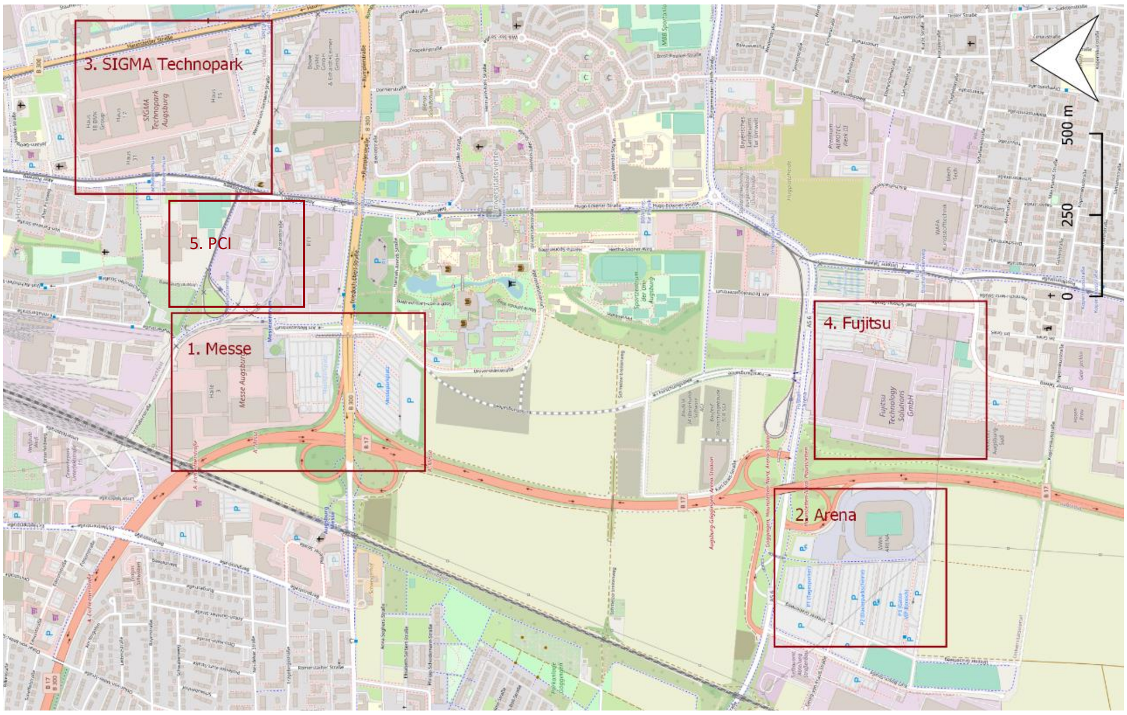


Figure 6: Messe Augsburg and some of the satellite parking lots around it (Basemap: OpenStreetMap) *(Created by Author)*

Payment method: A car can enter a parking lot by paying the parking fees to a parking lot supervisor (a cashier), which is a rather slow payment method (Figure 7). Based on the researcher's observation on Saturday 25.01.2020 (during afa 2020), the waiting time for cars to enter the parking lots were not consistent or having a fixed pattern, and it was affected by many factors such as, whether the driver already knew the parking fee or should ask about it, whether the driver paid the exact amount of parking fee or waited for change, whether the driver asked other questions from the parking supervisor, etc. Therefore, even though the observation time was not a crowded time, the waiting times were at least 20 seconds, and the queue of waiting cars was created immediately.

There is not any estimate of parking lot service rate (number of vehicles per unit of time, that can enter the parking lot) available. However, depending on the traffic volume, up to six cashiers are used. Cars stagger on 2 or 3 lanes with 2-3 employees on each lane in the entrance area of the parking lot.

Parking fees: North parking lot (owned by Messe) has a parking fee of €5 (on average for different events). The south parking lot (owned by the city) is free of charge on normal days, but with a parking fee on Messe days (Figure 8).

Surprisingly, according to reports, there have been inconsistencies in receiving fees in different parking lots (north and south); While the parking fee in the north parking lot was €5, no fee was collected in the south parking lot (owned by the city) several times.

8 Control methods: Average control times and their capacities

Control method	Entry			Exit		
	Control Time [s/pcu]		Capacity [pcu/h]	Control Time [s/pcu]		Capacity [pcu/h]
	One vehicle	Following vehicle		One vehicle	Following vehicle	
Short-term parking						
1 credit / debit cards	24,4	21,6	160	19,5	16,5	210
2 credit balances / Loyalty cards	16,4	16,7 ©	210	24,9	22,0	160
3 Cashier	17,8	14,9	240	-	-	-
4 smart card tickets	10,9	10,4	340	11,1	9,9	360
5 magnetic stripe / Barcode tickets / ChipCoins	13,3	12,3	290	11,6	10,6	340
6 magnetic stripe tickets (Lateral position)	13,3	12,3	290	15,2	14,0	250[2]
Long-term parking						
7 magnetic stripe / Smart card tickets	15,5	15,2	235	14,7	13,3	270
8 Magnetic Key / transponder technology	10,3	9,4	380	11,2	9,9	360

Figure 7: Service rate of different parking control methods *(Source: Lecture slide, urban planning course, Winter semester 2019/2020, Technical University of Munich)*

Figure 8: left: Parking fee sign at north parking lot entrance (€5 for car, €10 for bus), right: Parking fee sign at south parking lot entrance (fee required on a certain date-variable message-) *(Photos by Author)*

This may create a bias towards parking in the south parking lot in drivers who have experienced once such a fee-free parking space.

Augsburger Allgemeine 11.02.2019 (31):

Franziska Hay parked in the south parking lot with her three children and mother-in-law and walked over the bridge to the Messe. "You have to expect to walk a bit, that's why I have a baby carriage," says the mother. She was surprised, however, that ***she was not charged in the south parking lot, while visitors had to pay five euros for parking at the Messe [north parking].***

In fact, ***there was no parking guard in the city parking lot*** *that afternoon, although a sign says that parking during the fair costs five euros. "****It was the same last year****, so we drove straight here," says a family man.*

Parking management system: Currently there is no integrated parking management system in two parking lots. Moreover, there is no real-time parking guidance display or a real-time parking availability system on the roads to Messe parking lots. Figure 9 shows a defective parking display on B300, and Figure 10 shows a simple parking signpost on B300 (east-west). Therefore, even if a parking lot is full, the driver is not informed in advance (32). The parking attendants do not count the number of vehicles entering and exiting the parking lots. Therefore, the number of free parking spaces cannot be determined easily (26). However, there is information on the temporal distribution of parking tickets sold for the parking spaces available.

A chronicle of parking around Messe Augsburg:

The following pieces of information have been collected from different articles in Augsburger Allgemeine newspaper (28) (32) (31) (29) (27) (30).

2012:

In 2012 Augsburg hosted parallel events in Arena and Messe.

A shuttle bus service from Messe parking lot (supposedly south parking lot) to Arena (and from Arena to Messe parking lot, after the game) was provided for the Berliner Hertha versus FC Augsburg match. It cost 4 Euros (parking fee + free shuttle bus service). About 300 drivers had used the same shuttle bus service during FC Augsburg versus FC Nuremberg.

There was the afa between 7 April and 15 April in Messe. Parking lot P1 (supposedly north parking lot) was available for afa visitors. Moreover, on weekends, the big SIGMA Technopark parking lot including a shuttle bus service was available for Messe visitors.

Figure 9: Messezentrum parking lots display on B300 (between Alter Postweg and Universitätsstraße) is out of order *(Photo by Author)*

Figure 10:Simple parking signpost on B300 (east-west) between Alterpostwegstr. and Am Messezentrumstr. *(Photo by Author)*

2014:

In 2014 Augsburg hosted parallel events in Arena and Messe: FC Augsburg vesrus FC Bayern Munich and afa at the same time.

Different parking lots were assigned to different groups of fans: Fujitsu parking lot (served by a shuttle bus service) to FC Augsburg fans, and a parking lot in Inningen (served by a shuttle bus service) to guest fans. So, there was no traffic chaos on 05.04.2014, and just a traffic jam on B17 (like all FC Augsburg games). There were also special tramlines (8 & 9 to Arena and Messe).

2018:

In 2018 Augsburg hosted parallel events in Arena and Messe: FC Augsburg versus FC Bayern Munich and afa at the same time on the 7th of April.

Noone charged drivers who parked in the south parking lot.

2019:

In 2019 Augsburg hosted parallel events in Arena and Messe: afa, Kreativ Markt, and FC Augsburg match.

Apparently, parking spaces were enough, but there were always traffic jams.

For afa: there was a traffic jam at the entrance of parking lots, and a traffic jam on B17.

For Immobilientage and Bau im Lot (the week after afa), there was no traffic chaos.

The managing directors of afa believed that this happened because the parking lots were not in one hand, there are no dynamic signposting to parking lots, parallel events were held in Messe and Arena, and the parking guidance system on Fredrich Ebert Str. was out of order.

Drivers were not informed about the availability of parking spaces, and were confused between full parking lots. Visitors had different experiences.

The managing director of afa stated that they would manage both parking lots for Interlift and Grindtec, so they could change for example payment method (on exit instead of on entrance).

2020:

This year the city and organizers had plans, and there were no parallel events. So, even parking lot in Arena with a shuttle bus could be used to serve the Messe visitors. But again on Monday, there was a traffic chaos, so they activated the Arena parking and shuttle bus service for visitors.

For afa the parking lots are still managed separately. But for Interlift and AMERICANA the parking lots would be in one hand.

Apparently, the signposting to parking lots were better, and also the drivers could be informed about parking places by SMS or Whatsapp services in advance.

However, the city of Augsburg sees a need for a long term action. According to the future change in land use in the south parking lot, there would be a need for even more parking spaces (around 3700). And also redirecting the traffic to the new street (Forschungsallee) can improve the traffic situation in Messe intersection.

Road network

New street: Forschungsallee

Currently, vehicles can access both parking lots via B300. However, a new street, which is called Forschungsallee, is going to connect B17 to Universitätsstraße, at which the south parking lot is located. Supposedly, vehicles from B17 can be guided to parking lots (especially the south parking lot) via Forschungsallee (instead of B300)(Figure 11).

Figure 11: From B17(south-north) to Messe intersection via Forschungsallee (Basemap:OpenStreetMap) *(Created by Author)*

Traffic signal

The signal systems adapt automatically to the current traffic situation, using the traffic management system INES+ (The intelligent adaptive traffic control system). The system records the traffic situation by means of the existing induction loops and then automatically switches into a suitable signal program (8).

Undoubtedly, when Forschungsallee is used as an access road to Messe intersection, traffic volumes at traffic signals (at B17 eastern ramp/ Bgm. Ulrich Str. and Messe intersection will change), and consequently the required green times will change. Thus, new signal programs should be designed and applied in these cases.

Traffic management system

Introduction of the rule-based system.

Currently, when there is an event held in Augsburg Arena (WWK Arena) or in Messe Augsburg, there is a traffic management system in service. The signposts along B17 (both directions) include fixed and variable messages, which give travelers information such as, the direction of Messe/Arena, special events in Messe/ Arena, and traffic jam warning. Figure 12 shows the content of signposts on 10.02.2017-12.02.2017, when Immobilientage event was held in Messe Augsburg (33).

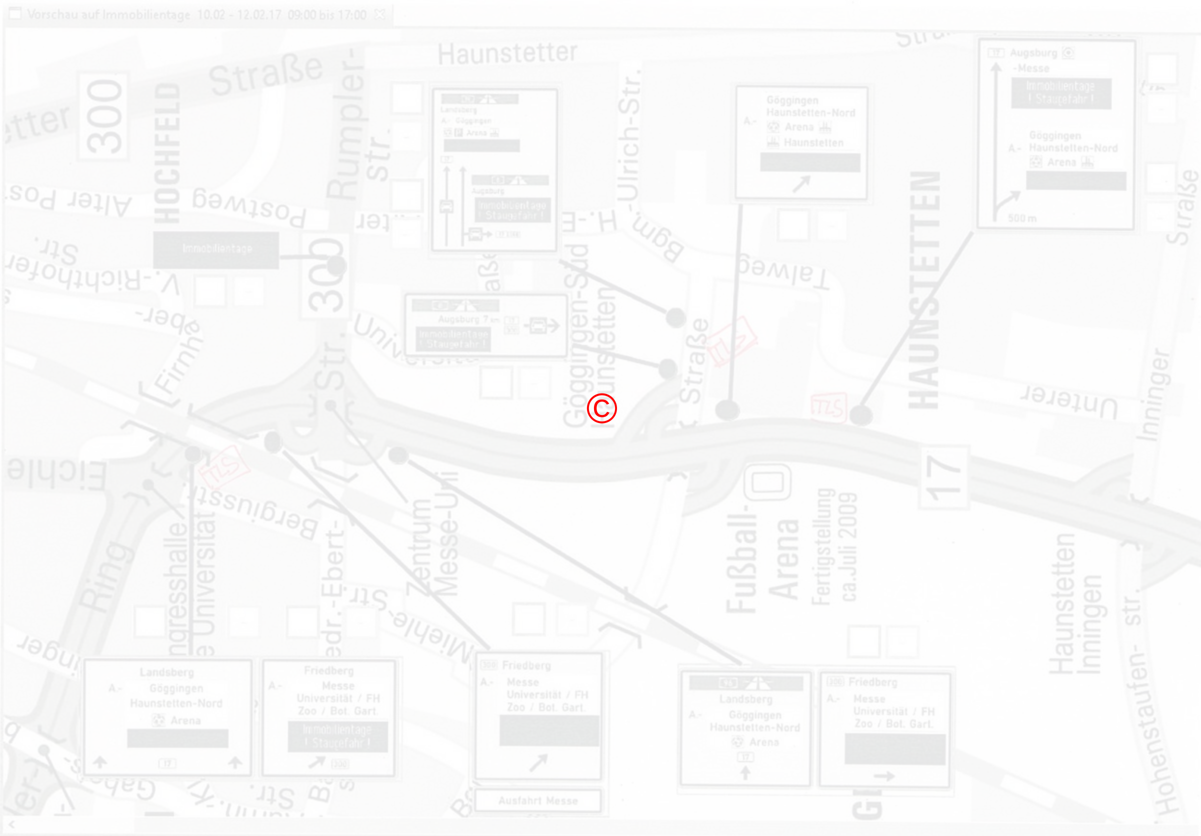


Figure 12: B17 traffic management *(Source: Stadt Augsburg, Tiefbauamt)*

The traffic conditions are mainly monitored by Police via cameras. The colleagues on-site can switch between pre-installed scenarios. In fact, there is a police mission control center in Arena, where they monitor both private and public transport (33).

The traffic management system in this area includes also variable speed signs, which are operated by the Staatliches Bauaumt Augsburg. While doing this thesis, there was no access to this data (33).

3. Research Questions and Research Objectives

To design an approach to deal with the situation, we have to ask questions about the problems with system elements (e.g.: When/ Where/ Why/ How does problem X happen? How does measure Y affect problem X?)

It is noticeable that the measures cannot lead to true or false outcomes, but they can be more or less effective. Thus, we compare the efficiency of the measures based on our objective-indicator system.

3.1. Research Questions

How does traffic conditions look like in the current situation?

How do traffic jams propagate in the current situation?

How do parking lots contribute to traffic jams?

How effective is the changing of the parking lot payment method?

How do reductions in Messe traffic volumes coming from B17 (both directions) affect the traffic situation around Messe Augsburg (Sensitivity Analysis)?

How effective is guiding Messe traffic coming from B17 (south-north) via Forschungsallee (different scenarios)?

How can an “if-then” system be achieved based on different traffic conditions and guidance strategies?

3.2. Research Objectives

Table 1 shows the objective-indicator system in this thesis project.

Table 1: Objective-indicator system

Goal	Objective	Sub-objective	Measure	Indicator
Introduction of a concept for dynamic traffic management for Messe Augsburg	Improve on parking management system	Service process management	Implementing an automatic payment system (instead of cashier)	Queue length
	Improve on B17-Messe congested off-ramps	Arrival process management	Guiding vehicles from B17 to parking lots via B300 and Forschungsallee	Queue length
		Arrival process management	Decreasing Messe travel demand on B17	Queue length

In the following, the basic concepts behind the objective-indicator system are explained.

Queuing theory is a branch of *Operations Research*, where mathematical analysis of queuing processes during which certain units pass through a service system is done.

There are three components in queuing theory:

1. Arrival process: How many units do arrive at the service point per unit of time?

2. Queuing order (first in first out, last in first out, etc.): How do the units are going to be served?

3. Service process: How many units do pass through the service system per unit of time?

When the arrival rate (q(t) [veh/time]) is higher than the service rate (s(t) [veh/time]) a queue is forming and waiting times occur.

Driving in a parking lot is an example of a queuing process. Vehicles arrive at the parking entrance form access roads (Arrival process), they may have to pay parking fees, wait for the parking barrier to open, or face other conditions (Service process). Whenever the service rate is lower than the arrival rate, a queue will form.

4. Methodology

Methodology refers to a system of methods, which is used to answer the research questions. After reviewing the recent literature around the topic, I basically use the traffic simulation to answer the research questions.

4.1. Traffic simulation

To understand the current traffic conditions, real traffic observations and traffic simulation are useful. In this research, simulation is more practical than real-world observations. The following reasons justify the statement (34):

- Models can help to understand and to investigate interesting phenomena of the real world, especially when the real system is not available. In the case of this project, because of Corona crisis all major events in Germany have been canceled. Therefore, there is no chance of investigating the real traffic conditions during major events in the study area.

- We can test measures before we implement them (effect of new technologies, traffic guidance scenarios, changes in signal control logic, etc.). It is faster and less expensive, and modifications can be simply implemented to a model.

- We can visualize our planning work.

In other words, we can analyze traffic flow and traffic control, and foster decision making by showing decision points, impacts of modifications to system elements, and range of possible futures (scenarios)!

Requirements for Models

Sensitivity:
A model should be as close to reality as possible or necessary, therefore, interesting effects can be modeled sensitively and reliably.

Logical Consistency:

The structure of the model must be consistent, i.e. it should not allow for internal contradictions

Operability:
The implementation and application of the model must be possible within the reasonable effort, e.g. the built model in this project is within effort possible for the duration of a Master’s thesis.

Transparency

The structure of the model must be clear and understandable so that results can be understood and double-checked.

Reliability:

If the experiment is repeated and the simulation is repeated several times, the same results with the same external conditions should be achieved.

Validity:

Results must be valid, i.e. must be suitable for representation and analysis of the intended (scientific) problem or situation (35).

4.2. PTV Vissim microsimulation

In this project, PTV Vissim 2020 Thesis (Academic License) is used for traffic microsimulation. This software provides a platform to interconnect many models including the road environment, traffic control, the behavior of drivers, etc. The simulated environment is a complex system in which models interact to form an overall system that is more than the sum of the independent models (34).

To run the simulation in Vissim, PTV Vissim Tutorial “First Steps” and contents of Traffic Flow Simulation course, summer semester 2020, at Technical University of Munich have been used. Figure 13 shows the inputs and outputs of the Vissim simulation.

The following sections describe the inputs to the Vissim software.

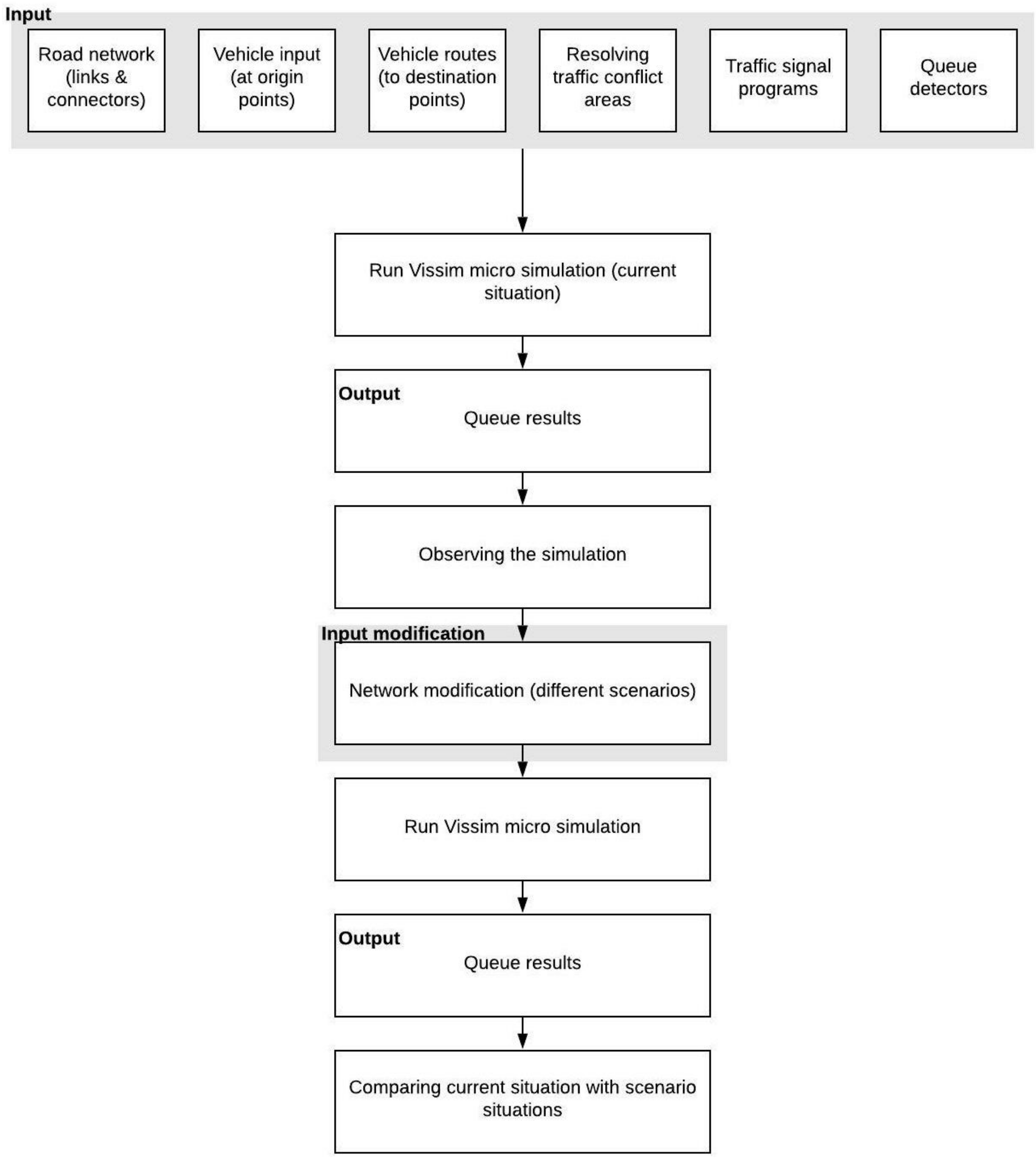


Figure 13: Simulation process

Inputs

Here is a compact overview of input data for this Vissim project. Figure 14 shows the *Network Objects* menu on Vissim software. The objects, that have been manipulated in this project, have been highlighted in green.

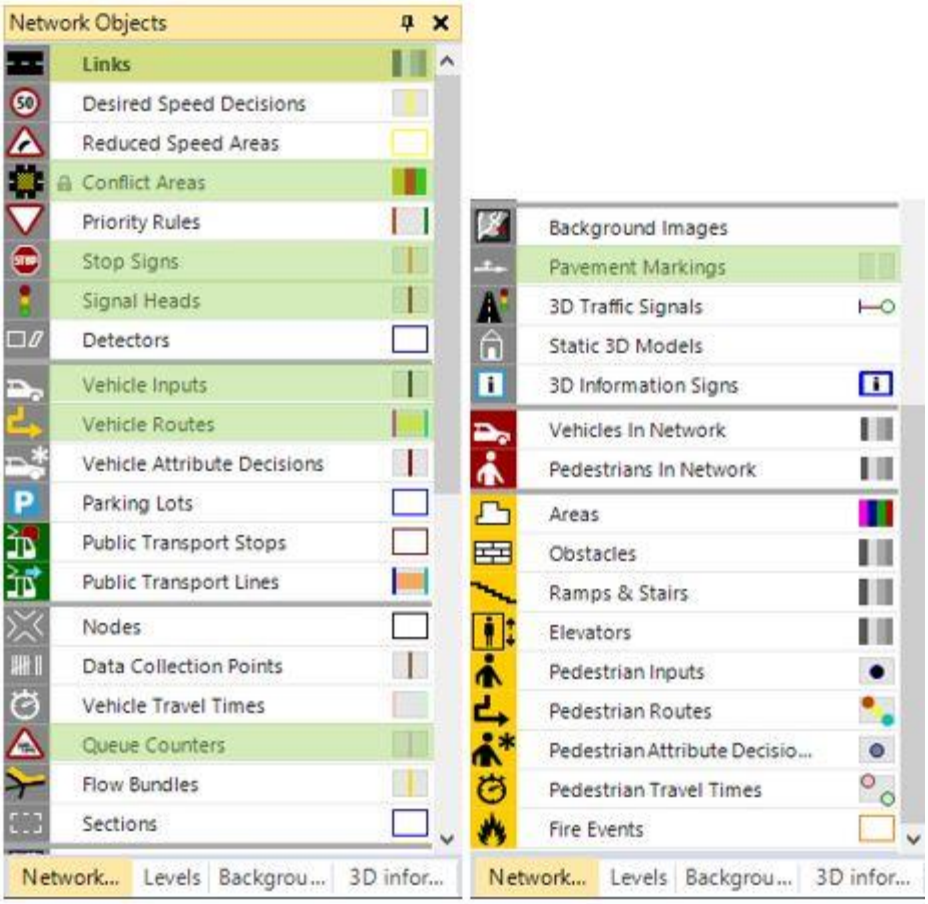


Figure 14: Vissim Network Objects; the network objects highlighted in green have been manipulated in this stage of project

Road network (Links):

The major road network components are (Figure 15):

- About 3 km of B17 (south-north) (including Arena exit ramp (Figure 16) and Messe exit ramp (Figure 17)

- B17 (south-north) eastern ramp/ Bürgermeister-Ulrich-Straße intersection

- About 830 m of B17 (north-south) (including Messe exit ramp)

- About 850 meters of B300 west- east (including Messe intersection)

- About 1400 meters of B300 east-west (including Messe intersection and on-ramp to B17

- Messe intersection

- Forschungsallee street[8] (Figure 16)

[8] https://geoportal.augsburg.de/WebDaten/synserver?project=stadtplan&client=auto&view=stadtplan

- Universitätsstraße between Forschungsallee and Hugo-Eckener-Straße

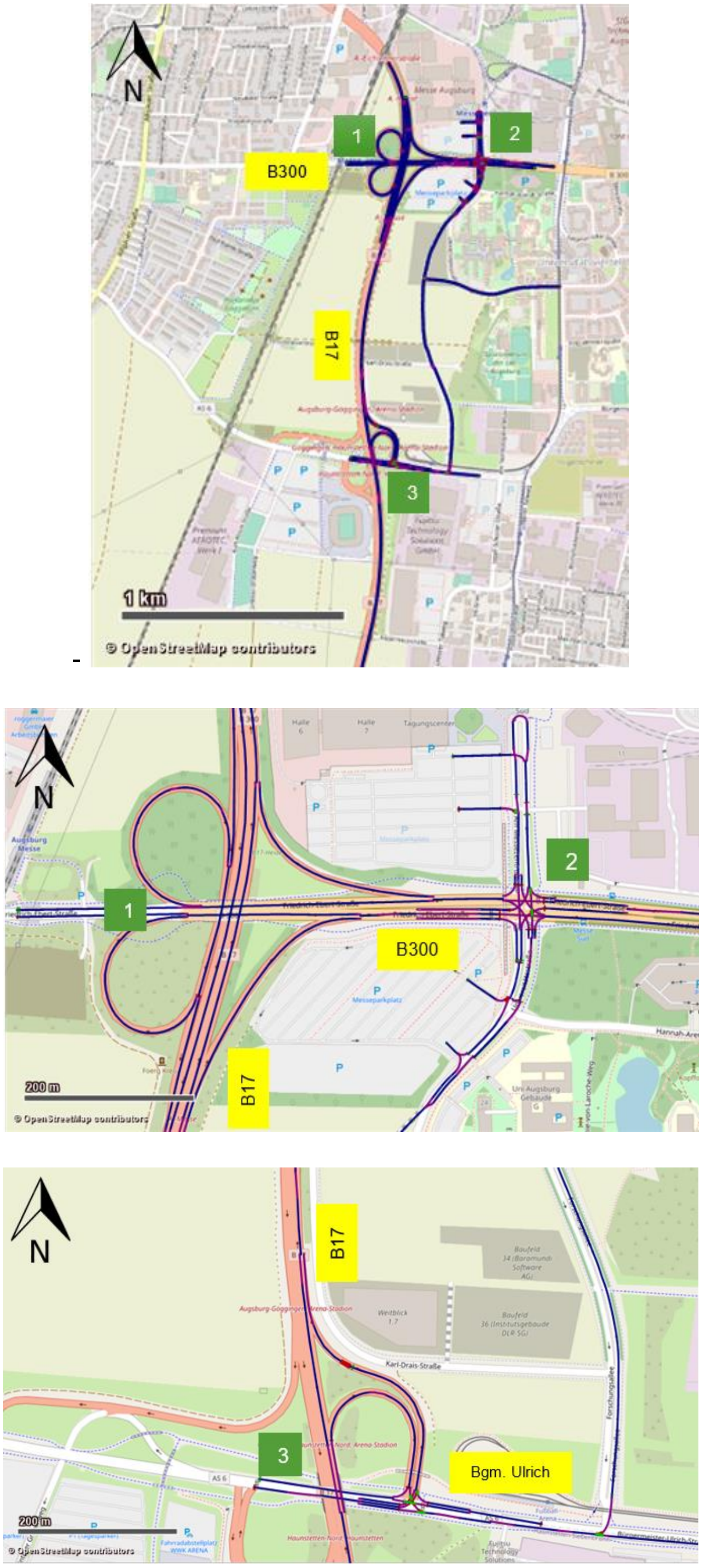


Figure 15: Network in wireframe (blue & purple lines): 1: B17-B300 interchange, 2: Messe intersection, 3: B17 eastern ramp/ Bgm. Ulrich Str. intersection *(Source: Vissim screenshots, Edited by Author)*

Figure 16: B17 south-north, Arena exit ramp and Forschungsallee *(Source: first photo: www.impuls-arena.de/, second photo: screenshot from Vissim model)*

Figure 17: B17 highway and the Messe exit ramps in both directions

Figure 18: On-ramp from B300 to B17

Vehicle inputs:

Assuming that there are imaginary boundaries around the network in our study area, there are points, from where the vehicles can enter the boundaries. In Vissim, vehicles can be inserted to network via *Vehicle Inputs* tab, where we can determine vehicle volume and vehicle composition (the proportion of cars, HGV[9], etc.).

Stadt Augsburg Tiefbauamt has provided some detailed vehicle counting data[10] in three sub-networks in the study area (Figure 19, Figure 20, Figure 21), and a predicted background vehicle volume on Forschungsallee (Figure 22).

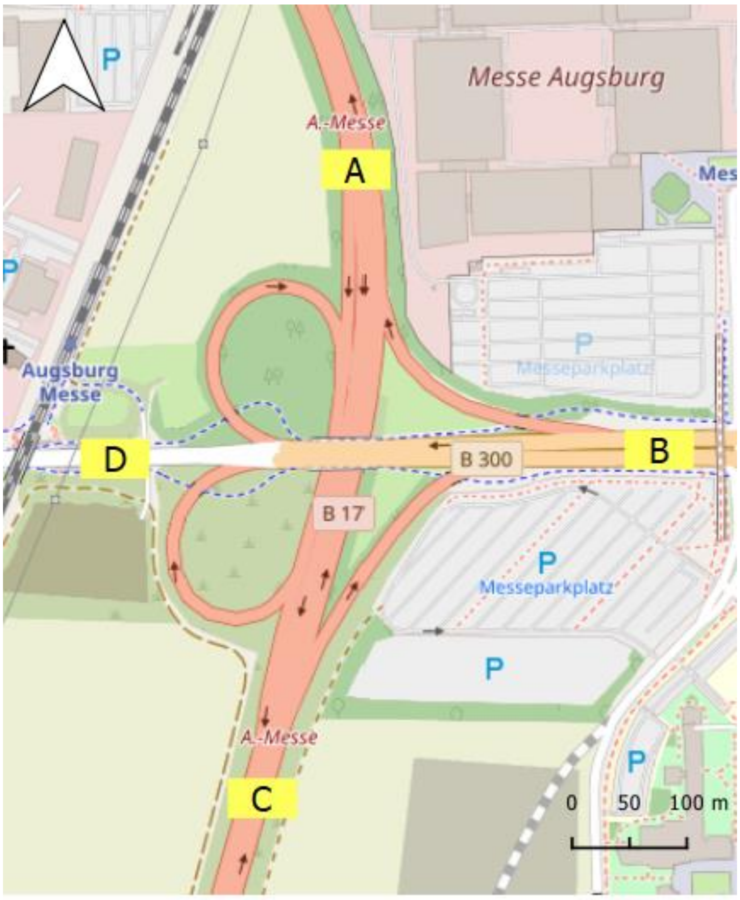


Figure 19: B17-B300 interchange vehicle counting spots (A, B, C, D) (Basemap: OpenStreetMap) *(Created by Author)*

[9] Heavy Goods Vehicle
[10] Provided by Robert Hösle, Stadt Augsburg, Tiefbauamt

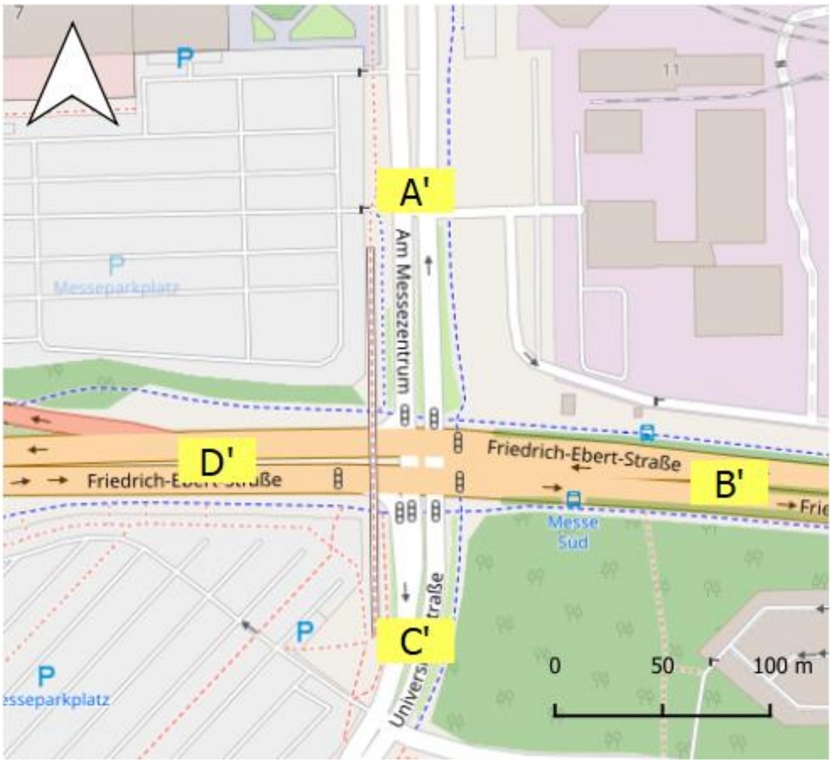


Figure 20: Messe intersection vehicle counting spots (A’, B’, C’, D’) (Basemap: OpenStreetMap) *(Source: Created by Author)*

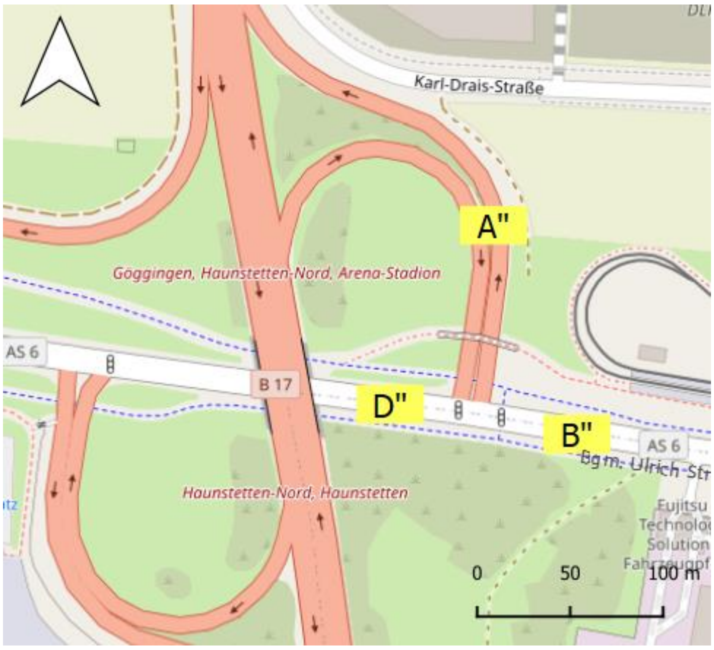


Figure 21: B17-Bürgermeister-Ulrich-Straße interchange (A“, B“, D“) (Basemap: OpenStreetMap) *(Source: Created by Author)*

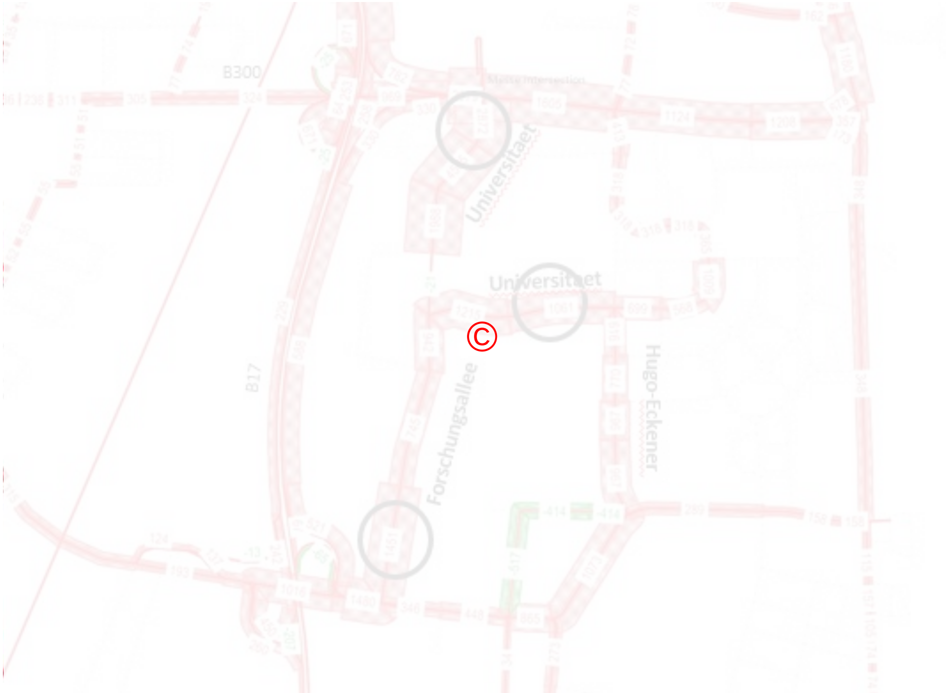


Figure 22:Predicted background traffic on Forschungsallee *(Source: Tiefbauamt – Verkehrsplanung)*

Table 2 shows the data collection locations and dates, and the files, from which data have been extracted.

Table 2: Vehicle counting data

Data collection location	**Data collection date**	**Data recorded in**	**Comments**
Messe intersection	15.03.2018	Verkehrsgutachten Messe in Augsburg, page 46/91	Messe day
B17-B300 interchange	24.06.2019	15 1625 (Friedrich Ebert B17) KP 17.xlsm, “Ausdruck” tab	
B17-Bürgermeister-Ulrich-Straße interchange	26.10.2019	17 1884 KP 12mov.xlsx, “Ausdruck” tab	
Forschungsallee	Model prediction	Belastungsübersicht_Bilder.pptx	Background traffic

“Ausdruck” tab (mentioned in Table 2) includes vehicle counting data in the form of OD-matrixes for different times of the day (from 6:00 to 10:00 as well as from 15:00 to 19:00). However, for Messe intersection, data is available only for morning peak hours (from 8:00 to 9:00), and there is no separate data for cars and HGVs. Figure 23, is a screenshot, showing a part of Ausdruck tab.

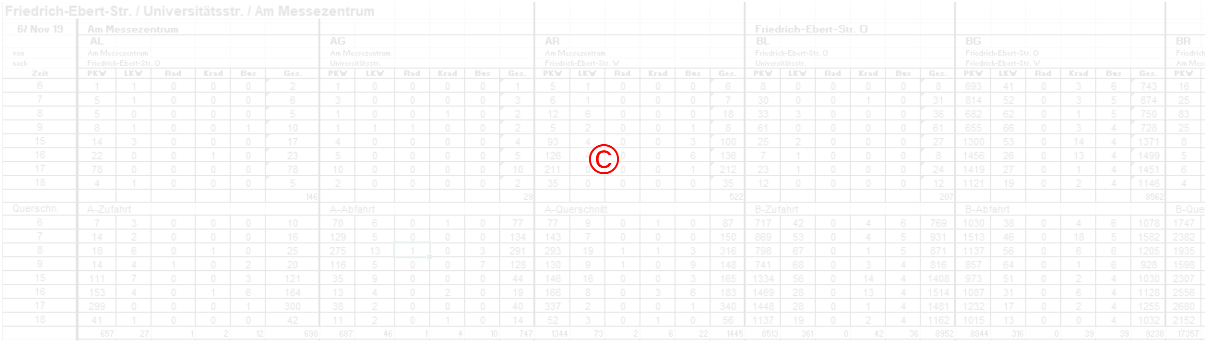


Figure 23: Part of "Ausdruck" tab on the provided .xlsx files

I have cleaned the data in the form of simple OD-matrixes in each vehicle counting location for cars, HGVs, and vehicles (cars and HGVs), for hour 6, 7 and 8 (from 6:00 to 9:00). Table 3 shows a sample OD-matrix at B17-B300 interchange for car, HGV, and car-HGV volumes between 06:00 to 07:00. You can find all OD-matrixes in *Appendix: OD-matrixes in sub-networks in study area*.

Table 3: OD-matrix at B17-B300 interchange between 6:00 to 7:00

B17-B300 / car volumes					
6:00 AM					
to from	A	B	C	D	sum
A	0	270	2192	0	2462
B	394	0	564	225	1183
C	1492	316	0	0	1808
D	0	107	0	0	107
sum	1886	693	2756	225	

B17-B300 / HGV volumes					
6:00 AM					
to from	A	B	C	D	sum
A	0	18	110	0	128
B	15	0	18	10	43
C	210	32	0	0	242
D	0	7	0	0	7
sum	225	57	128	10	

B17-B300 / vehicle volumes					
6:00 AM					
to from	A	B	C	D	sum
A	0	288	2302	0	2590
B	409	0	582	235	1226
C	1702	348	0	0	2050
D	0	114	0	0	114
sum	2111	750	2884	235	

Fusing OD-Matrixes: scaling and calculation

Vehicle counting at Messe intersection on 15.03.2018 (a Messe day) is the basis for the calculations (Table 4). In fact, the vehicle counting at B17-B300 interchange (on 24.06.2019) should be scaled (up) to be in harmony with Messe intersection counting (Table 5).

Table 4: Vehicle counting at Messe intersection on 15.03.2018 between 8:00-9:00

Messe intersection / vehicle volumes					
8:00 AM					
to from	A'	B'	C'	D'	sum
A'	0	277	58	414	749
B'	39	0	3	963	1005
C'	106	160	0	942	1208
D'	91	716	117	0	924
sum	236	1153	178	2319	

Table 5: Vehicle counting at B17-B300 interchange on 24.06.2019 between 8:00-9:00

B17-B300 / vehicle volumes					
8:00 AM					
to from	A	B	C	D	sum
A	0	301	2271	0	2572
B	622	0	601	344	1567
C	1824	283	0	0	2107
D	0	234	0	0	234
sum	2446	818	2872	344	

To do so, the following equations are used:

$$\sum D_B = \sum O_{D'}$$

$$\sum O_B = \sum D_{D'}$$

$$\sum D_B = 1567 \quad , \quad \sum O_{D'} = 2319 \quad , \quad \frac{2319}{1567} = 1.45$$

$$\sum O_B = 818 \quad , \quad \sum D_{D'} = 924 \quad , \quad \frac{924}{818} = 1.13$$

If the extra traffic is only because of the event in Messe, I assume that the traffic departing from (or arriving at) B is scaled up, and the rest will remain the same.

Table 6: Scaling up the number of trips from/to B

B17-B300 / vehicle volumes						
8:00 AM						
to from	A	B	C	D	sum	
A	0	301	2271	0	2572	
B	622	0	601	344	1567	X1.45
C	1824	283	0	0	2107	
D	0	234	0	0	234	
sum	2446	818	2872	344		
		X 1.13				

B17-B300 / vehicle volumes					
8:00 AM					
to from	A	B	C	D	sum
A	0	340	2271	0	2611
B	920	0	889	509	2319
C	1824	320	0	0	2144
D	0	264	0	0	264
sum	2744	924	3160	509	

Now, I can fuse OD-matrix at Messe intersection and the scaled-up OD-Matrix at B17-B300 interchange into one matrix. It is noticeable that, point B and D' can be considered as one midway point which is not an inherent origin or destination. Table 7 shows the fused matrix. The red cells (origins and destinations in the same sub-network) are extracted directly from one of the two matrixes. However, the green cells (origins and destinations are not in the same sub-network) are calculated, using the following sample equation:

AA' = AB X D'A'(%) => 920 X (414/749) = 508

In these calculations, I assumed that the turning ratio at point B (or D'), is the same for all vehicle flows, which is an unreal situation. However, because there is no data available about turning ratios (for example from A to A'), I had to make this basic assumption.

You can find the complete calculation in *Appendix: Fused OD-matrix calculations*.

Table 7: Fused OD-Matrix 8:00-9:00

to from	A	C	D	A'	B'	C'	sum
A	0	2271	0	33	263	43	2610
C	1824	0	0	32	248	41	2145
D	0	0	0	26	205	33	264
A'	164	159	91	0	277	58	749
B'	382	369	211	39	0	3	1004
C'	374	361	207	106	160	0	1208
vehicle input	2744	3160	509	236	1153	178	

There is another sub-network, at the bottom of the study area, where B17 (from south-north) is connected to Bürgermeister-Ulrich-Straße via an exit ramp, which has its own effects on the fused matrix (Figure 24). Therefore, there is a superior vehicle input (V1) to vehicle input C, which its volume is calculated based on the following equations. Moreover, there are two independent vehicle input points on this sub-network at east and west side of Bg. Ulrich Str, which does not change the vehicle volumes at vehicle input points (A, D, A', B' C'). The following equations apply to Figure 24.

$$V1 - V2 + V3 = \sum O_C \ , V3 = \sum D_{A"} \ , V2 = \sum O_{A"}$$

$$V1 = \sum O_C + \sum O_{A"} - \sum D_{A"}$$

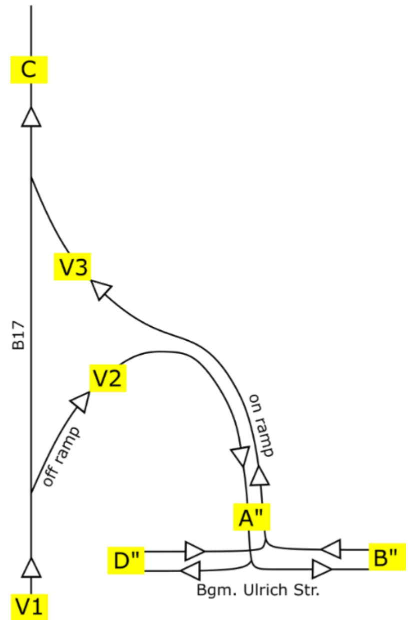


Figure 24: Sub-network B17 ramp-Bgm. Ulrich Str. *(Created by Author)*

Table 8: Vehicle counting at B17 ramp-Bgm. Ulrich Str. intersection between 8:00-9:00

B17-Bgm. Ulrich / vehicle volumes					
8:00 AM					
to from	A"	B"	C"	D"	sum
A"	0	247	0	24	271
B"	174	0	0	510	684
C"	0	0	0	0	0
D"	78	180	0	0	258
sum	252	427	0	534	

Therefore, based on the mentioned equations and Table 8, the calculated vehicle volume at vehicle input point V1 is:

4307 + 252 – 271 = 4288

See *Appendix: Vehicle input V1: volume calculations.*

The last piece of information that has been incorporated into vehicle input calculations was the data from Figure 22. Therefore, another vehicle input has been added to the east of Forschungsallee (in Universitätsstraße), and vehicle inputs in the southern part of the network have been manipulated in a way to include the prediction numbers in Figure 22.

To sum up, in this model, there are 8 vehicle input points: A, V1, D, A', B' C', B", D" and Z. Table 9 includes the vehicle volume at these points between 6:00 to 9:00 AM.

Table 9: Vehicle volume (number of vehicles per hour) at vehicle input points

	Volume		
Vehicle input point	6	7	8
A	2111	3163	2744
V1	2809	3993	3141
D	235	441	509
A'	9	16	236
B'	759	922	1153
C'	93	138	178
B"	326	462	427
D"	485	628	607
Z	53	53	53

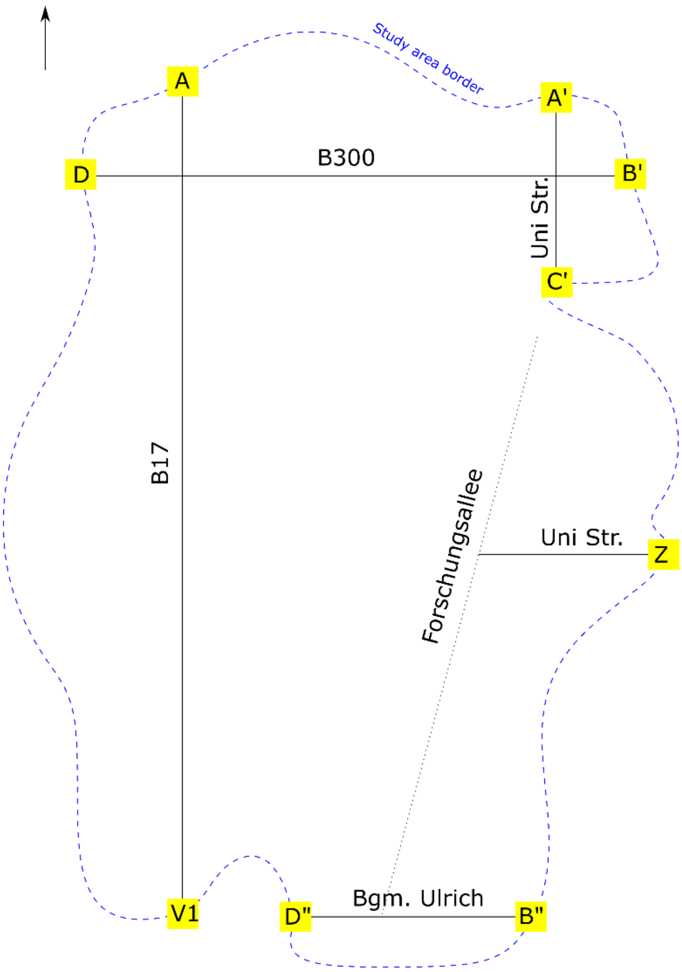
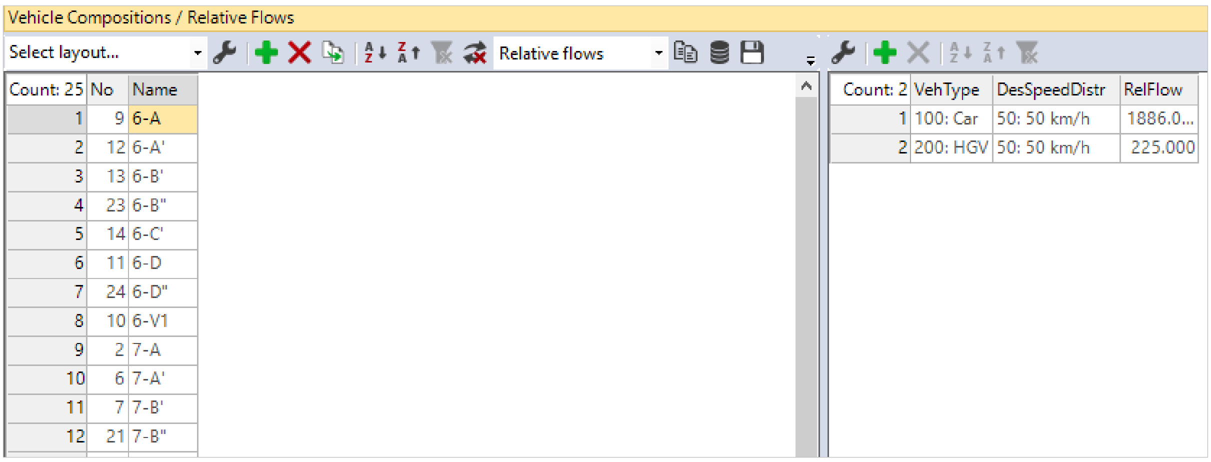


Figure 25: Network boundary and vehicle input points within the study area *(Created by Author)*

Figure 26 is a screenshot of Vissim, that shows part of the vehicle composition table.



Count: 25	No	Name
1	9	6-A
2	12	6-A'
3	13	6-B'
4	23	6-B"
5	14	6-C'
6	11	6-D
7	24	6-D"
8	10	6-V1
9	2	7-A
10	6	7-A'
11	7	7-B'
12	21	7-B"

Count: 2	VehType	DesSpeedDistr	RelFlow
1	100: Car	50: 50 km/h	1886.0...
2	200: HGV	50: 50 km/h	225.000

Figure 26: Vehicle composition (cars, HGVs) at each vehicle input point at 6, 7 and 8 (Source:Vissim screenshot)

It is noticeable that, vehicle volumes change by time interval. Vissim has provided us with an opportunity to insert different vehicle volumes (number of vehicles per hour and not per time interval) for each time interval in simulation seconds (900 seconds = 15 minutes). Figure 27 shows at different time intervals (from 0-3600,3600-7200 and 7200-10800 seconds), different vehicle volumes (2111, 3163 and 2744 vehicles per hour), and different vehicle compositions (6-A, 7-A, and 8-A) have been defined at point A.

Count: 12	Cont	TimeInt	Volume	VehComp	VolType
1	☐	0-900	2111.0	9: 6-A	Stocha...
2	☑	900-18...	2111.0	9: 6-A	Stocha...
3	☑	1800-2...	2111.0	9: 6-A	Stocha...
4	☑	2700-3...	2111.0	9: 6-A	Stocha...
5	☐	3600-4...	3163.0	2: 7-A	Stocha...
6	☑	4500-5...	3163.0	2: 7-A	Stocha...
7	☑	5400-6...	3163.0	2: 7-A	Stocha...
8	☑	6300-7...	3163.0	2: 7-A	Stocha...
9	☐	7200-8...	2744.0	15: 8-A	Stocha...
10	☑	8100-9...	2744.0	15: 8-A	Stocha...
11	☑	9000-9...	2744.0	15: 8-A	Stocha...
12	☑	9900-1...	2744.0	15: 8-A	Stocha...

Figure 27: Different volumes at different time intervals

Vehicle routes:

Vehicles start their action from the vehicle input locations, and they drive on the predefined static routes, which are defined by the modeler. In other words, a vehicle from one origin can drive on different routes. The share of one route within the vehicle routing decision is determined by Relative flow (RelFlow) attribute.Table 10 shows a sample list of static vehicle routing decisions starting from vehicle input V1. It is noticeable that, relative flows have been defined based on OD-matrix at 8.

Table 10: Static vehicle routing decisions, *) guidance through Forschungsallee

Origin-Destination	Relative flow
V1-A	2000
V1-A'	159
V1-B'	369
V1-C'	361
V1-For-C'*)	0
V1-B"	174
V1-For-A'*)	0
V1-For-B'*)	0
V1-D"	78

Conflict areas:

Vissim asks the modeler to determine the right of way, where there is a conflict between two routes.

Traffic signal programs:

In the selected road network, Messe intersection and Bürgermeister-Ulrich-Straße/B17 eastern ramp are equipped with signal heads. Although LISA[11] is used to plan, evaluate and optimize traffic controls for these intersections, signal controllers have been set to be "Fixed time" to avoid more errors to the model. The signal program at Messe intersection is based on the program mentioned in Messe Augsburg Traffic Report (3), page 24/91 (Figure 28). This is the signal program that is used during events in Messe. The signal program at Bürgermeister-Ulrich-Straße/B17 eastern ramp has been provided by Augsburg Stadt, Tiefbauamt[12] (Verkehrstechnische Unterlagen Bürgermeister-Ulrich-Straße/ AS B17(Ost)). For the sake of modeling the current situation, I have used the P1_Morgenspitze (morning peak hour)(page 20/42) in the mentioned report.

Figure 28: Signal program at Messe intersection during events *(Source: Messe Augsburg traffic report)*

[11] https://www.schlothauer.de/en/software-systems/lisa/
[12] Thomas Gastl, Stadt Augsburg, Tiefbauamt, Öffentliche Beleuchtung und Verkehrstechnik

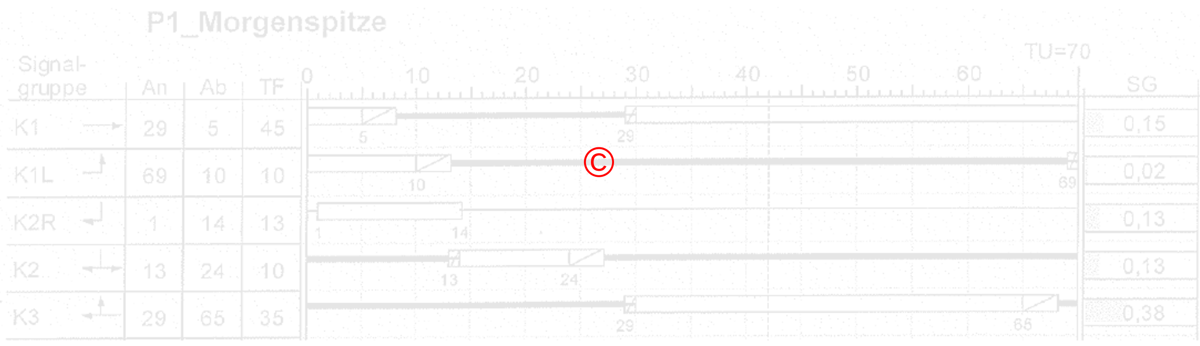


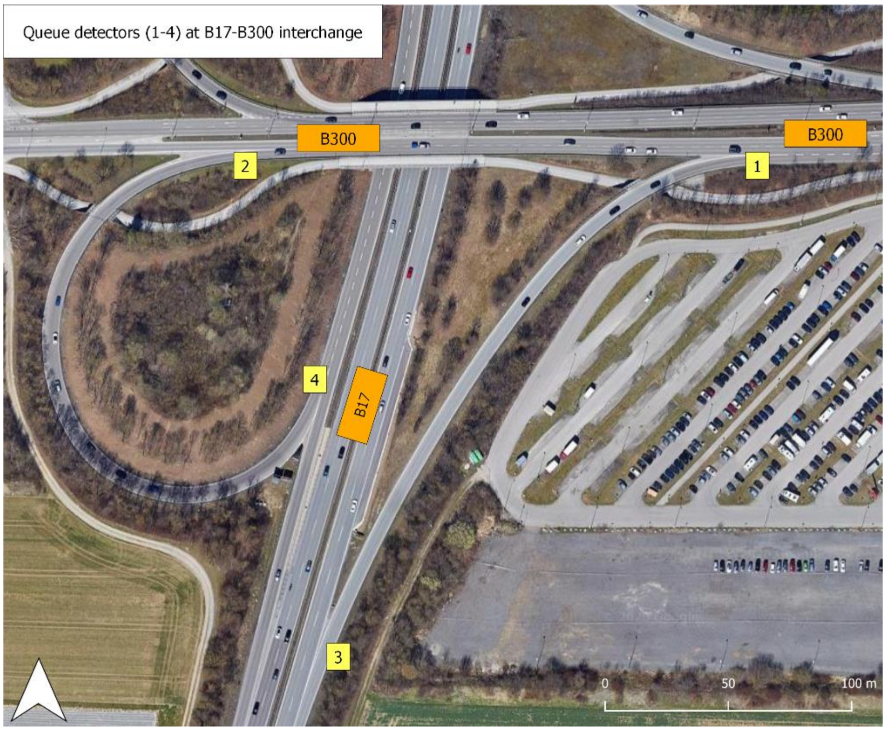
Figure 29: Signal program at Bgm. Ulrich Str. B17 eastern ramp during morning peak hour *(Source: Tiefbauamt)*

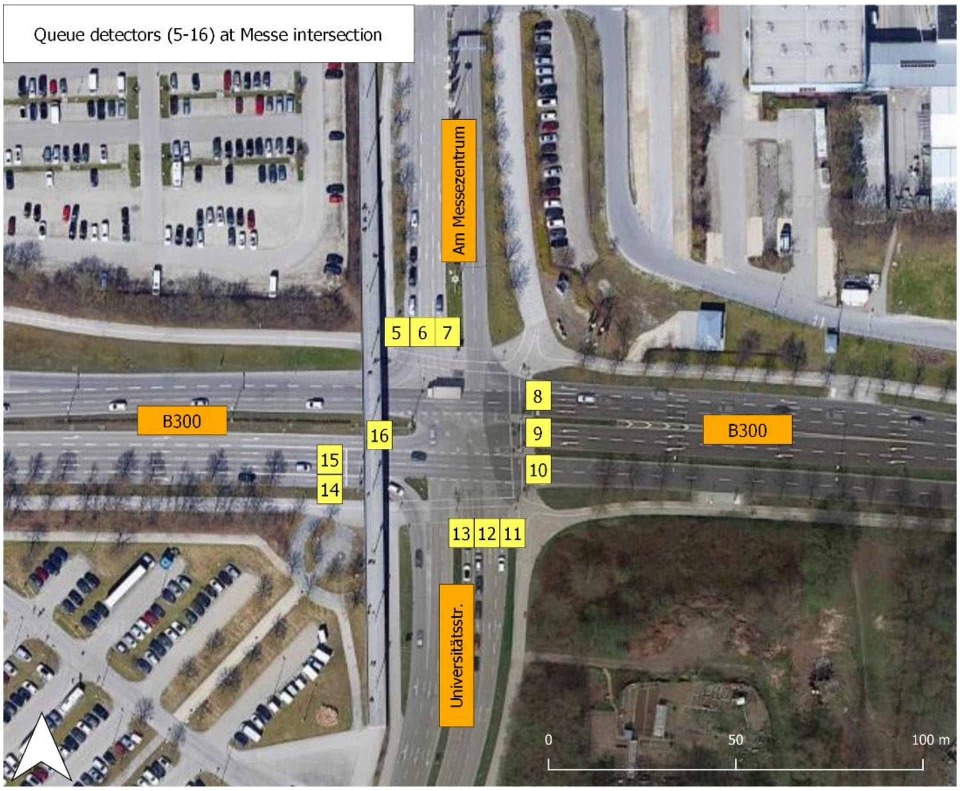
Stop signs:

To reflect the stops for payment at the parking lot entrances, stop signs have been placed on north and south parking lot entrances. Dwell time can be defined for each vehicle class at stop signs.

Queue detectors:

B17 highway is connected to B300 via two exit ramps. Therefore, if traffic in B300 exceeds the queuing space on exit ramps, it will enter into B17 and cripples the traffic on it. So, in Sprint 1 two queue counters (queue detectors) have been put on the B300-exit ramps intersection. In Sprint 2, two other queue counters (3 and 4) have been added to the start point of the ramps (where traffic diverges from the highway to ramps). These points are accident-prone. In Sprint 3, more queue counters have been added to the signalized intersections (Figure 30).





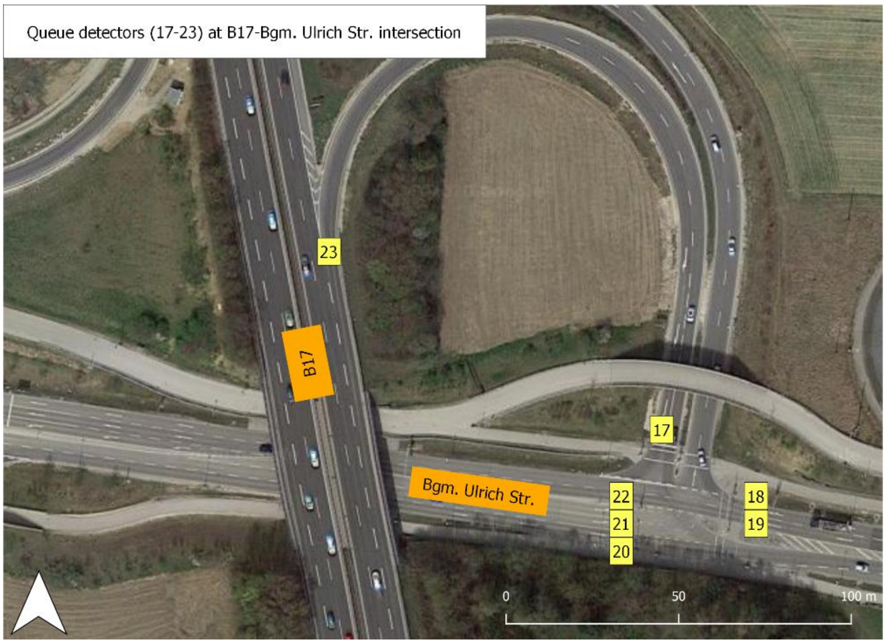


Figure 30: Queue detectors (1-4) at B17 Messe exit ramps (to B300), queue detectors (5-16) at Messe intersection, and queue detectors (17-22) at B17 eastern ramp/ Bgm. Ulrich Str. intersection (Basemap: Google Satellite) *(Created by Author)*

Scenarios

Scenarios are divided into three categories (Figure 31): 1. Parking lot payment method (dwell time) analysis, 2. Travel demand sensitivity analysis, and 3. Guidance scenarios.

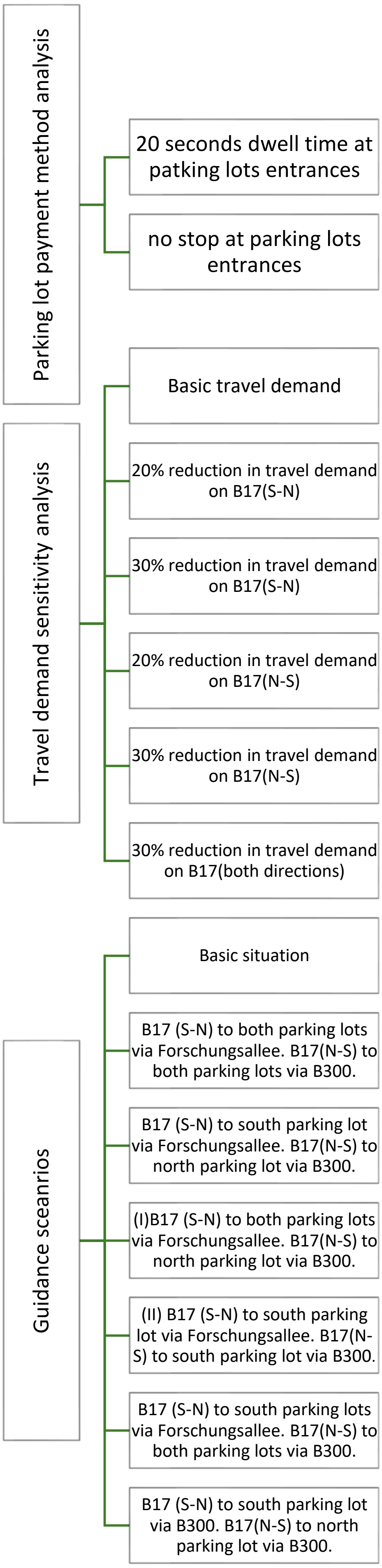


Figure 31: Scenario categories

Parking lot payment method (dwell time) analysis

Scenario D1[13]:

This scenario refers to the case, when vehicles stop at parking lots entrances for 20 seconds (to pay the parking fee to cashier, etc.).

Scenario D2:

This scenario refers to the modified payment method. Therefore, vehicles enter the parking lots without any stop at the entrance. This scenario is similar to scenario 1.1.

Travel demand sensitivity analysis

In this traffic model, the sensitivity analysis of travel demand measures how the impact of reduced travel demand (changes in vehicle input variable) can lead to different queue lengths (output variables). Reduced travel demand may occur because of the promotion of using public transport to reach Messe, using the available Park & Ride facilities, etc.

In All scenarios in this category: Vehicles find access to parking lots through B300 (Forschungsallee is not under service), and there is no dwell time at parking lots entrances.

Scenario 1.1:

Travel demand on B17 south to north is calculated based on the traffic counting data provided by Stadt Augsburg Tiefbauamt.

Scenario 1.2:

Travel demand on B17 south to north is reduced to 80% of existing travel demand from 7:00 to 9:00.

Scenario 1.3:

Travel demand on B17 south-north is reduced to 70% of existing travel demand from 7:00 to 9:00.

Scenario 1.4:

Travel demand on B17 north-south is reduced to 80% of existing travel demand from 7:00 to 9:00.

Scenario 1.5:

Travel demand on B17 north-south is reduced to 70% of existing travel demand from 7:00 to 9:00.

---

[13] D stands for Dwell

Scenario 1.6:

Travel demand on B17 (both directions) is reduced to 70%.

Guidance scenarios (with/out Forschungsallee)

Vehicles on B17 (from north to south(N-S) and from south to north(S-N)) find access to Messe parking lots (north and south) via either B300 or Forschungsallee. However, the Forschungsallee is not a functional (practical and useful) access road for vehicles on B17 north to south (N-S).

Table 11 shows the possible accessibility options for vehicles to parking lots. The orange cells are the scenarios that are going to be modeled in this project.

Table 11: Guidance matrix; Forsch.=Forschungsallee *(Created by Author)*

			B17(N-S)					
			North parking lot		South parking lot		Both parking lots	
			via B300	via Forschungsallee	via B300	via Forschungsallee	via B300	via Forschungsallee
B17(S-N)	North parking lot	via B300	not realistic for Messe days	not applicable	not realistic for Messe days	not applicable	not realistic for Messe days	not applicable
		via Forsch.	not realistic for Messe days	not applicable	interesting, but not in the scope of this thesis	not applicable	not in the scope of this thesis	not applicable
	South parking lot	via B300	Scenario 2.6	not applicable	not realistic for Messe days	not applicable	not suitable due to lane changes	not applicable
		via Forsch.	Scenario 2.3	not applicable	Scenario 2.4(II)	not applicable	Scenario 2.5	not applicable
	Both parking lots	via B300	not realistic for Messe days	not applicable	not realistic for Messe days	not applicable	Scenario 2.1	not applicable
		via Forsch.	Scenario 2.4(I)	not applicable	interesting, but not in the scope of this thesis	not applicable	Scenario 2.2	not applicable

Scenario 2.1:

base situation: both streams on B17 find access to both parking lots via B300

Scenario 2.2:

- B17 (S-N) finds access to both parking lots via Forschungsallee.
- B17 (N-S) finds access to both parking lots via B300.

Scenario 2.3:

- B17 (S-N) finds access to south parking lot via Forschungsallee.
- B17(N-S) finds access to north parking lots via B300.

Scenario 2.4:

- Phase I:
  - B17 (S-N) finds access to both parking lots via Forschungsallee.
  - B17(N-S) via B300 to north parking lot until the north parking lot is full,
- Phase II:
  - B17 (S-N) finds access to south parking lot via Forschungsallee.
  - B17 (N-S) finds access to south parking lots via B300.

Scenario 2.5:

- B17 (S-N) finds access to south parking lot via Forschungsallee.
- B17(N-S) finds access to both parking lots via B300.

Scenario 2.6:

- B17 (S-N) finds access to south parking lot via B300.
- B17 (N-S) finds access to north parking lot via B300.

5. Results & Discussion

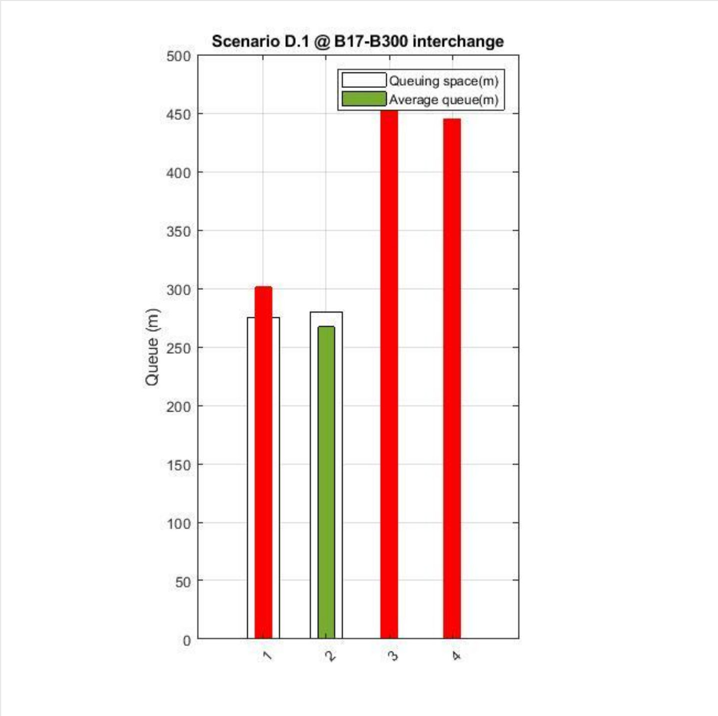
In this chapter, the main findings of the simulation are reported and discussed.

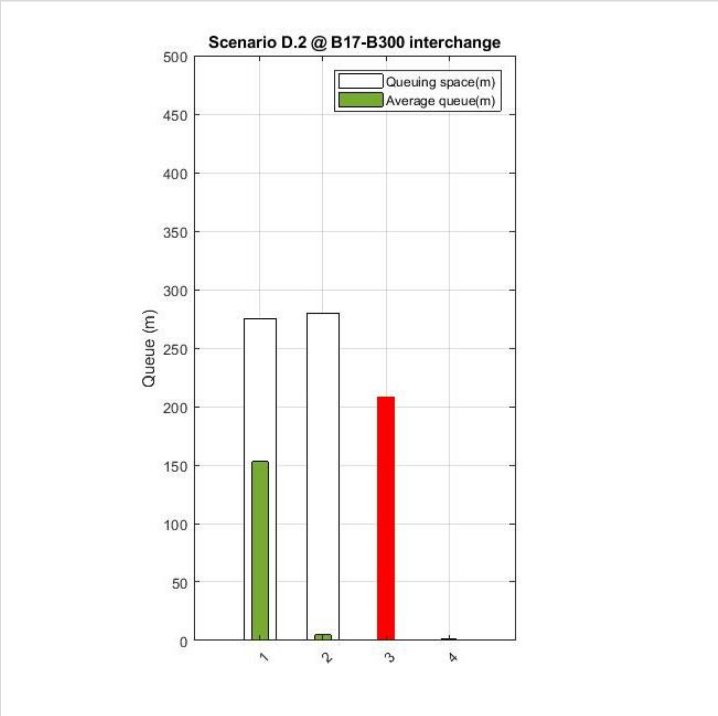
This model simulates three hours (from 6:00 to 9:00 AM), which include the morning rush hours. Each scenario has been simulated with 10 different random seeds (logical value range: depends on use case 5 - 20.). In fact, the variation of the random seed is used for the stochastic saving of results. Varying the random seed allows you to simulate stochastic variations of vehicle arrivals in the network, which may result in different simulation results. So, we can check meaningful values for various result attributes during its evaluations, e.g. minimum value, maximum value, and mean (36).

The following results indicate the average of average queue length of 10 simulation runs for each scenario. Average queue length is the arithmetic mean of queue length upstream by the queue counter. You can find the maximum values in *Appendix: Average maximum queue length for different scenarios*. It is noticeable that the maximum queue length has an instant nature; because, even if this queue length happens at one time step, the whole indicator will change. Therefore, average queue length has been chosen as the basis to compare different scenarios.

Figure 32 to Figure 34 show the results for parking lot payment method (dwell time) analysis. The bar chart shows the average queue length (green bar), and the queuing space (hollow bar) upstream each queue detector. In all bar charts when the average queue length exceeds the queueing space, the bar is brushed with red color. You can check the location of the queue detectors on the provided maps. The detailed results (similar to Figure 32 to Figure 34) for travel demand sensitivity analysis and guidance scenarios have been placed in *Appendix: Detailed results for travel demand sensitivity analysis and guidance scenarios*.

Figure 49 to Figure 56 show the results for travel demand sensitivity analysis. Figure 57 to Figure 65 show the results for guidance scenarios (with/out Forschungsallee). You can find a schematic of scenarios next to the results.





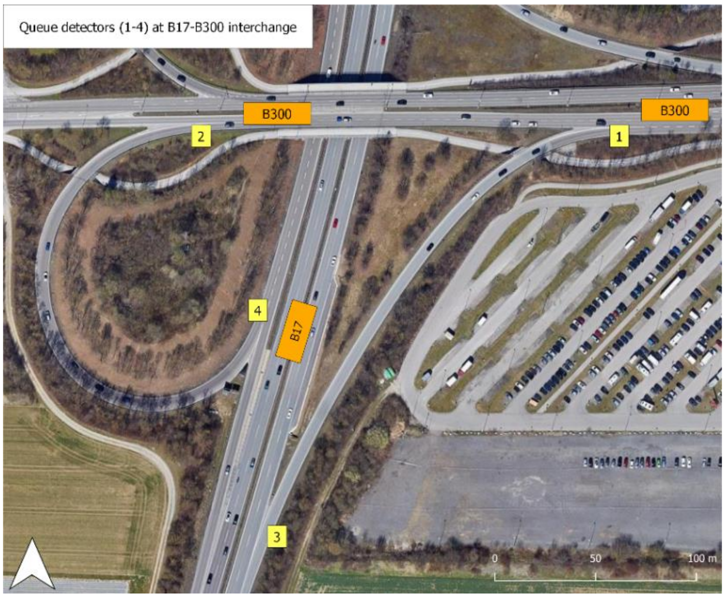
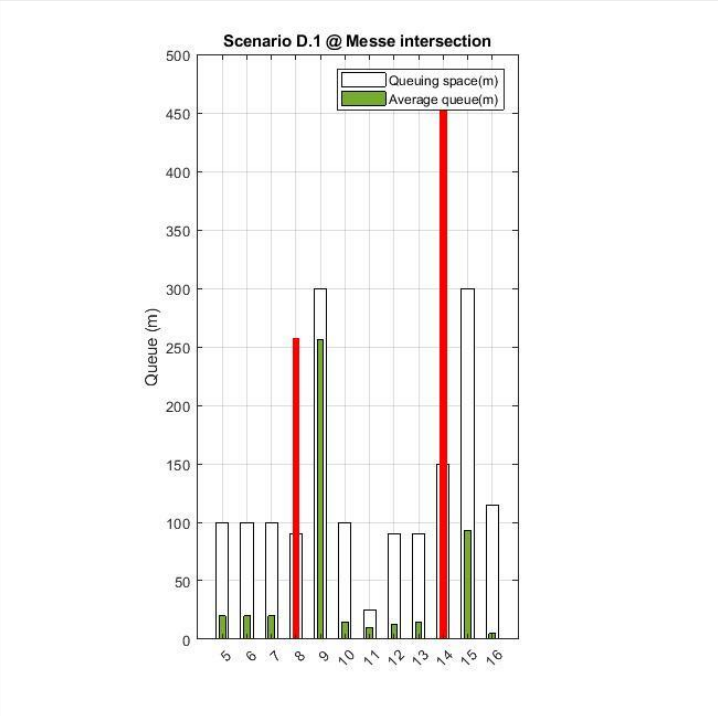


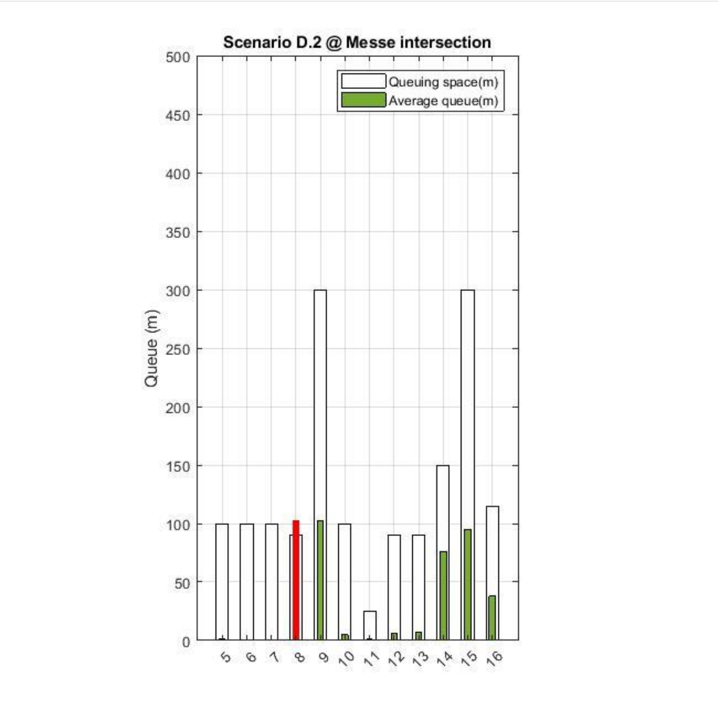
Figure 32: Scenario D.1 and scenario D.2 results at B17-B300 interchange

top: Queue results for scenario D.1 at queue detectors (1-4) at B17-B300

middle: Queue results for scenario D.2 at queue detectors (1-4) at B17-B300 interchange

bottom: Location of queue detectors (1-4) on map





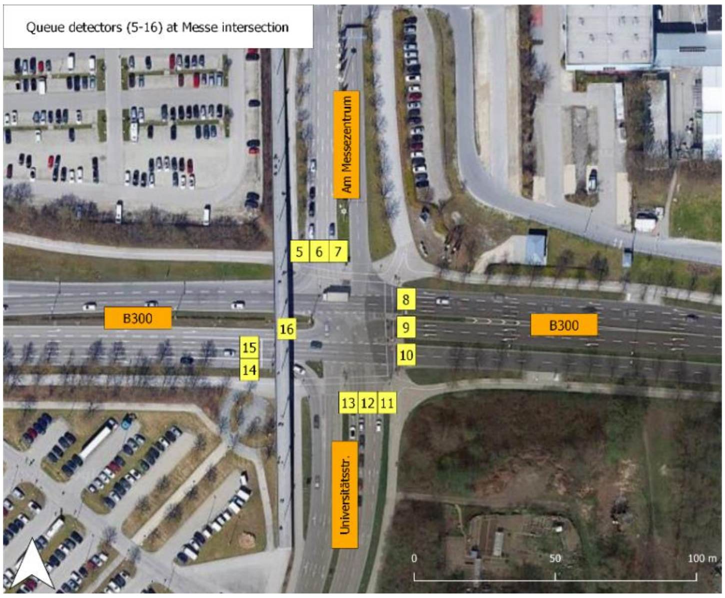
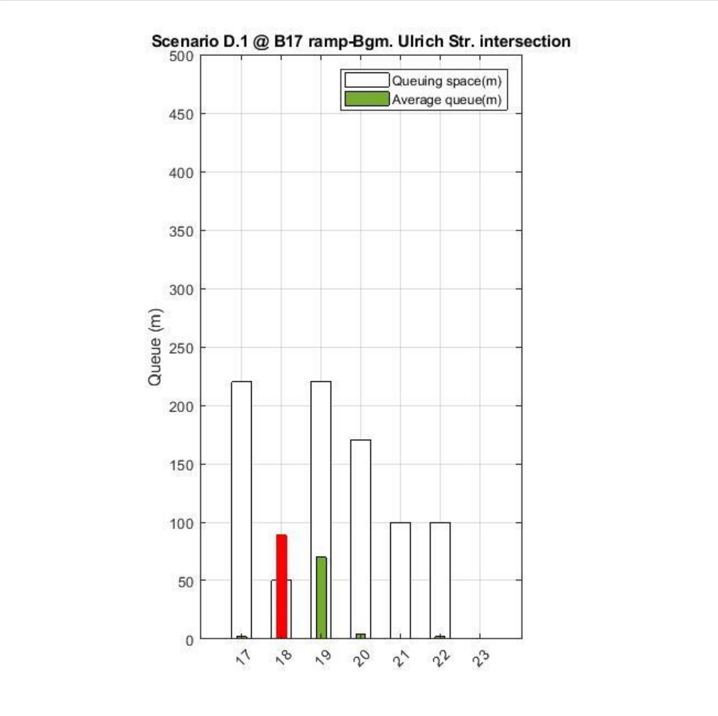


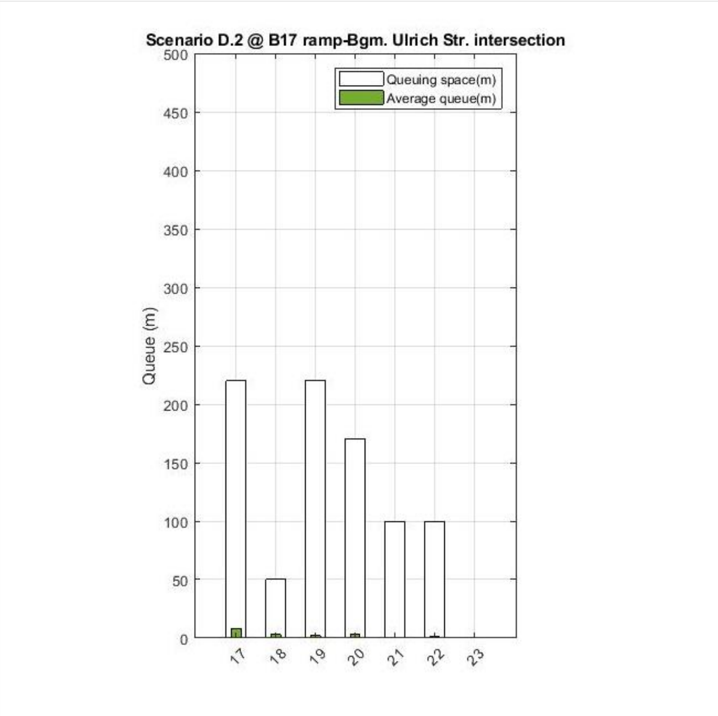
Figure 33: Scenario D.1 and scenario D.2 results at Messe intersection

top: Queue results for scenario D.1 at queue detectors (5-16) at Messe intersection

middle: Queue results for scenario D.2 at queue detectors (5-16) at Messe intersection

bottom: Location of queue detectors (5-16) on map





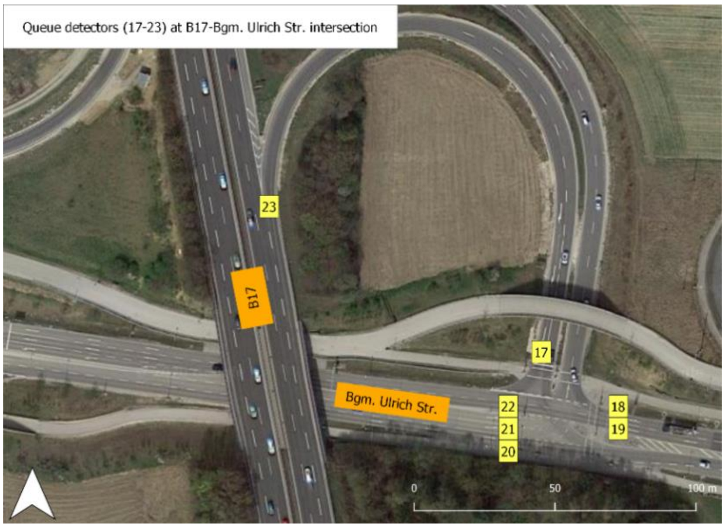


Figure 34: Scenario D.1 and scenario D.2 results at B17 ramp/Bgm. Ulrich Str. intersection

top: Queue results for scenario D.1 at queue detectors (17-23) at B17 ramp/Bgm. Ulrich Str. intersection

middle: Queue results for scenario D.2 at queue detectors (17-23) at B17 ramp/Bgm. Ulrich Str. intersection

bottom: Location of queue detectors (17-23) on map

In the following the results shown in the previous section and *Appendix: Detailed results for travel demand sensitivity analysis and guidance scenarios are discussed*.

5.1. Parking lot payment method (dwell time) analysis

Stopping at parking lot entrances to pay the parking fees to a cashier brings about long queues, especially upstream right-turn lanes to parking lots (queues upstream queue detectors 8 and 14). The queue on the right-turn lane to the south parking lot can grow into the Messe exit ramps on B17 highway, and after a while, it interferes with the traffic on B17 (queues upstream queue detectors 3 and 4). These statements are based on a comparison between two simulations with different dwell time at parking lot entrances; the first one with 20 seconds dwell time and the next one with no dwell time at parking lots entrances. It is noticeable that, payment time to a cashier depends on many factors, e.g. if the driver pays the exact fee or waits for a return, if the driver asks questions from the cashier, etc. Moreover, traffic disturbance on B17 may affect B17 eastern ramp/ Bgm. Ulrich Str. intersection, too, because the congestion will not allow the traffic from Bgm Ulrich Str. to enter the B17 via on-ramp (queues upstream queue detector 18).

There exist several smart payment methods, including an automatic ticket dispenser with a self-service payment method. In addition to faster service process at parking lot entrances, information like the number of free spaces, demand distribution over time (for further *Operations Research* studies) can be extracted from this system.

5.2. Travel demand sensitivity analysis

Scenario 1.1: This scenario models the current situation. Therefore, the network does not include Forschungsallee, and the traffic data have been generated based on the traffic data provided by Tiefbauamt. The average queue bar chart shows that we face queues in the northern part of the network, where traffic exits from B17 (south-north) to B300 via an exit ramp. Moreover, queues are formed on the right-turn lane to both parking lots (queue detectors 8 and 14).

Scenario 1.2 and 1.3: The results suggest that by 20% and 30% decrease in Messe travel demand coming from B17 (south-north), average queue lengths upstream the queue detectors stay almost the same (with minor changes). In fact, although there is a decrease in the number of vehicles to parking lots, there are still a lot of vehicles traveling from B17 (south-north) to the eastern part of B300.

Scenario 1.4 and 1.5: The results suggest that, in contrast to 1.2 and 1.3, by 20% and 30% decrease in Messe travel demand on B17 (north-south), there would decreases in average queue lengths at the queue detectors, and the traffic will move smoother from B17 (south-north) to B300.

Scenario 1.6: The results suggest that, by decreasing travel demand on both directions of B17 by 30%, the average queue lengths at detectors are more or less similar to the results of 1.4.

It is noticeable that queues upstream queue detector 8 are almost the same in all scenarios; because, in this project, we did not manipulate the conditions in the eastern part of B300.

Figure 35 to Figure 39 show the comparison of different scenarios at queue detector 1 and 3 (end and start of B17(south-north) Messe exit ramp), and queue detectors 14, 15, and 16 (western part of Messe intersection). Based on the results of queue detectors 1 and 3, scenario 1.6, which is cutting travel demand to Messe from B17 by 70%, has the best results. Based on the results of queue detector 14 (right-turn lane to the south parking lot), 15, and 16 (left-turn lane to the south parking lot), scenario 1.4, 1.5, and 1.6 have more or less the same results. This implies that travel demand reductions on B17 (north-south) are more effective on the result.

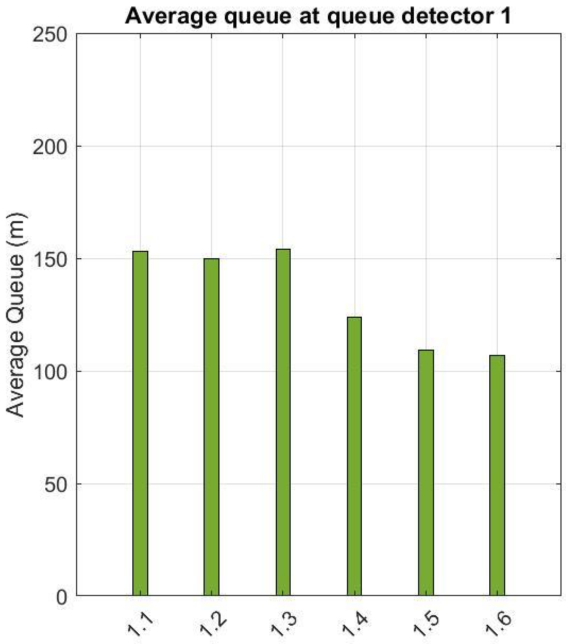


Figure 35: Average queue length comparison at queue detector 1 (Travel demand sensitivity analysis)

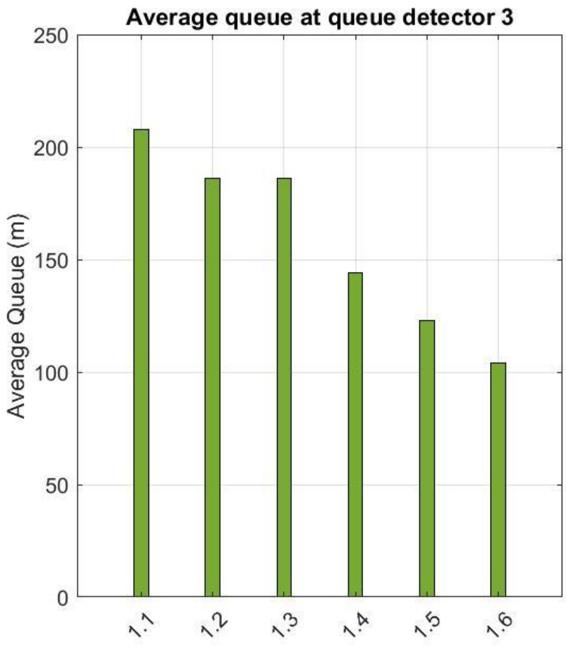


Figure 36: Average queue length comparison at queue detector 3 (Travel demand sensitivity analysis)

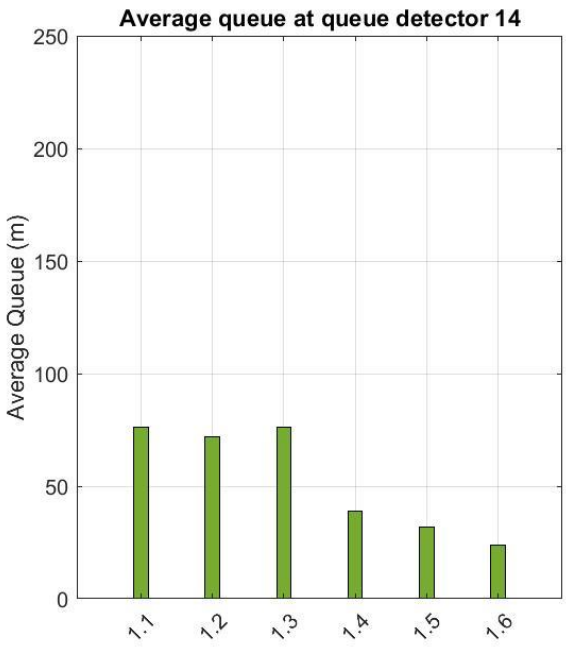


Figure 37: Average queue length comparison at queue detector 14 (Travel demand sensitivity analysis)

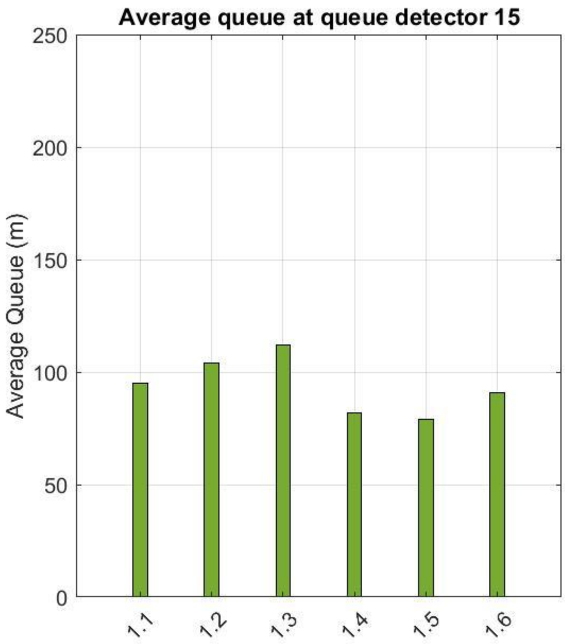


Figure 38: Average queue length comparison at queue detector 15 (Travel demand sensitivity analysis)

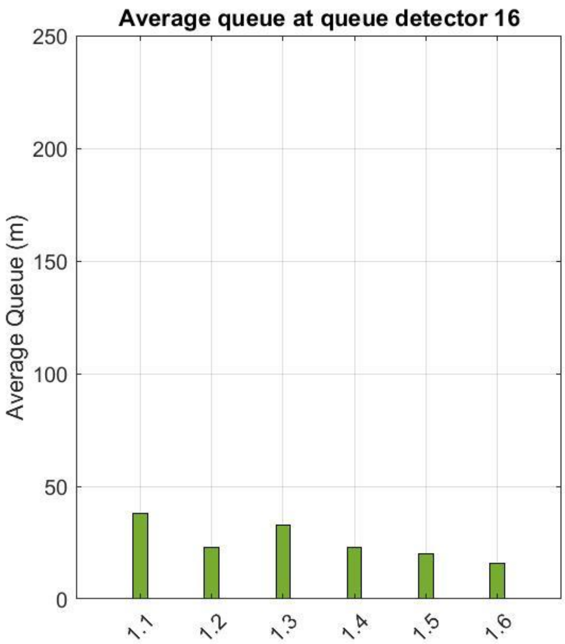


Figure 39: Average queue length comparison at queue detector 16 (Travel demand sensitivity analysis)

5.3. Guidance scenarios (with/out Forschungsallee)

Scenario 2.1: This scenario models the base situation; the network includes Forschungsallee, and parts of Universitaetsstr., which connects to Forschungsallee in the future, and the background traffic on this part of the network. In all scenarios of this category the B17 eastern ramp/ Bgm. Ulrich Str. intersection has been widened partly: two left-turn lanes to

Forschungsallee (starting from north of intersection), and Forschungsallee south-north is a two-lane street for 150 meters (starting from Bgm. Ulrich Str.). The results show that there would be traffic jams on Messe exit ramps and on B300 near Messe intersection.

Scenario 2.2: The results suggest that by guiding the traffic on B17 (south-north) to both parking lots via Forschungsallee, the traffic on Messe exit ramps will be prevented, and traffic at Messe intersection is smoothed. However, the traffic jam will be transferred to the southern part of the network, where vehicles want to exit B17 via Arena exit ramp, and enter Forschungsallee. This problem can be solved by implementing a customized signal program (has been done in Sprint 3 of this research project; see *Appendix: Customized signal program*, or reconstructing the B17 eastern ramp/ Bgm. Ulrich Str. intersection (more than what has been implemented in this model).

Scenario 2.3: The results suggest that by guiding the traffic on B17 (south-north) to *only* south parking lot via Forschungsallee, and the traffic on B17(N-S) *only* to north parking lots via B300, the overall traffic situation on Messe exit ramps will be improved. However, at some points in the modelling period, queues grow into B17. Therefore, Scenario 2.3 works less efficiently than scenario 2.2. Again the downside of this scenario is that the traffic jam will be transferred to the southern part of the network, where vehicles want to exit B17 via Arena exit ramp, and enter Forschungsallee. This problem can be solved by implementing a customized signal program or reconstructing the B17 eastern ramp/ Bgm. Ulrich Str. intersection.

Scenario 2.4: The results suggest that by guiding traffic differently, when parking lots are/not available, the system behaves stabler. this statement has been made based on the fact, that the queue results at queue detectors have been improved in comparison with 2.3.

Scenario 2.5: The results suggest that by guiding the traffic on B17 (south-north) to *only* south parking lot via Forschungsallee, and the traffic on B17(north-south) to both parking lots via B300 the system behaves similar to scenario 2.2.

Scenario 2.6 results suggest that, by guiding the traffic on B17 (south-north) to *only* south parking lot via B300, and the traffic on B17(north-south) to the north parking lot via B300, the queue lengths will decrease in comparison to scenario 2.1 (base scenario) where B17(south-north) exits B17 via Messe ramp. However, average queue lengths will increase at Messe intersection, which makes this solution undesirable.

Figure 40 to Figure 44 show the comparison of different scenarios at queue detector 1 and 3 (end and start of B17(south-north) Messe exit ramp), and queue detectors 14, 15, and 16 (western part of Messe intersection). Based on results of queue detectors 1 and 3, scenario 2.2, 2.3, 2.4, and 2.5 have the best results, and scenario 2.6 is better than the basic situation

(Figure 40 and Figure 41). Based on the results of queue detector 14 (right-turn lane to the south parking lot), scenario 2.2, 2.3, 2.4, and 2.5 have the best results. However, in contrast to queue detectors 1 and 3, scenario 2.6 is worse than the basic situation (Figure 42). Based on the results of queue detector 15 and 16 (straight lane from west to east of Messe intersection, and left-turn lane to the north parking lot), scenario 2.2 and 2.5 are the best. Similar to detector 14, scenario 2,6 has worse results than the basic situation (Figure 43 and Figure 44). Therefore, scenario 2.2 and 2.5 are the best scenarios (2.2 is even better), and scenario 2.6 is not recommended to be used.

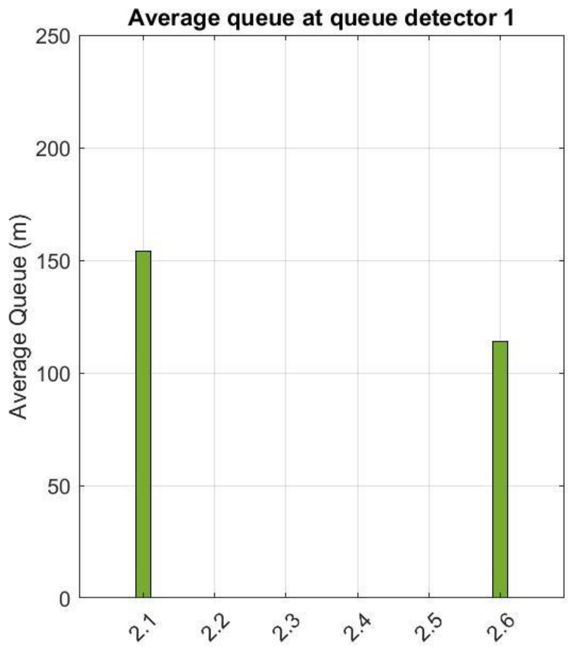


Figure 40: Average queue length comparison at queue detector 1 (Guidance scenarios)

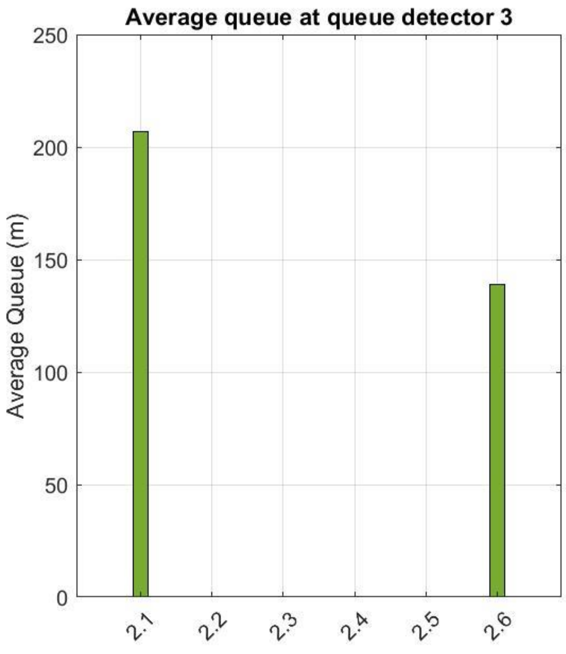


Figure 41: Average queue length comparison at queue detector 3 (Guidance scenarios)

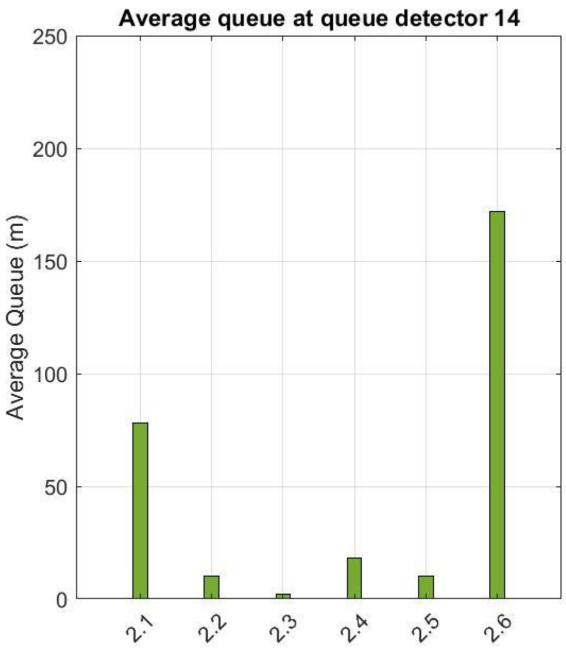


Figure 42: Average queue length comparison at queue detector 14 (Guidance scenarios)

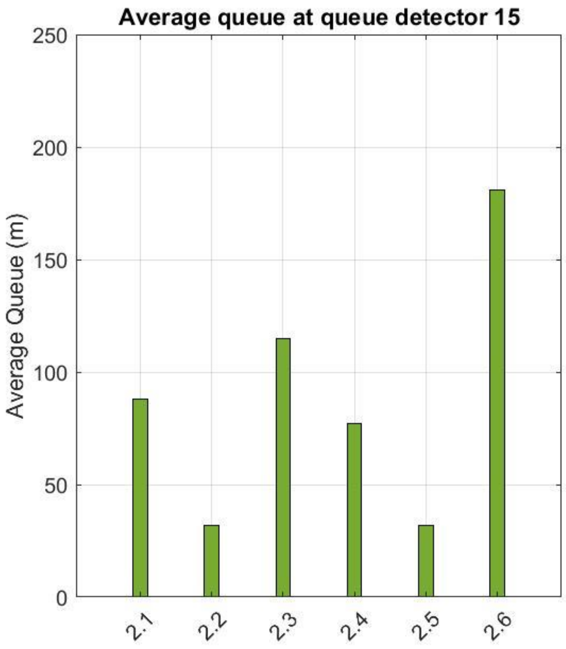


Figure 43: Average queue length comparison at queue detector 15 (Guidance scenarios)

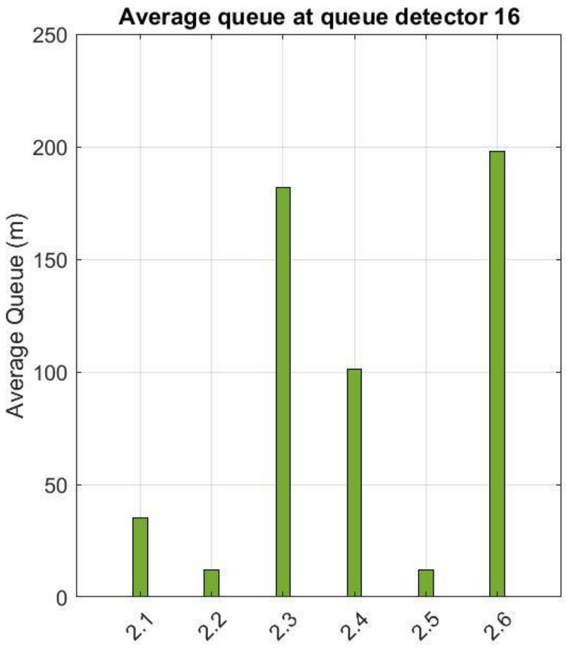


Figure 44: Average queue length comparison at queue detector 16 (Guidance scenarios)

5.4. Rule-based traffic management concept

Guiding the traffic on B17 (south-north) to Messe parking lots via Forschungsallee will improve traffic flow and traffic distribution in the network around Messe Augsburg, and will reduce congestion at Messe intersection and B17 Messe exit ramps. Using Forschungsallee as an alternative route is possible, because it is less utilized (compared to B17), and it has free capacities even in the foreseeable future. Therefore, it can avoid the capacity overloads on the original access roads to Messe parking lots from B17.

To control the traffic in the road network around Messe Augsburg, first, by checking the switch-on criteria, the congestion should be detected; then, the appropriate strategy (scenario) should be decided and implemented. Finally, the termination of the congestion should be detected (switch-off criteria), and the strategy should be deactivated/ changed.

In urban networks, a combination of *occupancy* and *speed* can be checked as congestion criteria. Inductive loop detectors that are normally embedded in each lane of the roadway at regular intervals on the network, report the number of passing vehicles, and the percentage of time that it was covered by a vehicle (e.g. every 30 seconds). The number of vehicles is called *flow*, and the percent coverage is called the *occupancy* (37). The following conditions have been extracted from the algorithms in MARZ, 1999 (current version in 2014) (38).

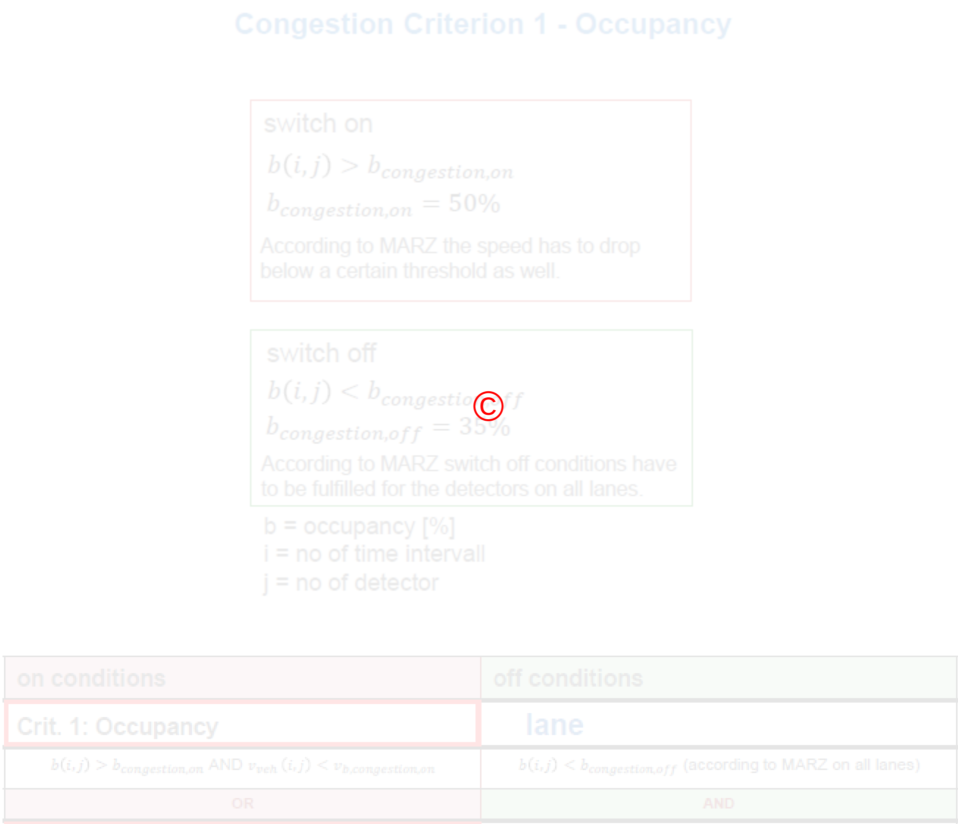


Figure 45: occupancy as an indicator of growing queue lengths *(Source:* (38)*)*

It is noticeable that, to avoid the oscillation between scenarios the switch-on and switch-off thresholds are not the same. Moreover, to avoid flipping over different scenarios a minimum running time is set for each scenario (e.g. 15 minutes).

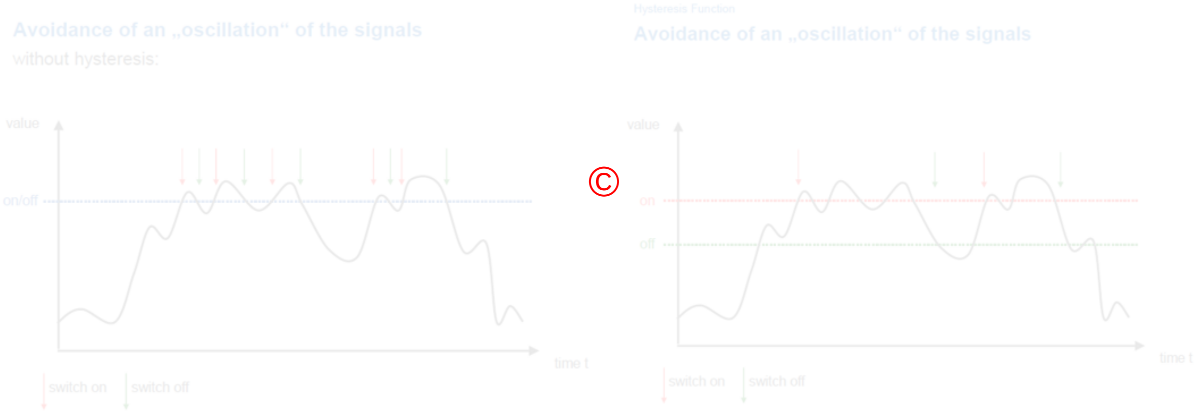


Figure 46: Hysteresis function to avoid oscillation between scenarios *(Source:* (38)*)*

The congestion can be detected by an operator in a traffic control center. Besides, the queue lengths upstream of the queue detectors can be measured using image processing sensors and cameras installed above the approach lanes (39). Furthermore, there are research papers that estimate the queue lengths based on a roll time occupancy data (40).

However, to confirm the plausibility of growing queue lengths (or increasing occupancy), and to smooth out rapid fluctuations and decide based on longer-term trends, a moving average of the time series data should be used (e.g. 10 minutes rolling average of queue lengths).

Based on the results, the following concept for a rule-based system for traffic management (dynamic traffic guidance) around Messe Augsburg is recommended (Figure 47 and Figure 48):

Based on the flowchart in Figure 47, the 10-minute rolling average of queues upstream queue detectors 14 (B300 (west-east) right-turn lane to the south parking lot) and 16 (B300 (west-east)left-turn lane to the north parking lot) are compared with 50% queuing space. If the queues exceed 50% of queuing space, the system will be switched to the substitute scenario. The substitute scenario will be chosen considering if there are parallel events in Messe and Arena and free spaces in the north parking lot are available. To switch off the substitute scenario, two conditiones are controlled: the minimum running time of the substitute scenario and the 10-minute rolling average of queues upstream queue detectors 14 and 16 compared to 35% of queuing space.

Based on the flowchart in Figure 48, the occupancies of loop detectors on B300 between B17 Messe exit ramp and Messe intersection are compared with 50% occupancy. If the occupancy of a detector in a selected time interval exceeds 50%, and the vehicle speeds are less than the congestion speed threshold(e.g. 35 km/hr). , the system will be switched to the substitute scenario. The substitute scenario will be chosen based on if there are parallel events in Messe and Arena and free spaces in the north parking lot are available. To switch off the substitute scenario, these conditions are controlled: the minimum running time of the substitute scenario , and the occupancy of a detector in a selected time interval should be less than 35%.

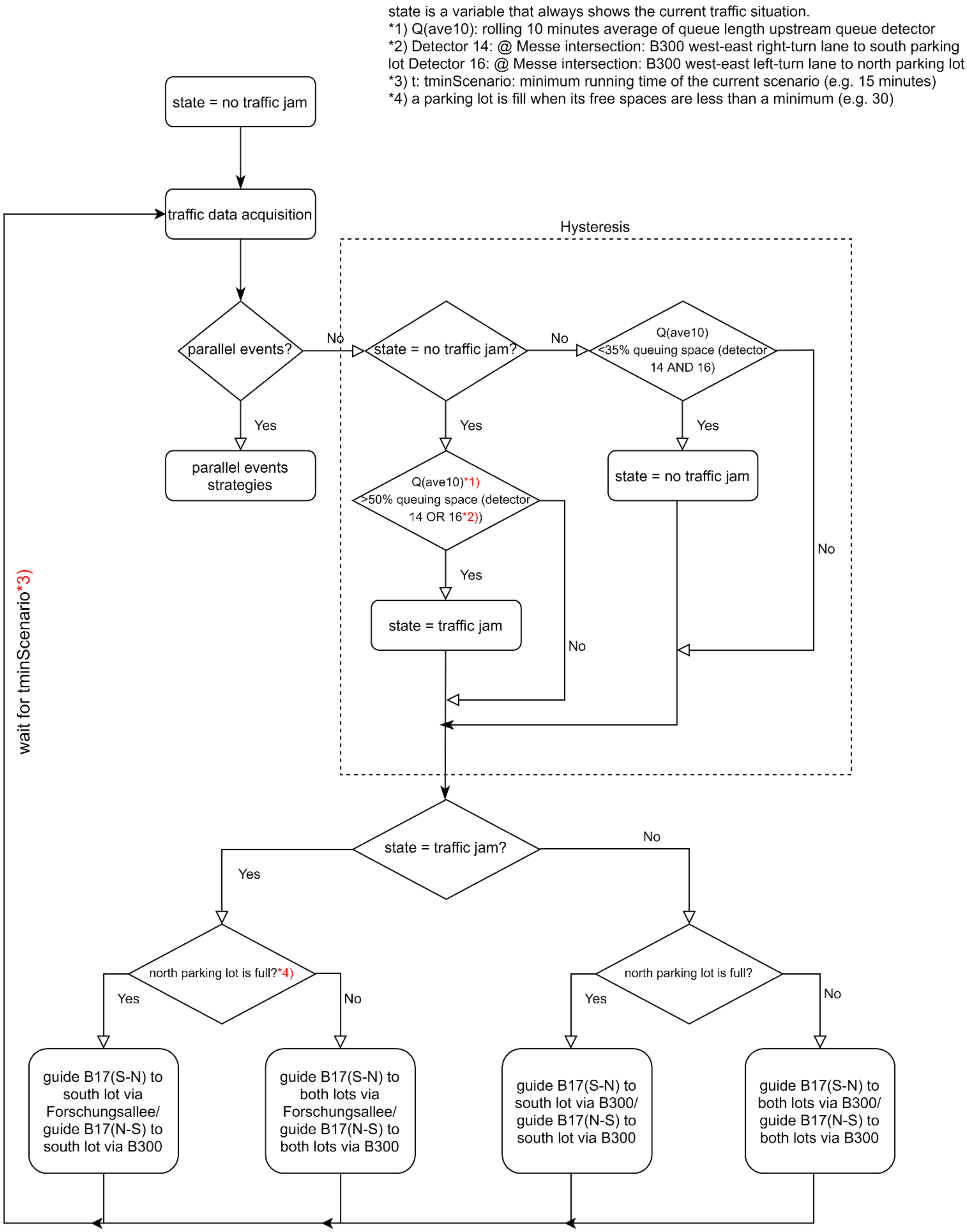


Figure 47:Rule-based traffic management concept (criteria: queuing space) *(Created by Author)*

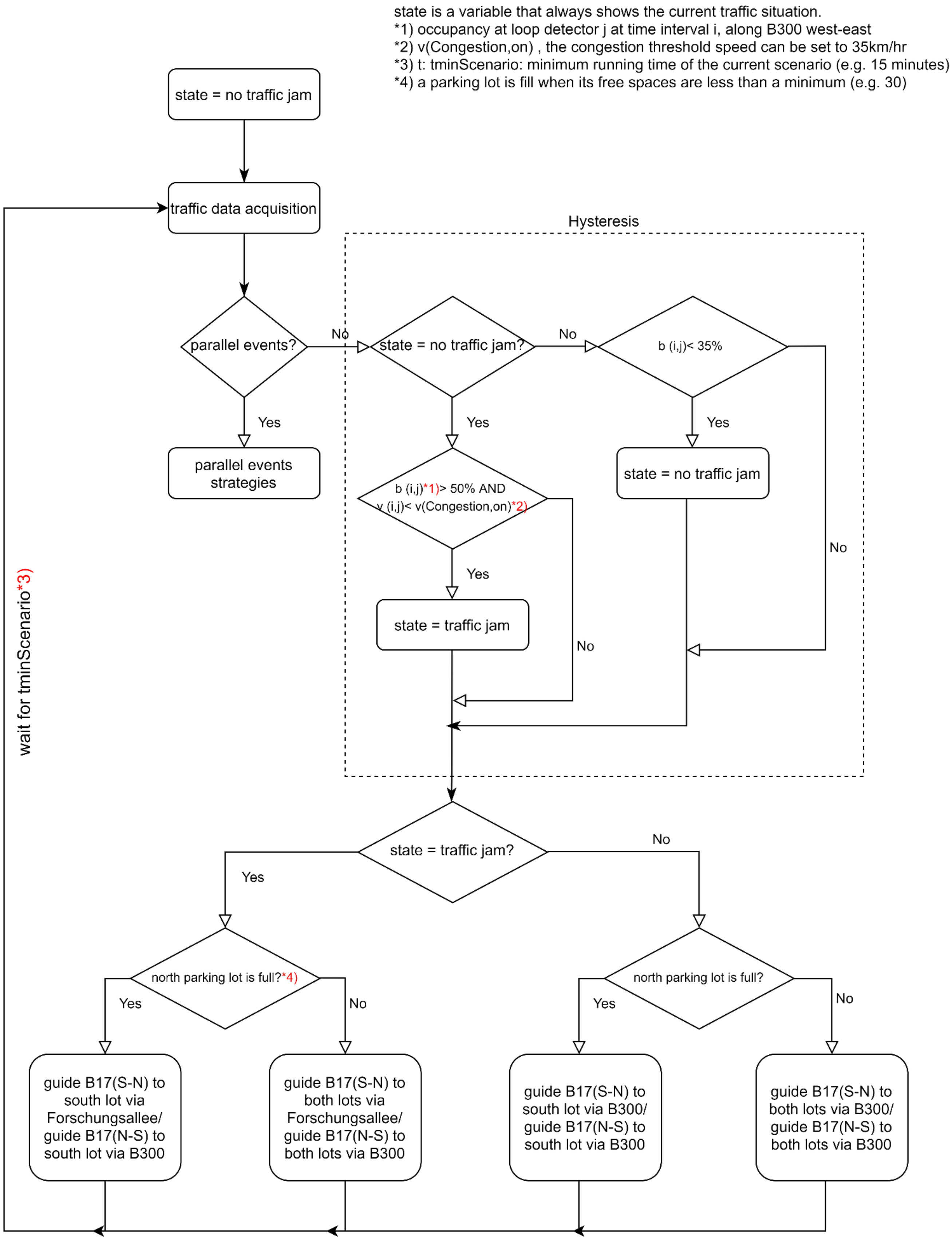


Figure 48:Rule-based traffic management concept (criteria: loop detector occupancy and threshold speed)
(Created by Author)

6. Conclusion

This thesis project set out to address a dynamic tarffic management concept around Messe Augsburg during events with simulation-based research. This research aimed to identify the system elements and their problems in the study area to some extent, and compare different traffic management strategies via traffic micro-simulation. Based on a simulation-based analysis of average queue lengths upstream several queue detectors in the study area in response to changes in dwell time at parking lots entrances, Messe travel demand coming from B17, and guiding part of traffic to Messe parking lots via Forschungsallee Str., it can be concluded that zeroing out the dwell time at parking lots entrances, decreasing Messe travel demand on B17 (north-south) to 70%, and guiding the Messe traffic on B17 (south-north) to Messe parking lots, are important game-changers to consider when designing an efficient traffic management system for Messe Augsburg.

Traffic flow simulation (using PTV Vissim software package) has been a powerful analysis tool in this research. Due to the outbreak of Coronavirus during doing this thesis project, all events in Messe Augsburg were canceled. Therefore, there was no chance to observe the real traffic disturbances in the study area. However, traffic simulation was very helpful also in modeling the current situation. While the lack of traffic counting data on a single day in the whole network made the researcher make a set of assumptions for vehicle input and static routes calculations, this approach provides a platform to *compare* a set of future scenarios. This research clearly illustrates that changing the current payment method at parking lots is an effective measure in smoothing the traffic situation on the whole network in the study area. Moreover, it shows that a 30% decrease in Messe travel demand coming from B17 (north-south) has a decreasing effect on average queue lengths at queue detectors. However, Messe travel demand reduction on B17 (south-north) was not as effective as what the researcher expected. Finally, guiding the traffic on B17 (south-north) to Messe parking lots via Forschungsallee cushions the severe traffic disturbances especially on B17 (south-north)-B300 off-ramp. But, it will negatively affect the traffic at B17 (south-north) Arena exit ramp/ Bgm. Ulrich Str. Therefore, there should be modifications to the signal program at both intersections. However, the results also raise the question that what is the effect of the acceptance rate of drivers in following the guidance information (thesis assumption: 100% acceptance rate), and how to increase this rate.

Further research is needed to determine the effects of acceptance of drivers in following the guiding information to parking lots on variable message signs. As a further matter, reductions in Messe travel demand by private transport can be addressed; e.g. introduction of some park and ride facilities, where vehicles from B17 (north-south) can exit the network, and continue to Messe by riding on public transport. Moreover, to better understand the implications of these results, future studies can address the modeling of future scenarios through Vissim COM, where it is possible to model the rule-based concept introduced in this project.

Appendices

Appendix: OD-matrixes in sub-networks in study area

Messe intersection / vehicle volumes					
8:00 AM					
to from	A'	B'	C'	D'	sum
A'	0	277	58	414	749
B'	39	0	3	963	1005
C'	106	160	0	942	1208
D'	91	716	117	0	924
sum	236	1153	178	2319	

B17-B300 / car volumes					
6:00 AM					
to from	A	B	C	D	sum
A	0	270	2192	0	2462
B	394	0	564	225	1183
C	1492	316	0	0	1808
D	0	107	0	0	107
sum	1886	693	2756	225	

B17-B300 / car volumes					
7:00 AM					
to from	A	B	C	D	sum
A	0	343	2876	0	3219
B	922	0	916	435	2273
C	1954	336	0	0	2290
D	0	195	0	0	195
sum	2876	874	3792	435	

B17-B300 / HGV volumes					
6:00 AM					
to from	A	B	C	D	sum
A	0	18	110	0	128
B	15	0	18	10	43
C	210	32	0	0	242
D	0	7	0	0	7
sum	225	57	128	10	

B17-B300 / HGV volumes					
7:00 AM					
to from	A	B	C	D	sum
A	0	14	172	0	186
B	24	0	30	6	60
C	263	28	0	0	291
D	0	14	0	0	14
sum	287	56	202	6	

B17-B300 / vehicle volumes					
6:00 AM					
to from	A	B	C	D	sum
A	0	288	2302	0	2590
B	409	0	582	235	1226
C	1702	348	0	0	2050
D	0	114	0	0	114
sum	2111	750	2884	235	

B17-B300 / vehicle volumes					
7:00 AM					
to from	A	B	C	D	sum
A	0	357	3048	0	3405
B	946	0	946	441	2333
C	2217	364	0	0	2581
D	0	209	0	0	209
sum	3163	930	3994	441	

B17-B300 / car volumes					
8:00 AM					
to from	A	B	C	D	sum
A	0	279	2073	0	2352
B	597	0	571	336	1504
C	1548	241	0	0	1789
D	0	229	0	0	229
sum	2145	749	2644	336	

B17-B300 / car volumes					
9:00 AM					
to from	A	B	C	D	sum
A	0	252	1376	0	1628
B	499	0	494	295	1288
C	1280	218	0	0	1498
D	0	219	0	0	219
sum	1779	689	1870	295	

B17-B300 / HGV volumes					
8:00 AM					
to from	A	B	C	D	sum
A	0	22	198	0	220
B	25	0	30	8	63
C	276	42	0	0	318
D	0	5	0	0	5
sum	301	69	228	8	

B17-B300 / HGV volumes					
9:00 AM					
to from	A	B	C	D	sum
A	0	19	238	0	257
B	20	0	52	5	77
C	226	27	0	0	253
D	0	8	0	0	8
sum	246	54	290	5	

B17-B300 / vehicle volumes					
8:00 AM					
to from	A	B	C	D	sum
A	0	301	2271	0	2572
B	622	0	601	344	1567
C	1824	283	0	0	2107
D	0	234	0	0	234
sum	2446	818	2872	344	

B17-B300 / vehicle volumes					
9:00 AM					
to from	A	B	C	D	sum
A	0	271	1614	0	1885
B	519	0	546	300	1365
C	1506	245	0	0	1751
D	0	227	0	0	227
sum	2025	743	2160	300	

B17-Bgm. Ulrich / car volumes					
6:00 AM					
to from	A"	B"	C"	D"	sum
A"	0	200	0	41	241
B"	97	0	0	360	457
C"	0	0	0	0	0
D"	76	112	0	0	188
sum	173	312	0	401	886

B17-Bgm. Ulrich / car volumes					
7:00 AM					
to from	A"	B"	C"	D"	sum
A"	0	279	0	28	307
B"	203	0	0	499	702
C"	0	0	0	0	0
D"	102	164	0	0	266
sum	305	443	0	527	

B17-Bgm. Ulrich / HGV volumes					
6:00 AM					
to from	A"	B"	C"	D"	sum
A"	0	10	0	1	11
B"	3	0	0	10	13
C"	0	0	0	0	0
D"	1	4	0	0	5
sum	4	14	0	11	

B17-Bgm. Ulrich / HGV volumes					
7:00 AM					
to from	A"	B"	C"	D"	sum
A"	0	12	0	4	16
B"	11	0	0	24	35
C"	0	0	0	0	0
D"	6	7	0	0	13
sum	17	19	0	28	

B17-Bgm. Ulrich / vehicle volumes					
6:00 AM					
to from	A"	B"	C"	D"	sum
A"	0	210	0	42	252
B"	100	0	0	370	470
C"	0	0	0	0	0
D"	77	116	0	0	193
sum	177	326	0	412	

B17-Bgm. Ulrich / vehicle volumes					
7:00 AM					
to from	A"	B"	C"	D"	sum
A"	0	291	0	32	323
B"	214	0	0	523	737
C"	0	0	0	0	0
D"	108	171	0	0	279
sum	322	462	0	555	

B17-Bgm. Ulrich / car volumes					
8:00 AM					
to / from	A"	B"	C"	D"	sum
A"	0	233	0	16	249
B"	165	0	0	486	651
C"	0	0	0	0	0
D"	67	166	0	0	233
sum	232	399	0	502	

B17-Bgm. Ulrich / car volumes					
9:00 AM					
to / from	A"	B"	C"	D"	sum
A"	0	166	0	27	193
B"	75	0	0	344	419
C"	0	0	0	0	0
D"	53	118	0	0	171
sum	128	284	0	371	

B17-Bgm. Ulrich / HGV volumes					
8:00 AM					
to / from	A"	B"	C"	D"	sum
A"	0	14	0	8	22
B"	9	0	0	24	33
C"	0	0	0	0	0
D"	11	14	0	0	25
sum	20	28	0	32	

B17-Bgm. Ulrich / HGV volumes					
9:00 AM					
to / from	A"	B"	C"	D"	sum
A"	0	17	0	9	26
B"	6	0	0	14	20
C"	0	0	0	0	0
D"	6	9	0	0	15
sum	12	26	0	23	

B17-Bgm. Ulrich / vehicle volumes					
8:00 AM					
to / from	A"	B"	C"	D"	sum
A"	0	247	0	24	271
B"	174	0	0	510	684
C"	0	0	0	0	0
D"	78	180	0	0	258
sum	252	427	0	534	

B17-Bgm. Ulrich / vehicle volumes					
9:00 AM					
to / from	A"	B"	C"	D"	sum
A"	0	183	0	36	219
B"	81	0	0	358	439
C"	0	0	0	0	0
D"	59	127	0	0	186
sum	140	310	0	394	

Appendix: Fused OD-matrix calculations

AA’ = AB X D’A’(%) => 920 X (414/2319) = 164

AB’ = AB X D’B’(%) => 920 X (963/2319) = 382

AC’ = AB X D’C’(%) => 920 X (942/2319) = 374

CA’ = CB X D’A’(%) => 889 X (414/2319) = 159

CB’ = CB X D’B’(%) => 889 X (963/2319) = 369

CC’ = CB X D’C’(%) => 889 X (942/2319) = 361

DA’ = DB X D’A’(%) => 509 X (414/2319) = 91

DB’ = DB X D’B’(%) => 509 X (963/2319) = 211

DC’ = DB X D’C’(%) => 509 X (942/2319) = 207

A’A = A’D‘ X BA(%) => 91 X (340/924) = 33

A’C = A’D‘ X BC(%) => 91 X (320/924) = 32

A’D = A’D‘ X BD(%) => 91 X (264/924) = 26

B’A = B’D‘ X BA(%) => 716 X (340/924) = 263

B'C = B'D' X BC(%) => 716 X (320/924) = 248

B'D = B'D' X BD(%) => 716 X (264/924) = 205

C'A = C'D' X BA(%) => 117 X (340/924) = 43

C'C = C'D' X BC(%) => 117 X (320/924) = 41

C'D = C'D' X BD(%) => 117 X (264/924) = 33

Appendix: Vehicle input V1: volume calculations

Numbers are extracted from *Appendix: OD-matrixes in sub-networks in study area.*

$$V1 = \sum O_C + \sum O_{A"} - \sum D_{A"}$$

6:00-7:00

Car: 2756 + 173 – 241 = 2688

HGV: 128 + 4 – 11 = 121

Sum: 2884 + 177 – 252 = 2809

7:00 – 8:00

Car: 3792 + 305 – 307 = 3790

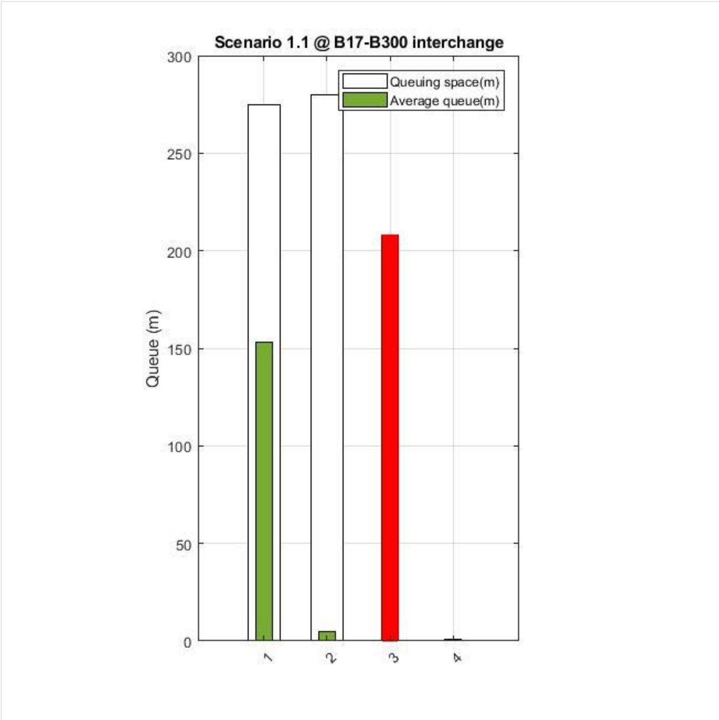
HGV: 202 + 17 – 16 = 203

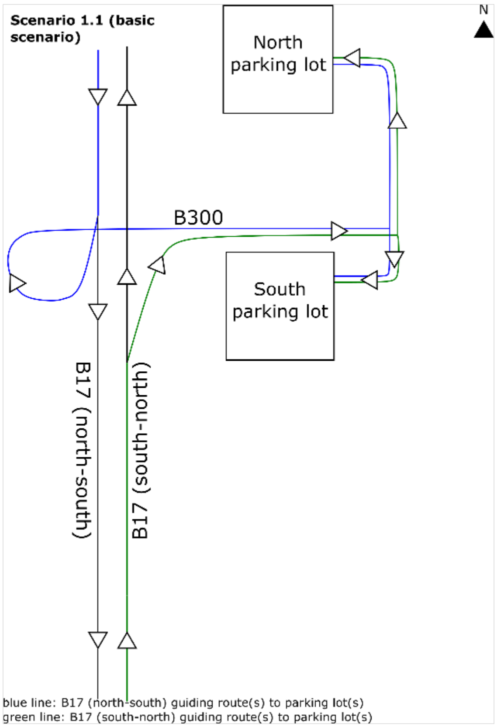
Sum: 3994 + 322 – 323 = 3993

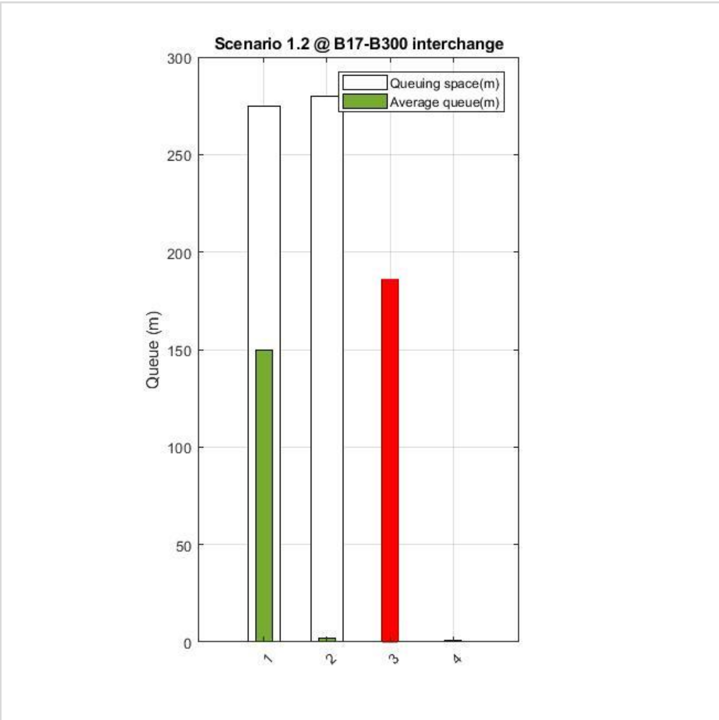
8:00-9:00

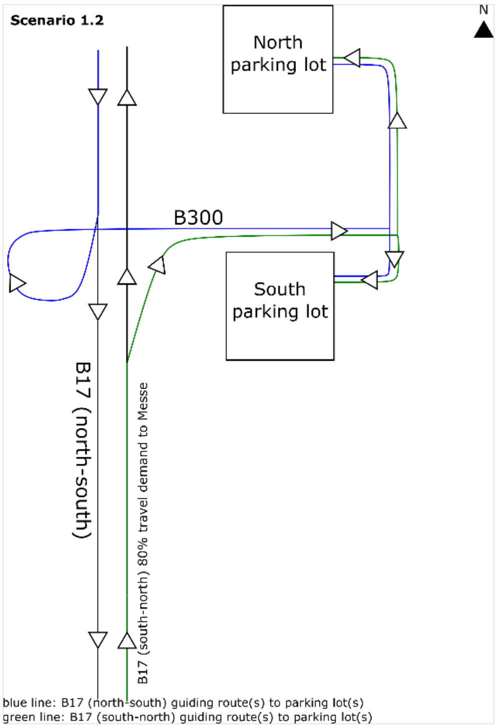
Sum: 3160 +252 – 271 = 3141

Appendix: Detailed results for travel demand sensitivity analysis and guidance scenarios









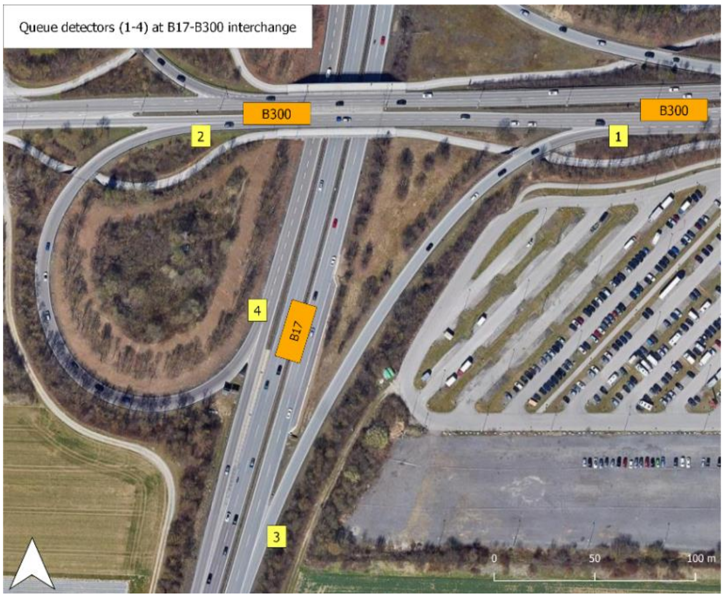
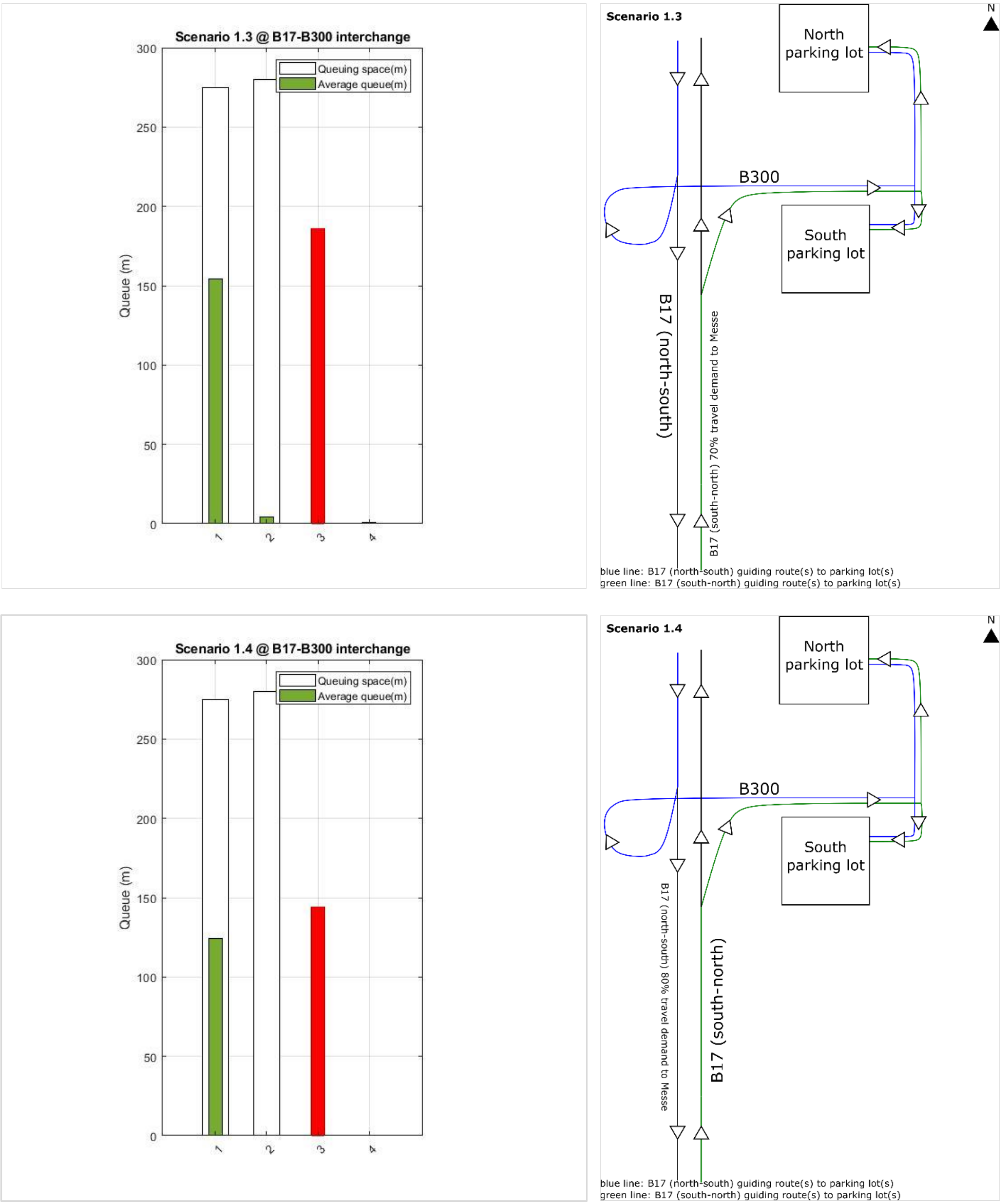


Figure 49: Scenario 1.1 and scenario 1.2 results at B17-B300 interchange

top-left: Queue results for scenario 1.1 at queue detectors (1-4) at B17-B300 interchange/ **top-right:** Scenario 1.1 sketch/ **middle-left:** Queue results for scenario 1.2 at queue detectors (1-4) at B17-B300 interchange / **middle-right:** Scenario 1.2 sketch/ **bottom:** Location of queue detectors (1-4) on map



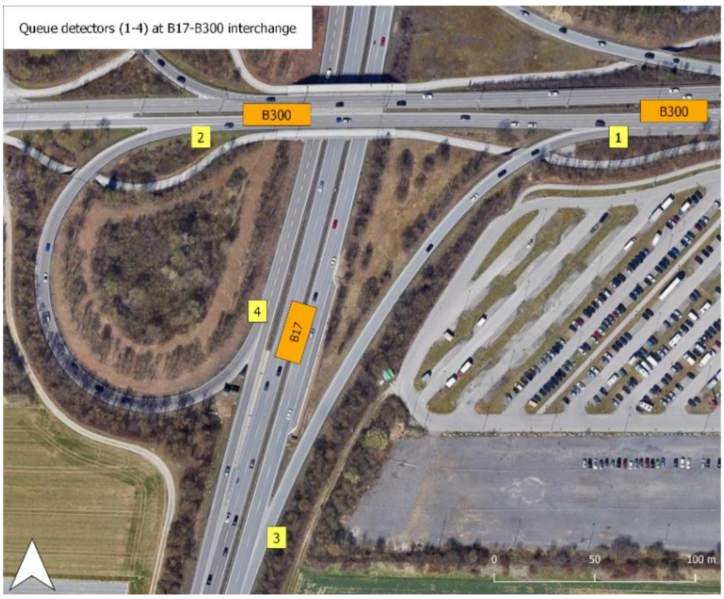
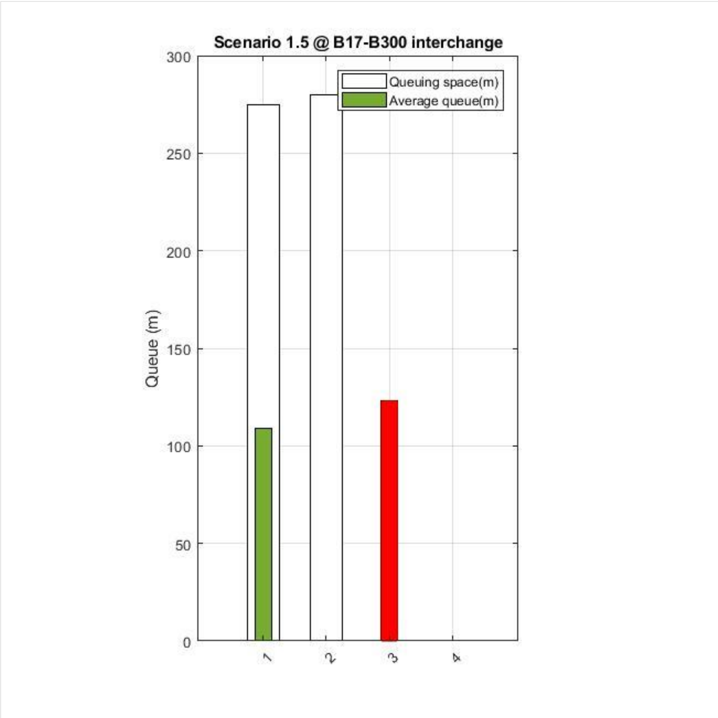
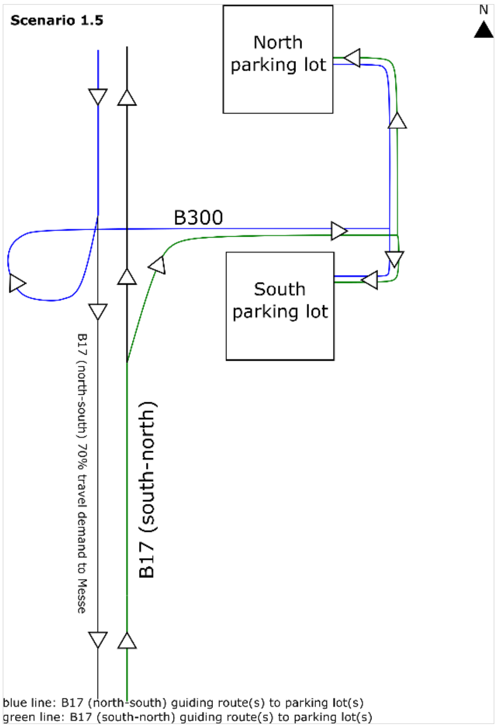
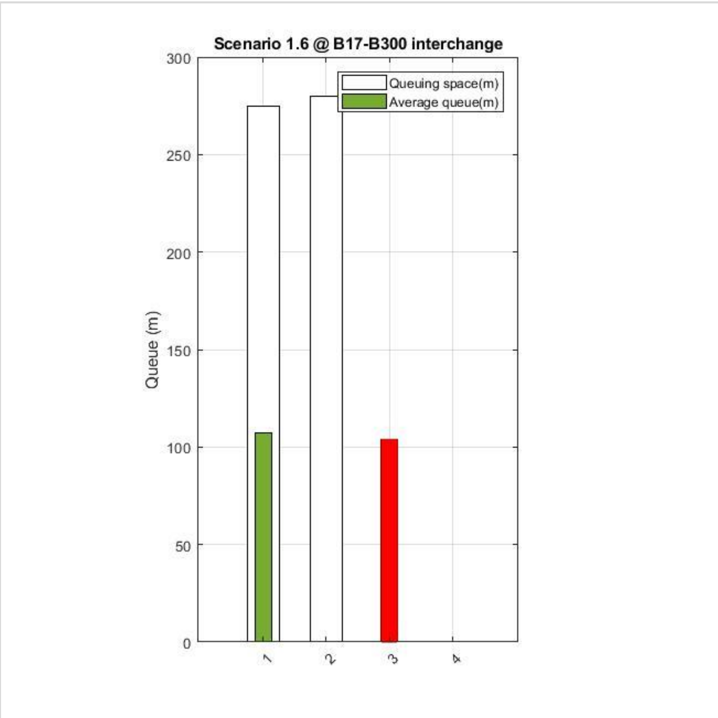


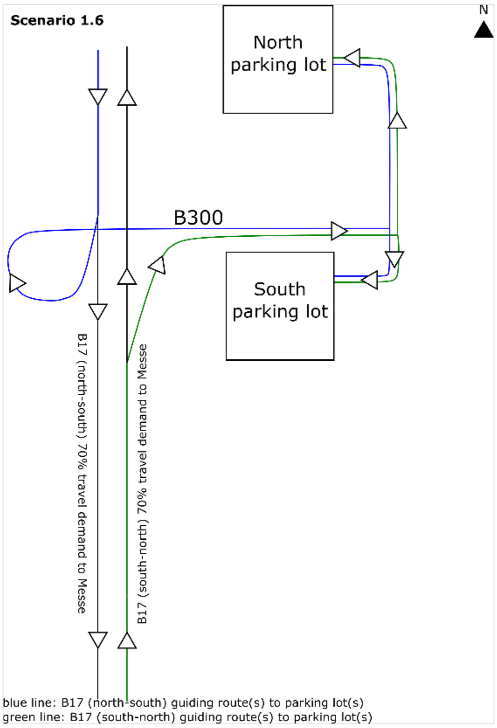
Figure 50: Scenario 1.3 and scenario 1.4 results at B17-B300 interchange

top-left: Queue results for scenario 1.3 at queue detectors (1-4) at B17-B300 interchange/ **top-right:** Scenario 1.3 sketch/ **middle-left:** Queue results for scenario 1.4 at queue detectors (1-4) at B17-B300 interchange / **middle-right:** Scenario 1.4 sketch/ **bottom:** Location of queue detectors (1-4) on map









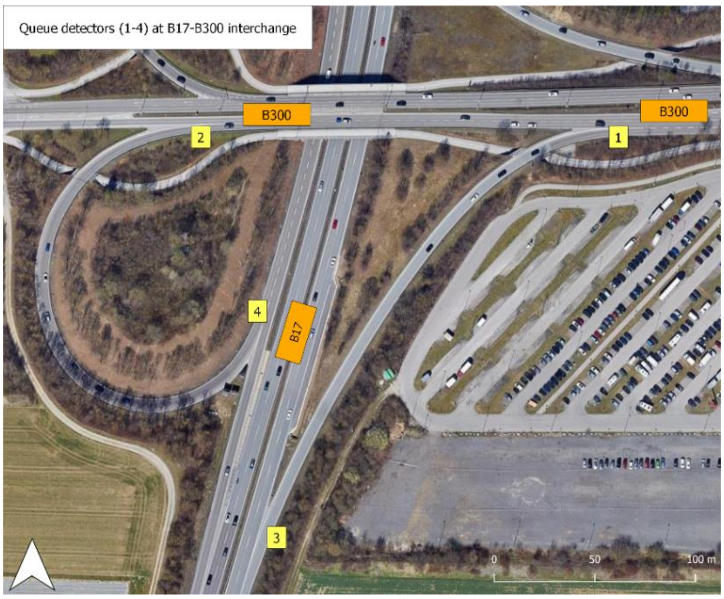
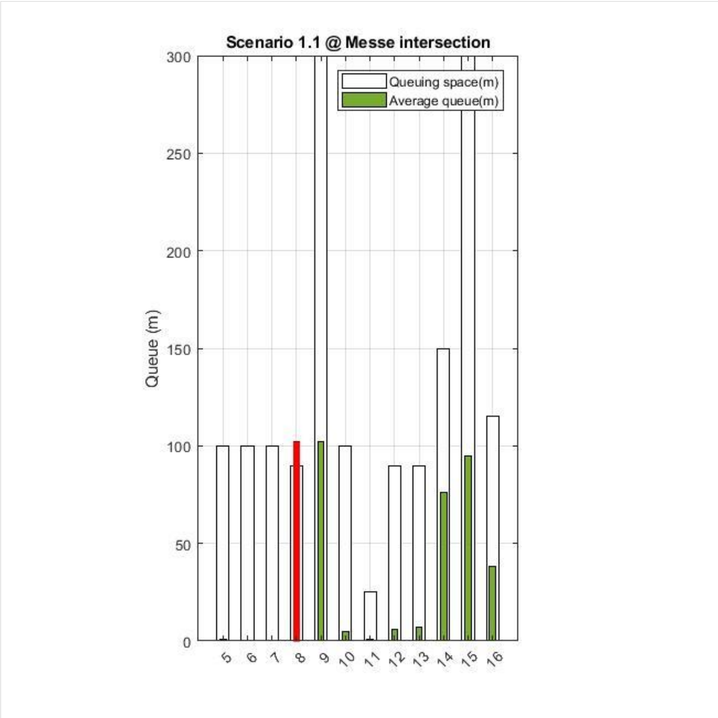
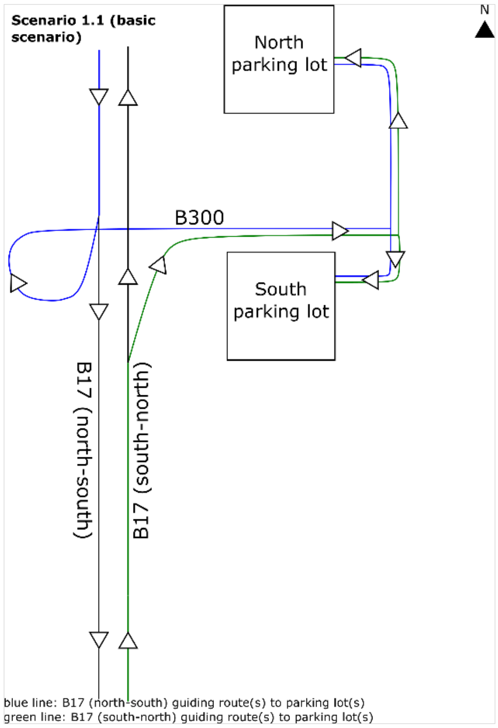
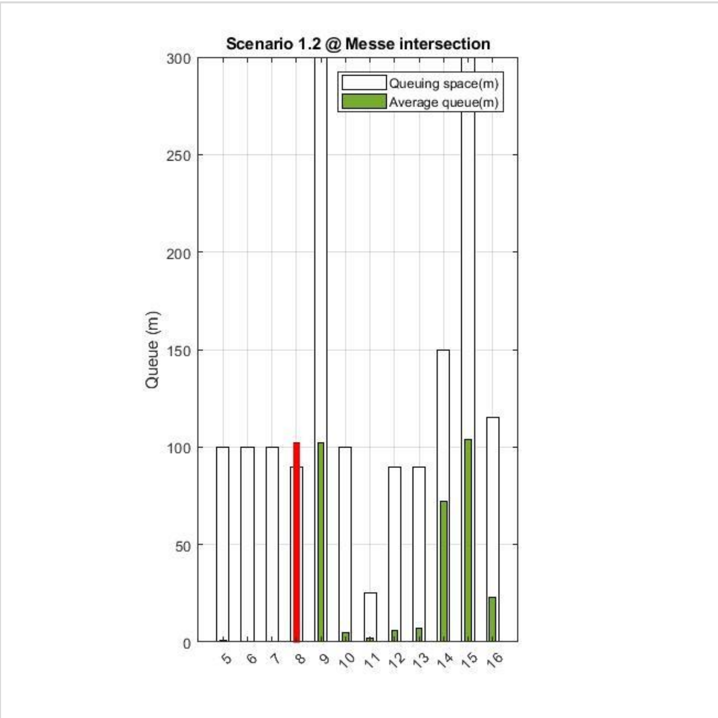


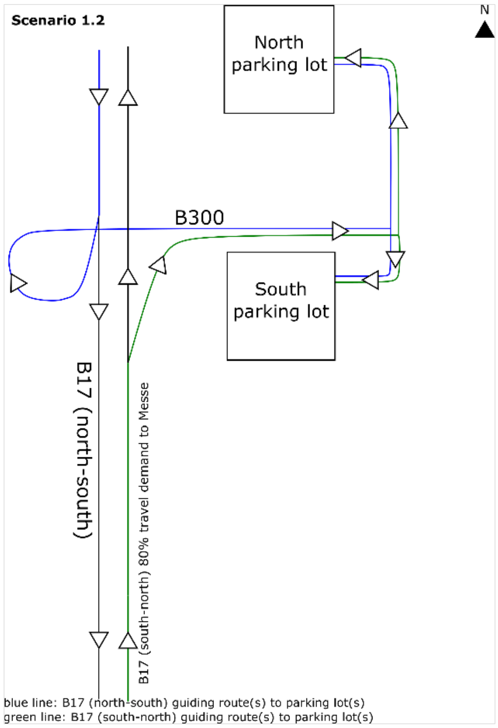
Figure 51: Scenario 1.5 and scenario 1.6 results at B17-B300 intersection

top-left: Queue results for scenario 1.5 at queue detectors (1-4) at B17-B300 interchange / top-right: Scenario 1.5 sketch/ middle-left: Queue results for scenario 1.6 at queue detectors (1-4) at B17-B300 interchange / middle-right: Scenario 1.6 sketch/ bottom: Location of queue detectors (1-4) on map









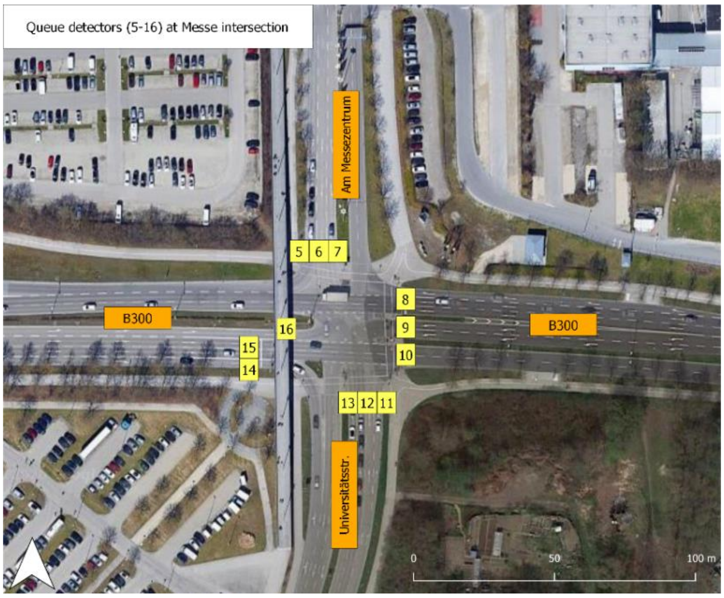
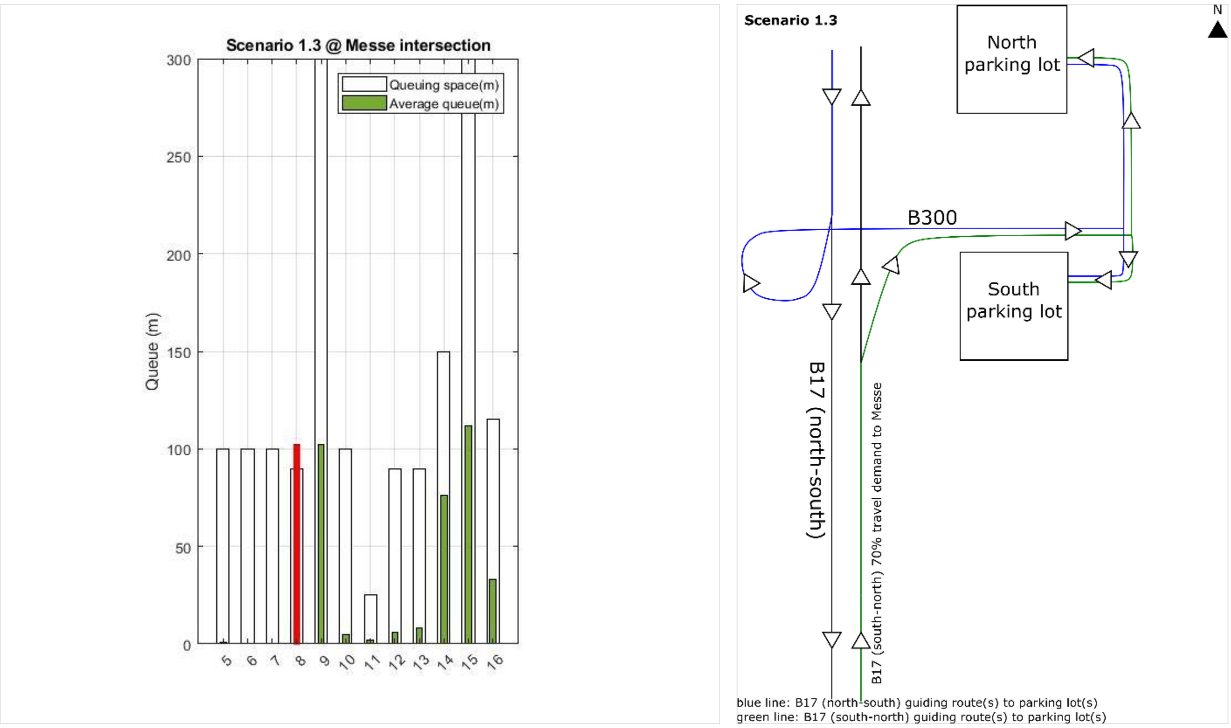
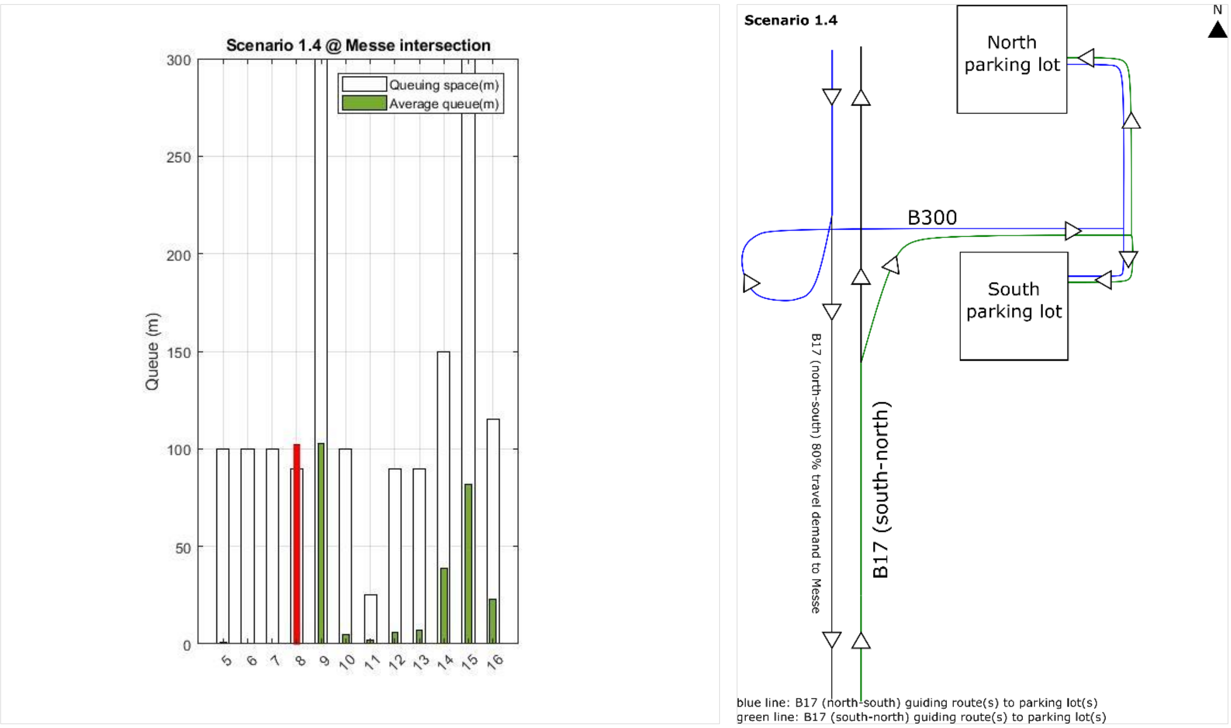


Figure 52: Scenario 1.1 and scenario 1.2 results at Messe intersection

top-left: Queue results for scenario 1.1 at queue detectors (5-16) at Messe intersection / top-right: Scenario 1.1 sketch/ middle-left: Queue results for scenario 1.2 at queue detectors (5-16) at Messe intersection / middle-right: Scenario 1.2 sketch/ bottom: Location of queue detectors (5-16) on map





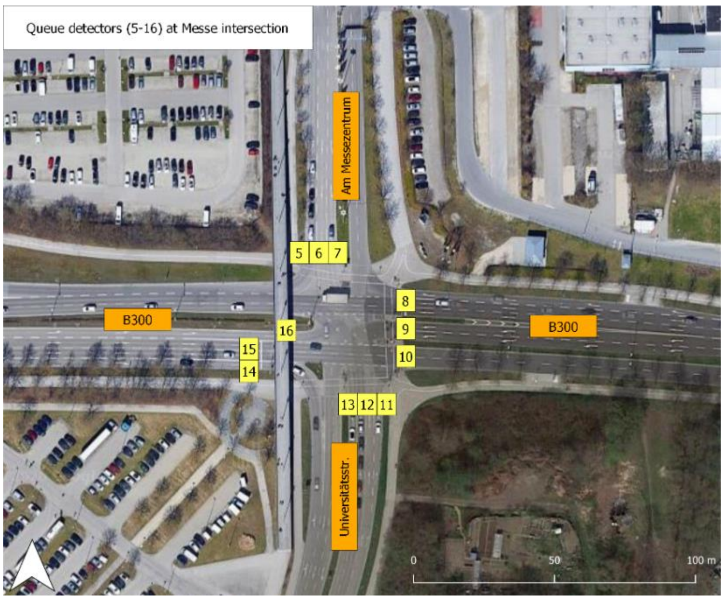
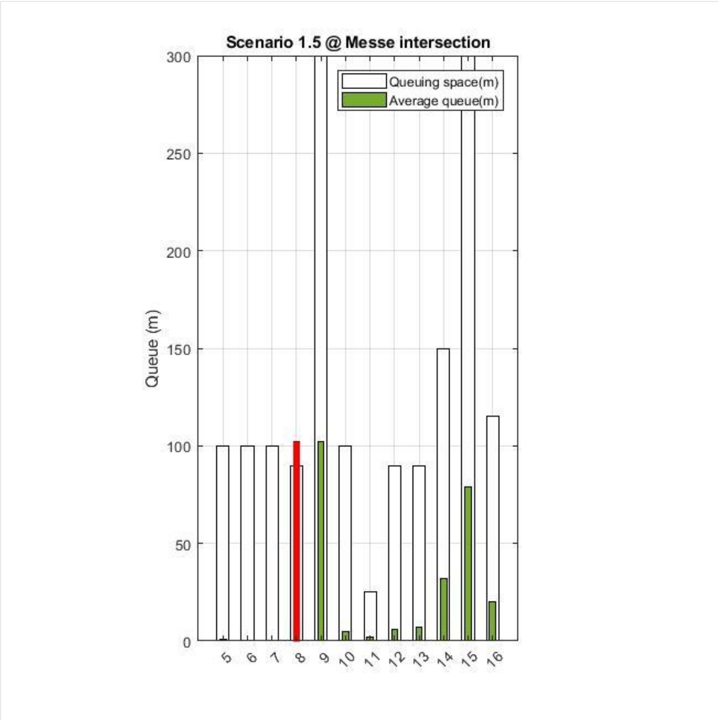
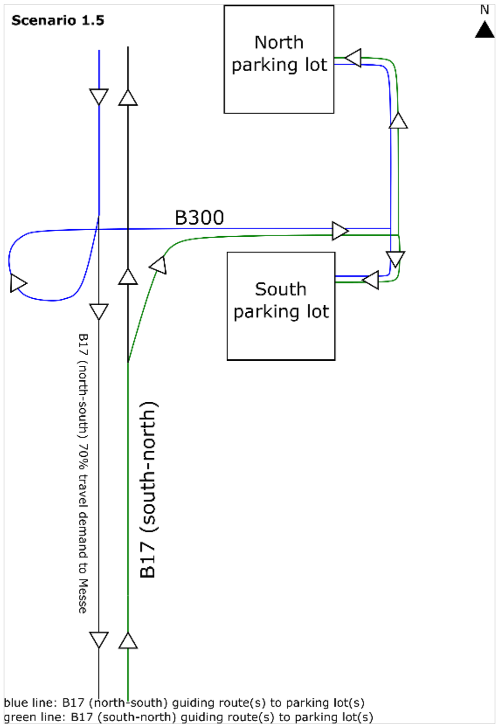
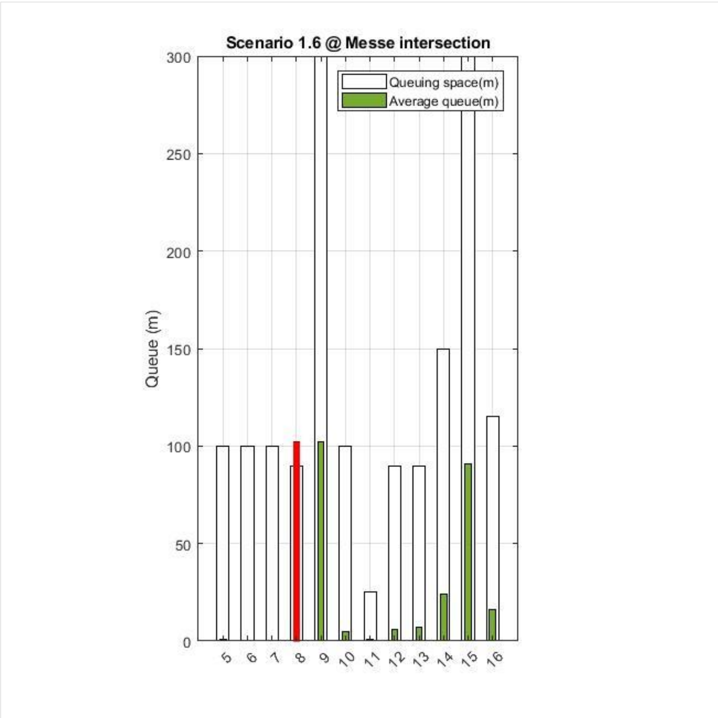


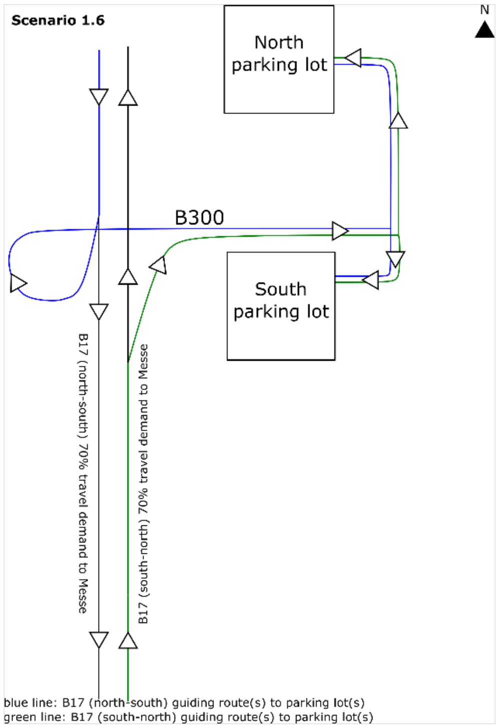
Figure 53: Scenario 1.3 and scenario 1.4 results at Messe intersection

top-left: Queue results for scenario 1.3 at queue detectors (5-16) at Messe intersection / **top-right:** Scenario 1.3 sketch/ **middle-left:** Queue results for scenario 1.4 at queue detectors (5-16) at Messe intersection / **middle-right:** Scenario 1.4 sketch/ **bottom:** Location of queue detectors (5-16) on map









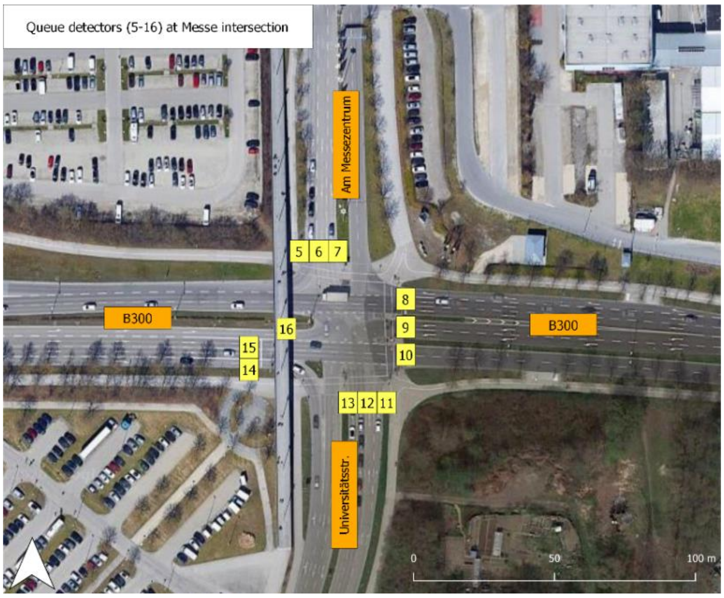
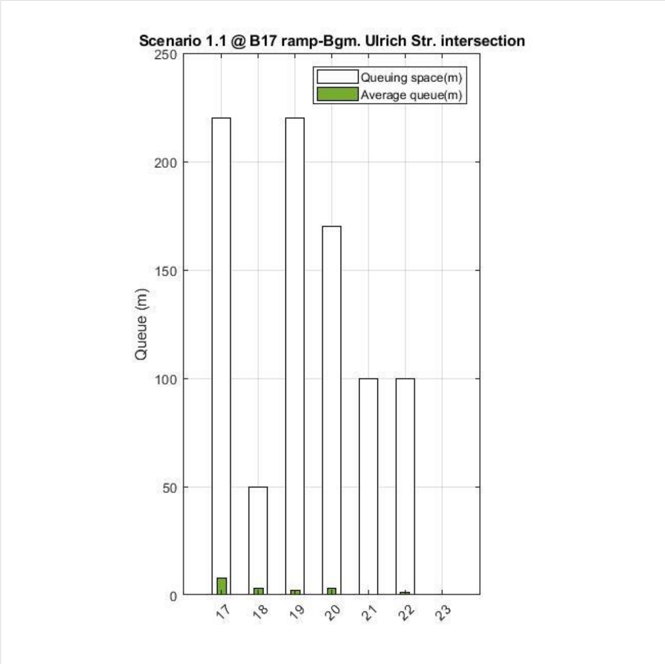
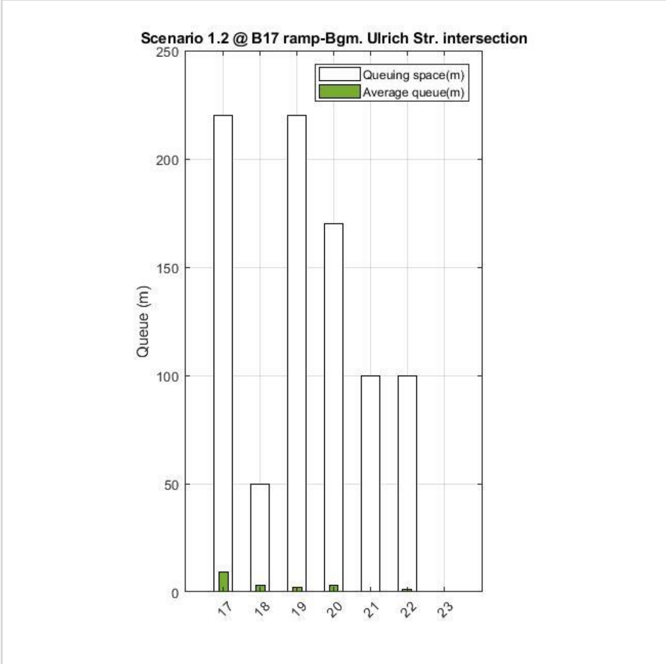
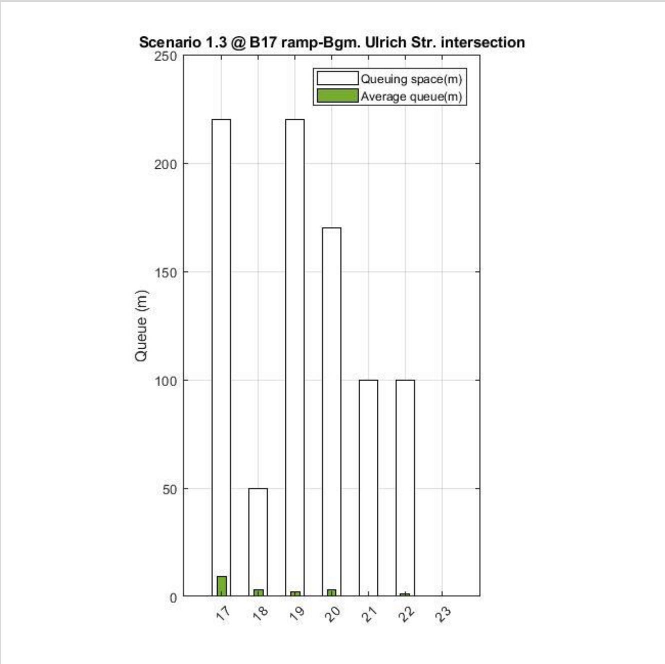


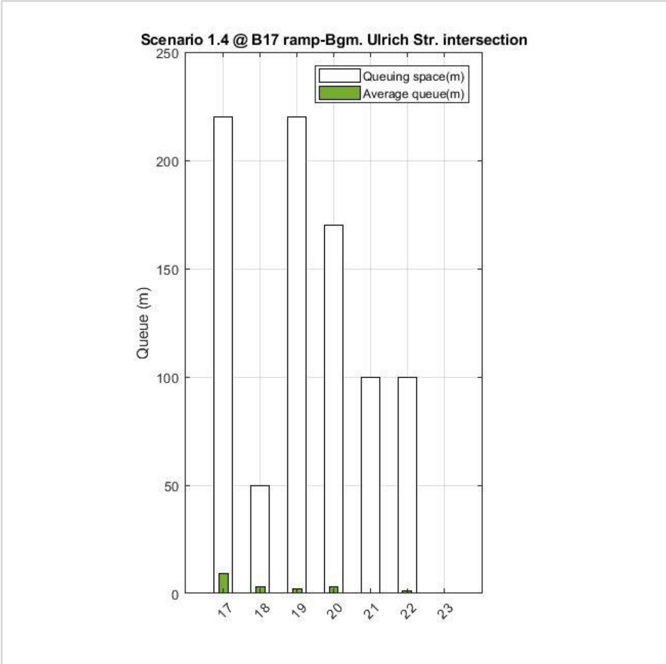
Figure 54: Scenario 1.5 and scenario 1.6 results at Messe intersection

top-left: Queue results for scenario 1.5 at queue detectors (5-16) at Messe intersection / **top-right:** Scenario 1.5 sketch/ **middle-left:** Queue results for scenario 1.6 at (5-16) at Messe intersection / **middle-right:** Scenario 1.6 sketch/ **bottom:** Location of queue detectors (5-16) on map









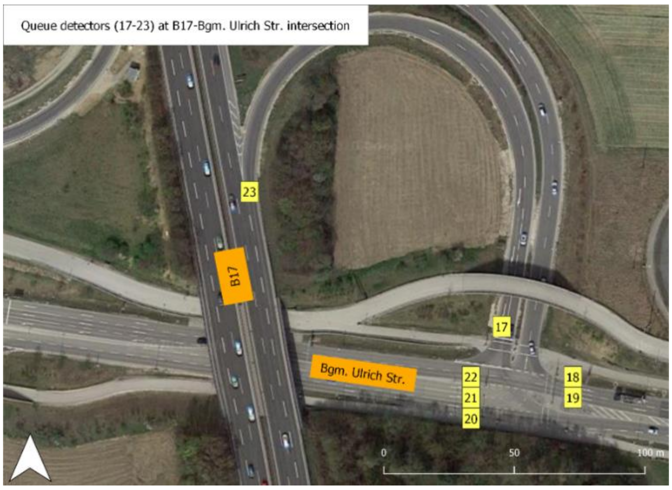
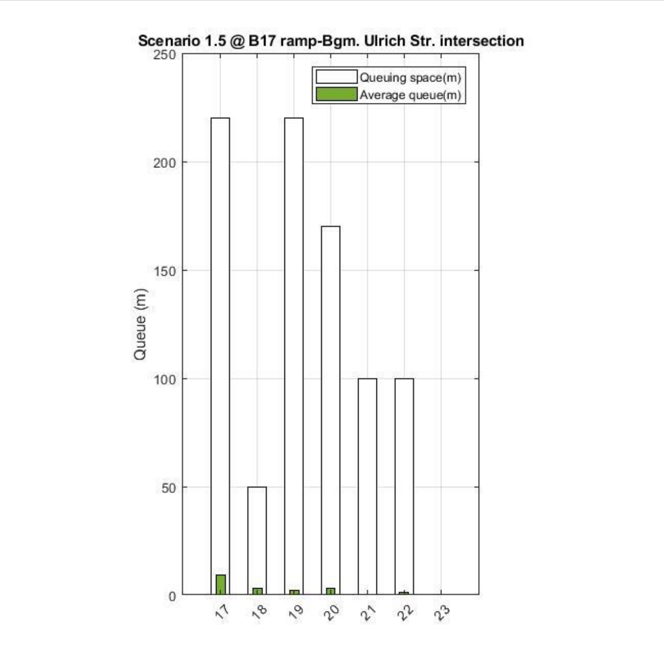
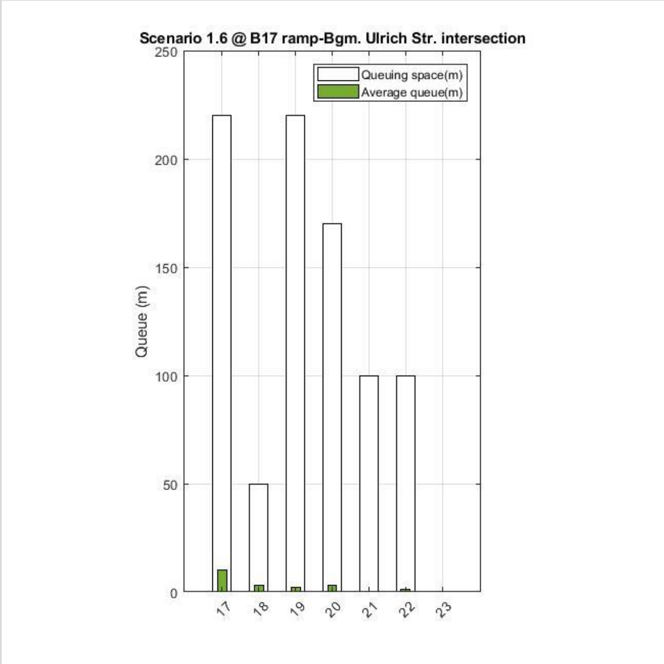


Figure 55: Scenario 1.1, 1.2, 1.3 and 1.4 results at B17 ramp/Bgm. Ulrich Str. Intersection (**top-left, top-right, middle-left, middle-right**)/ **bottom:** Location of queue detectors (17-23) on map





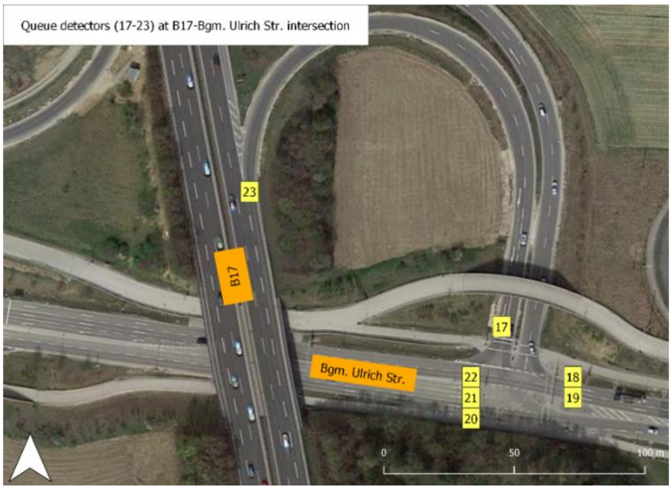
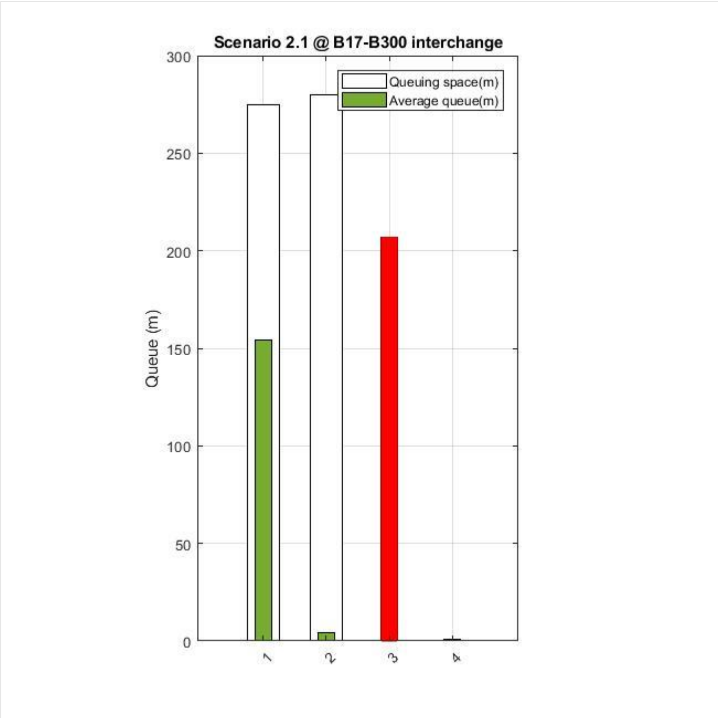
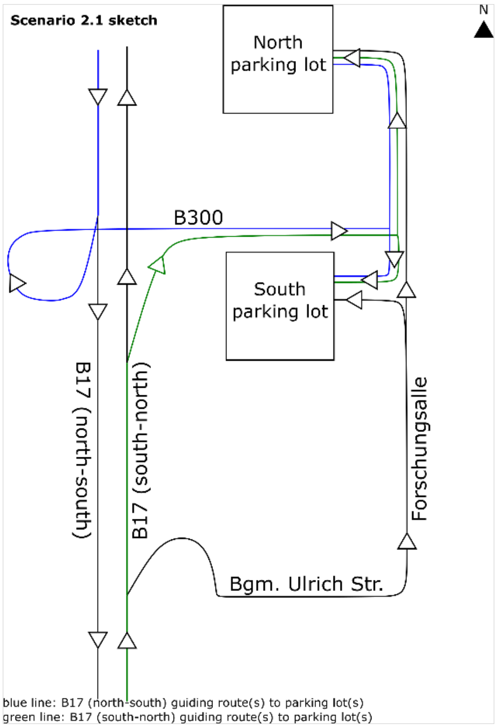
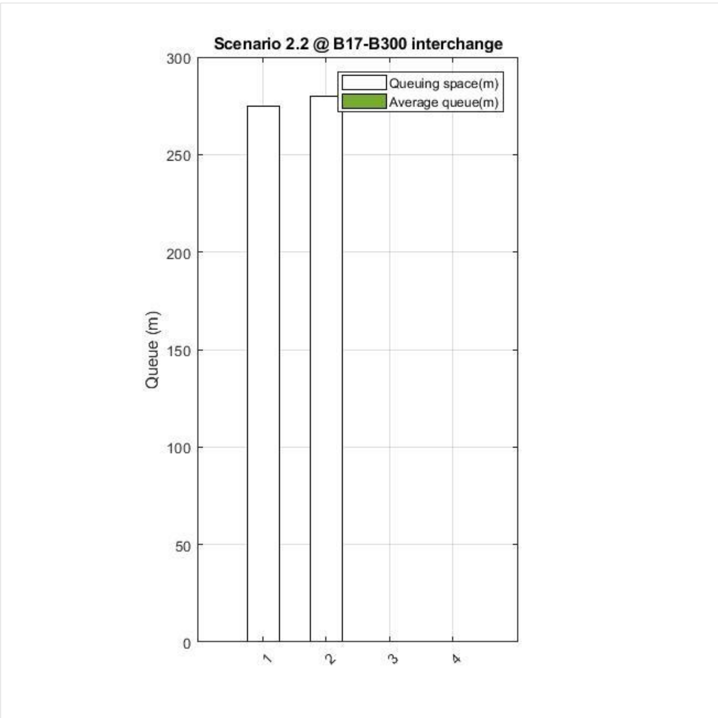
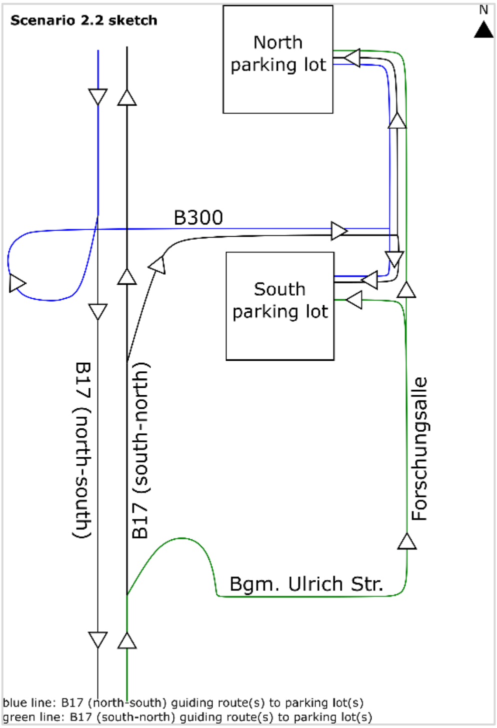


Figure 56: Scenario 1.5 and 1.6 results at B17 ramp/Bgm. Ulrich Str. Intersection (**top-left, top-right**)/ **bottom:** Location of queue detectors (17-23) on map









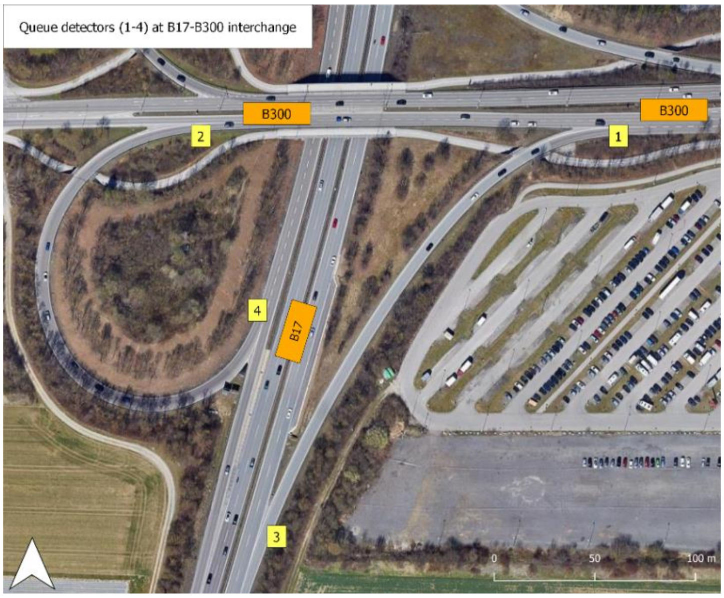
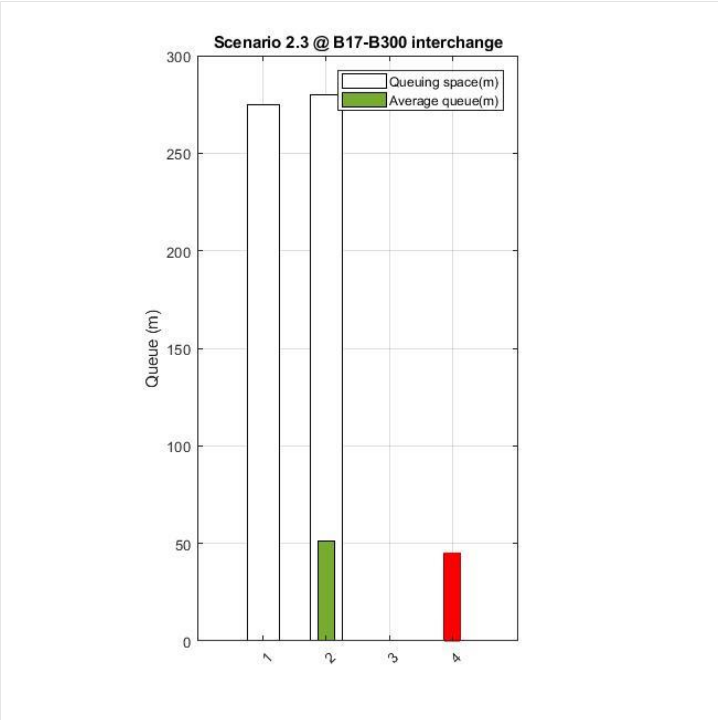
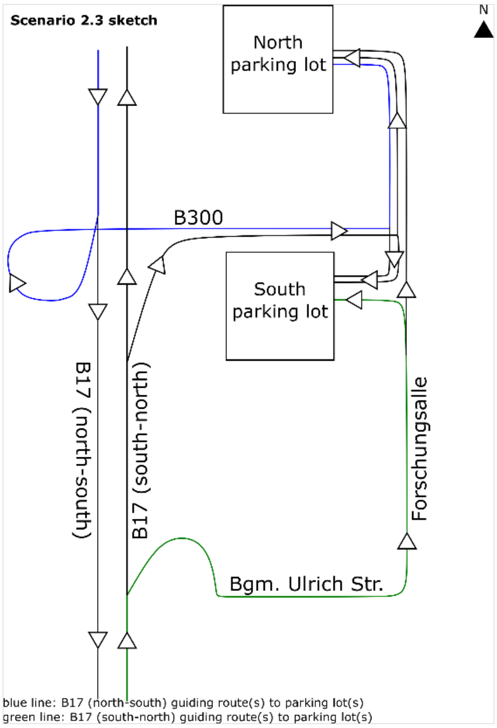
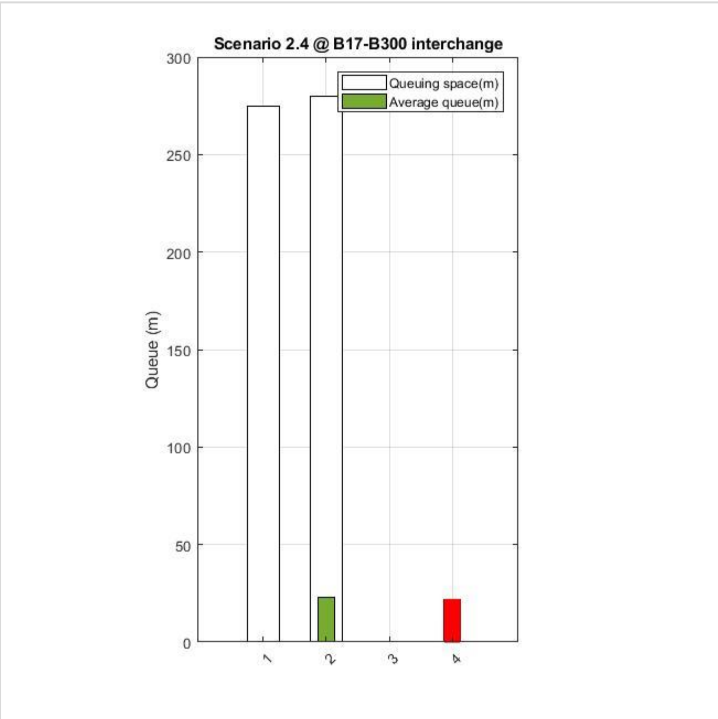


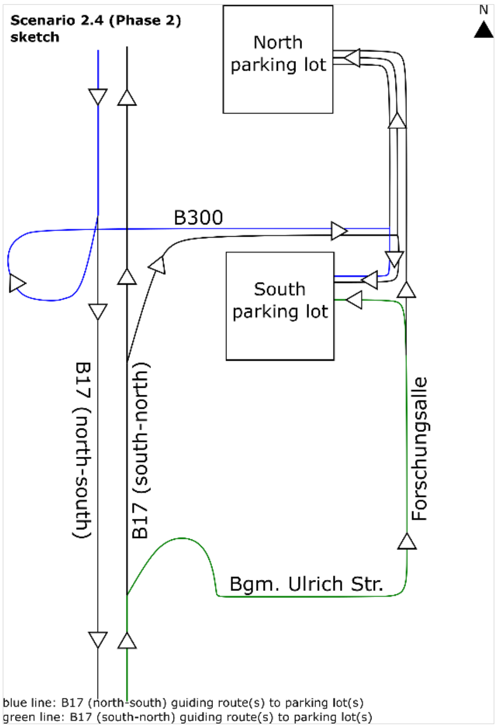
Figure 57: Scenario 2.1 and scenario 2.2 results

top-left: Queue results for scenario 2.1 at queue detectors (1-4) at B17-B300 interchange/ **top-right:** Scenario 2.1 sketch/ **middle-left:** Queue results for scenario 2.2 at queue detectors (1-4) at B17-B300 interchange/ **middle-right:** Scenario 2.2 sketch/ **bottom:** Location of queue detectors (1-4) on map









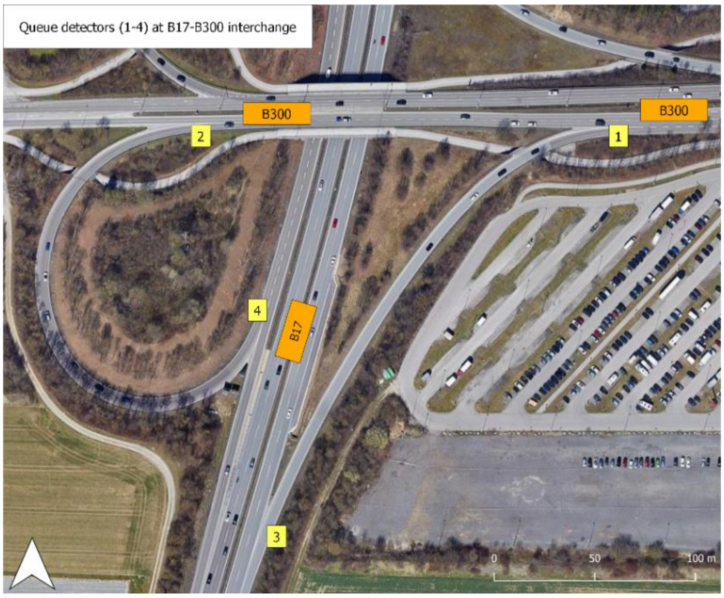
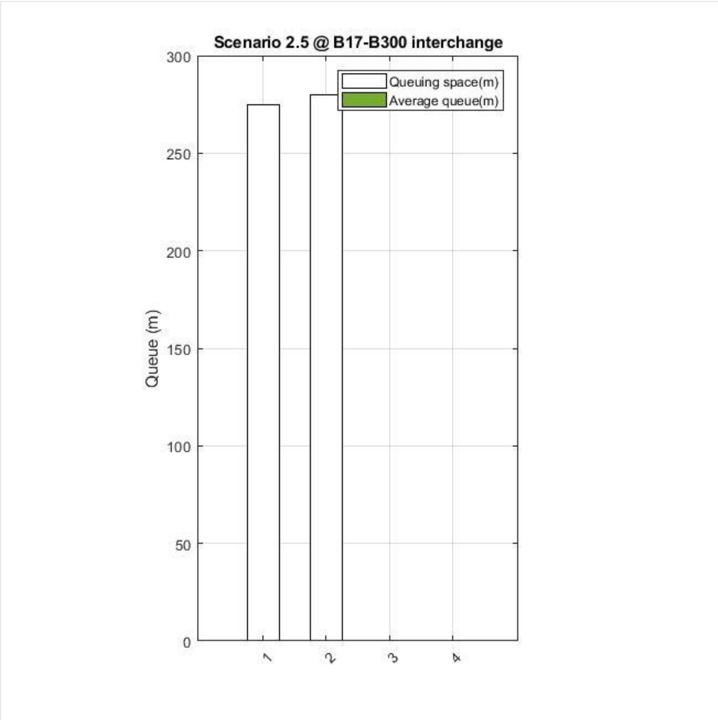
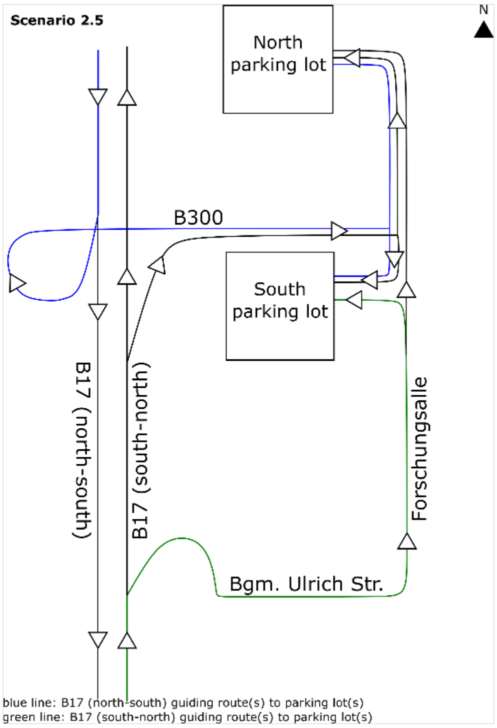
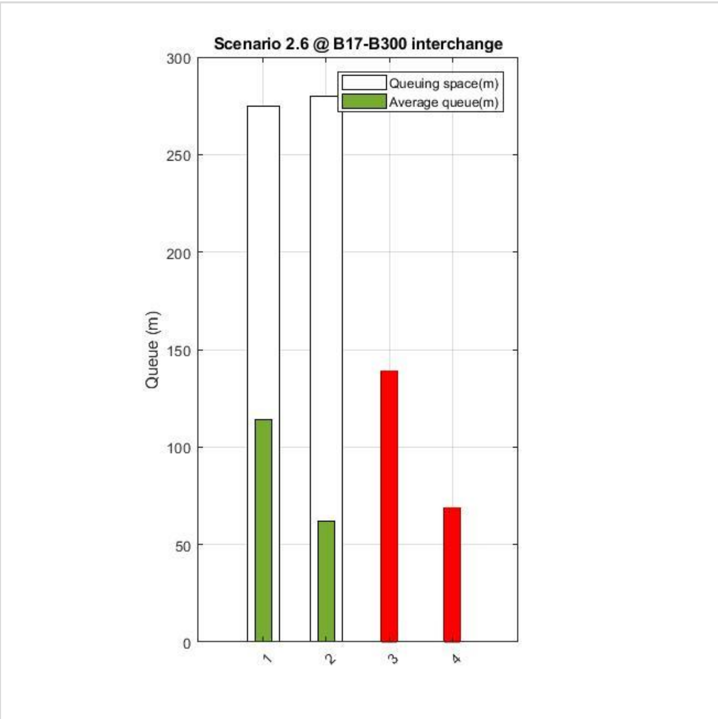


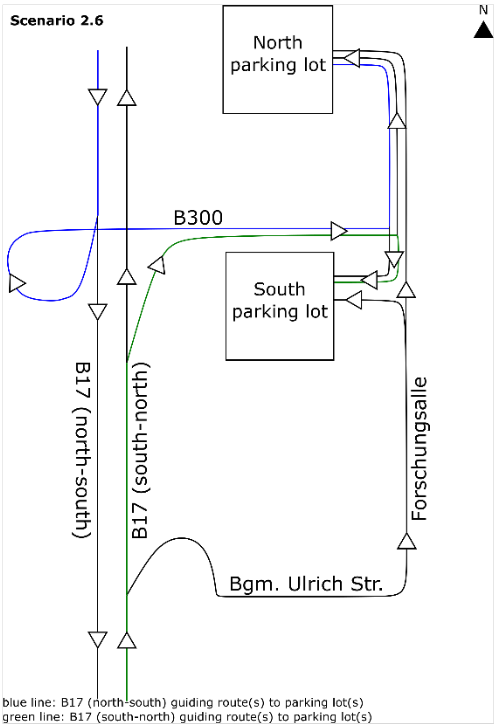
Figure 58: Scenario 2.3 and scenario 2.4 results

top-left: Queue results for scenario 2.3 at queue detectors (1-4) at B17-B300 interchange/ **top-right:** Scenario 2.3 sketch/ **middle-left:** Queue results for scenario 2.4 at queue detectors (1-4) at B17-B300 interchange/ **middle-right:** Scenario 2.4 sketch/ **bottom:** Location of queue detectors (1-4) on map









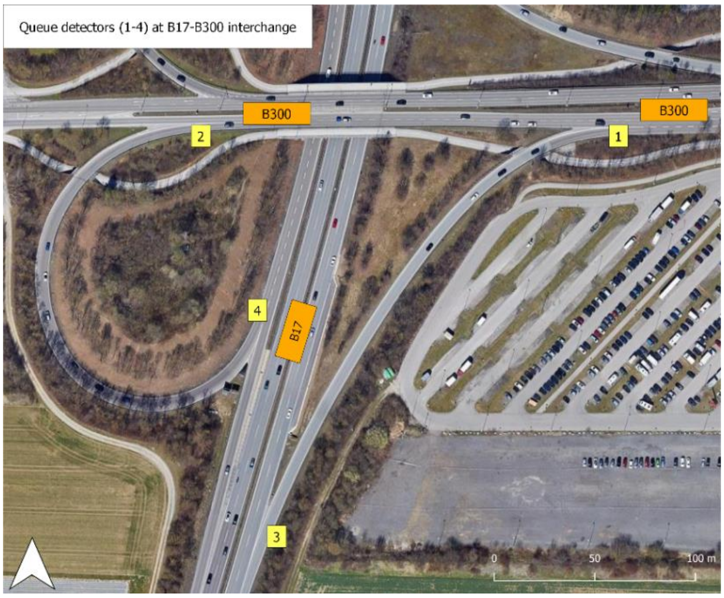
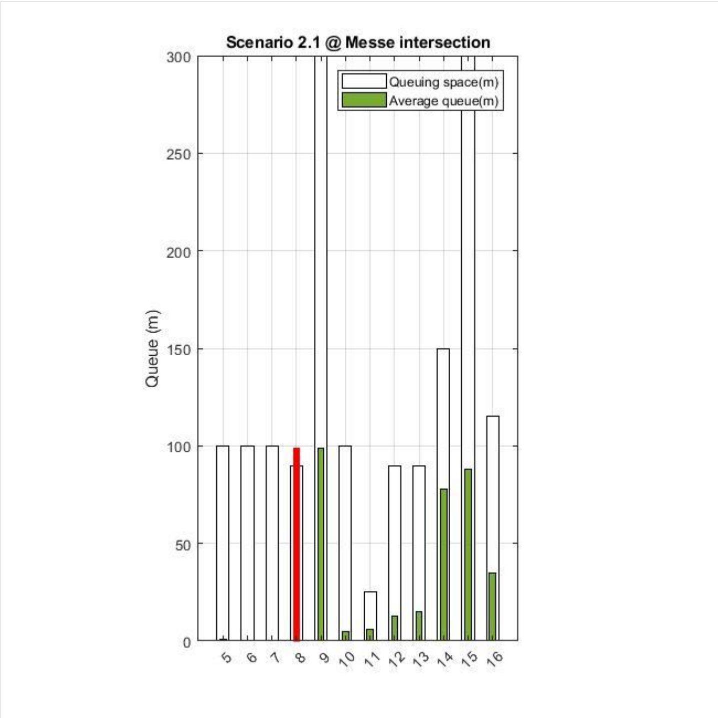
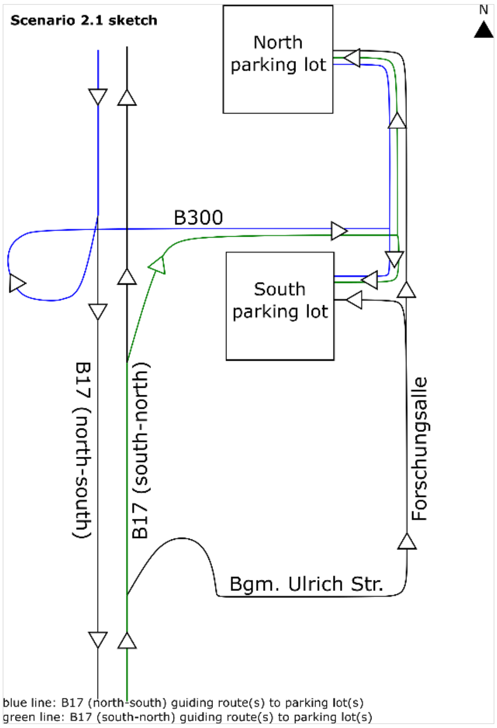
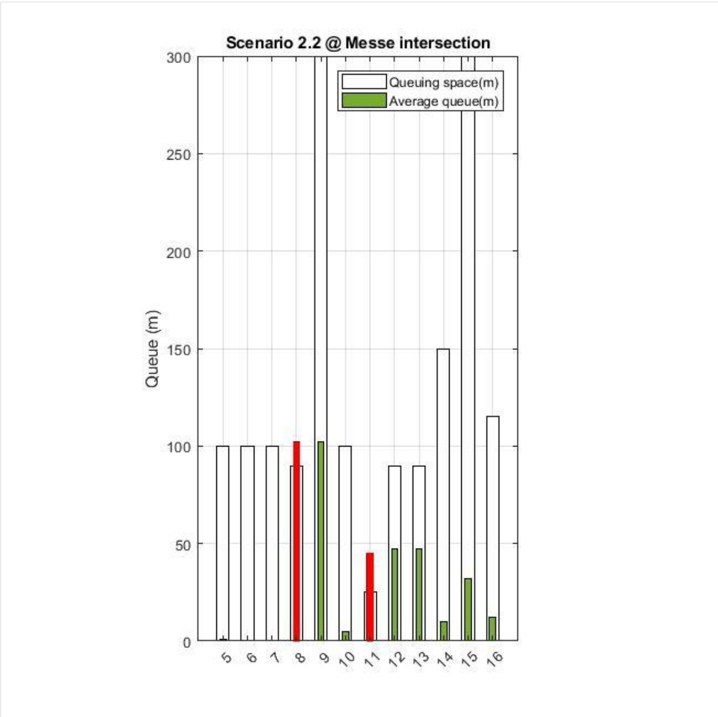


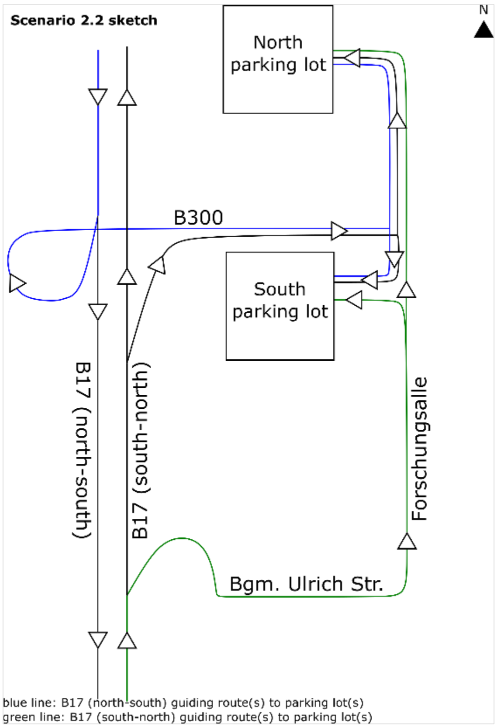
Figure 59: Scenario 2.5 and scenario 2.6 results

top-left: Queue results for scenario 2.5 at queue detectors (1-4) at B17-B300 interchange/ **top-right:** Scenario 2.5 sketch/ **middle-left:** Queue results for scenario 2.6 at queue detectors (1-4) at B17-B300 interchange/ **middle-right:** Scenario 2.6 sketch/ **bottom:** Location of queue detectors (1-4) on map









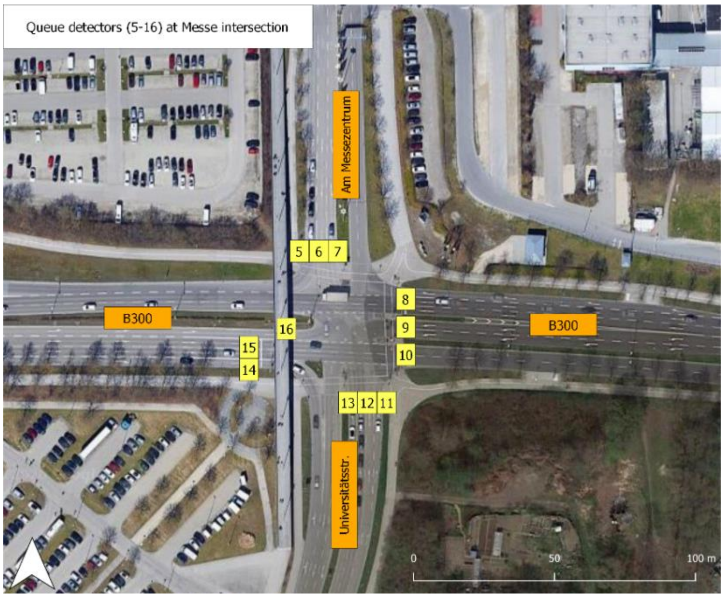
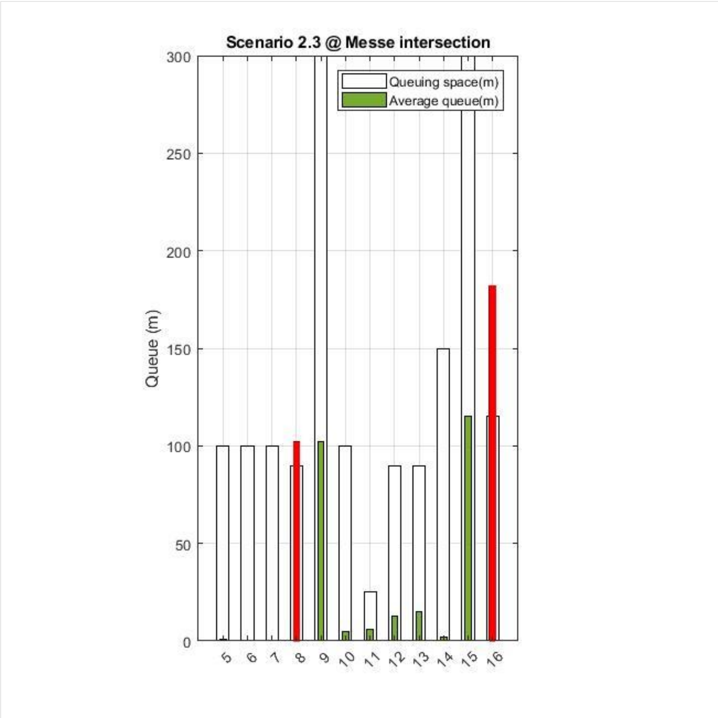
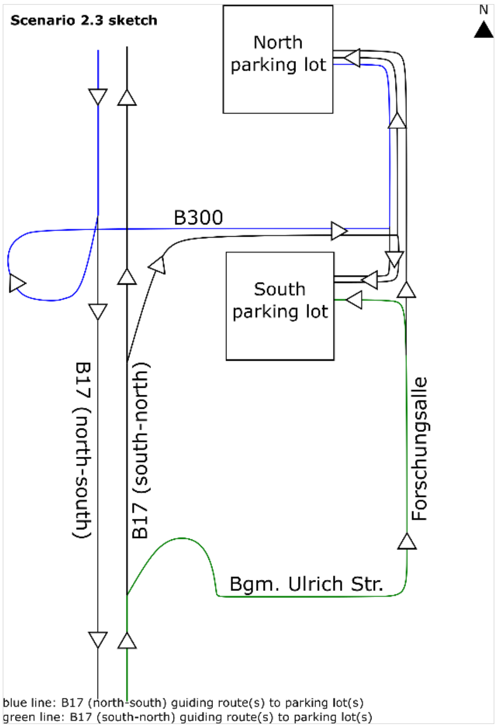
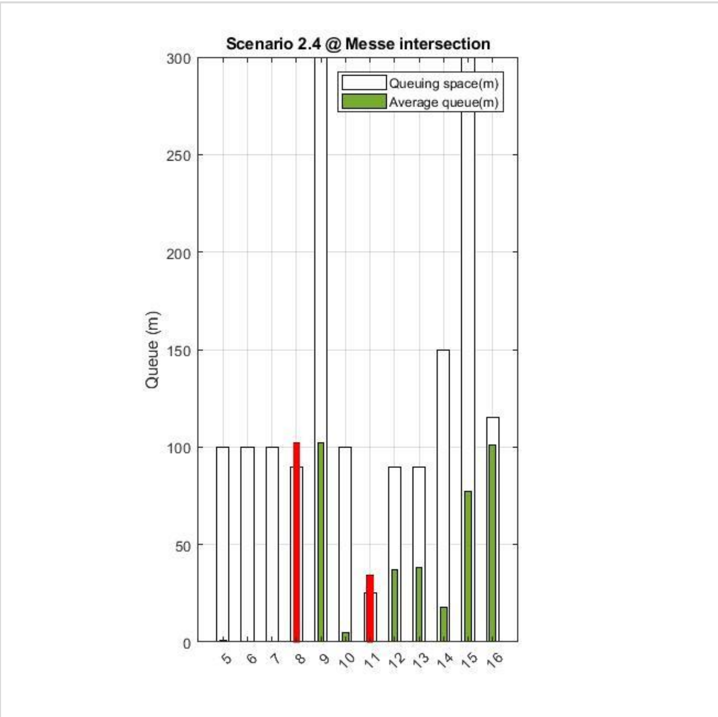


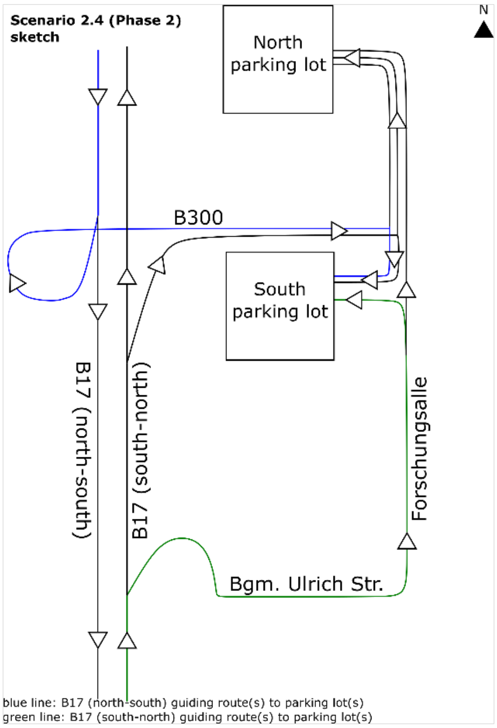
Figure 60: Scenario 2.1 and scenario 2.2 results at Messe intersection

top-left: Queue results for scenario 2.1 at queue detectors (5-16) at Messe intersection/ **top-right:** Scenario 2.1 sketch/ **middle-left:** Queue results for scenario 2.2 at queue detectors (5-16) at Messe intersection / **middle-right:** Scenario 2.2 sketch/ **bottom:** Location of queue detectors (5-16) on map









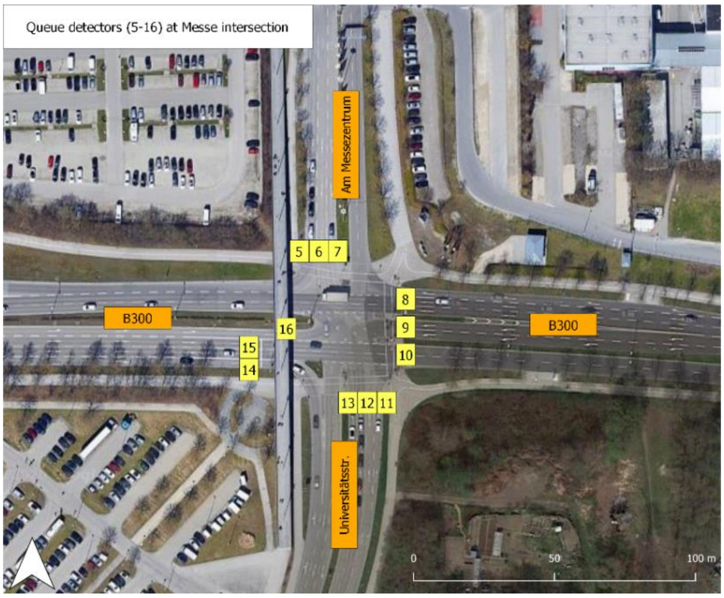
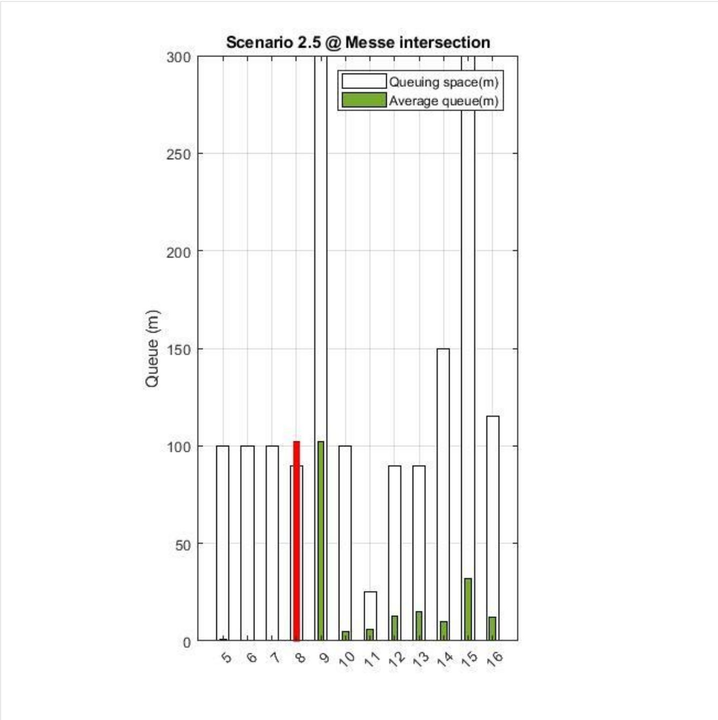
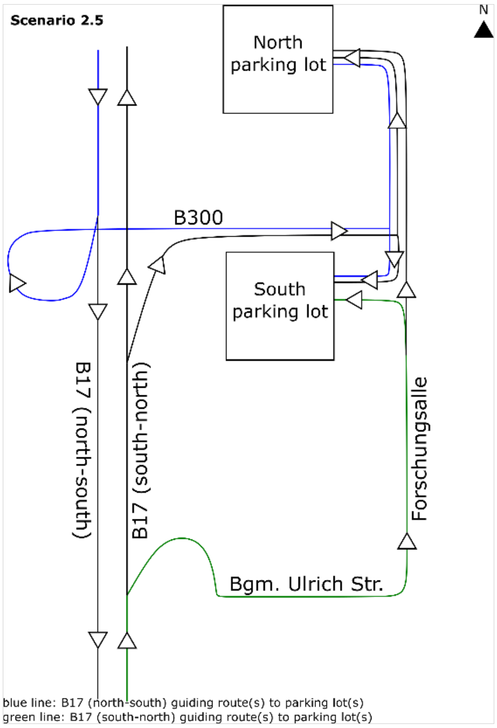
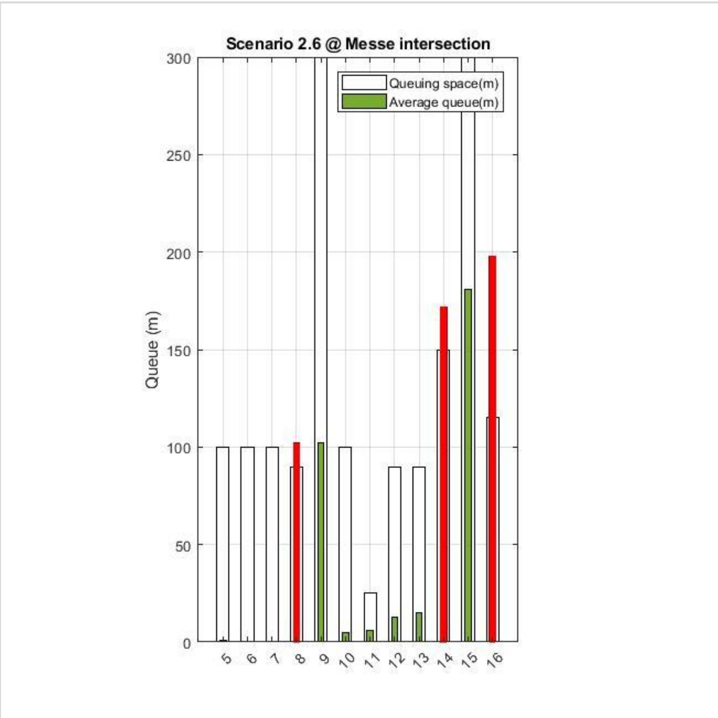


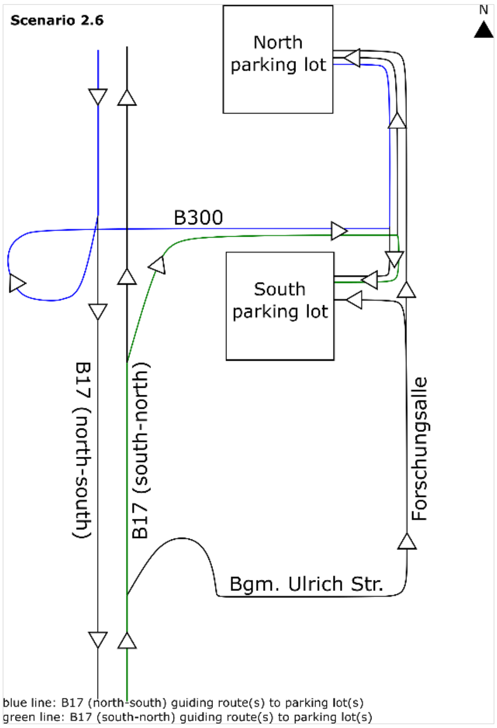
Figure 61: Scenario 2.3 and scenario 2.4 results at Messe intersection

top-left: Queue results for scenario 2.3 at queue detectors (5-16) at Messe intersection/ **top-right:** Scenario 2.3 sketch/ **middle-left:** Queue results for scenario 2.4 at queue detectors (5-16) at Messe intersection / **middle-right:** Scenario 2.4 sketch/ **bottom:** Location of queue detectors (5-16) on map









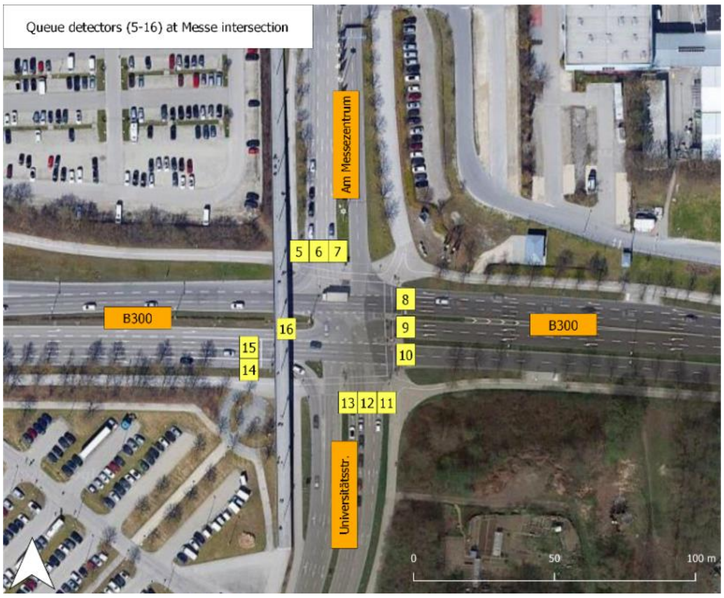
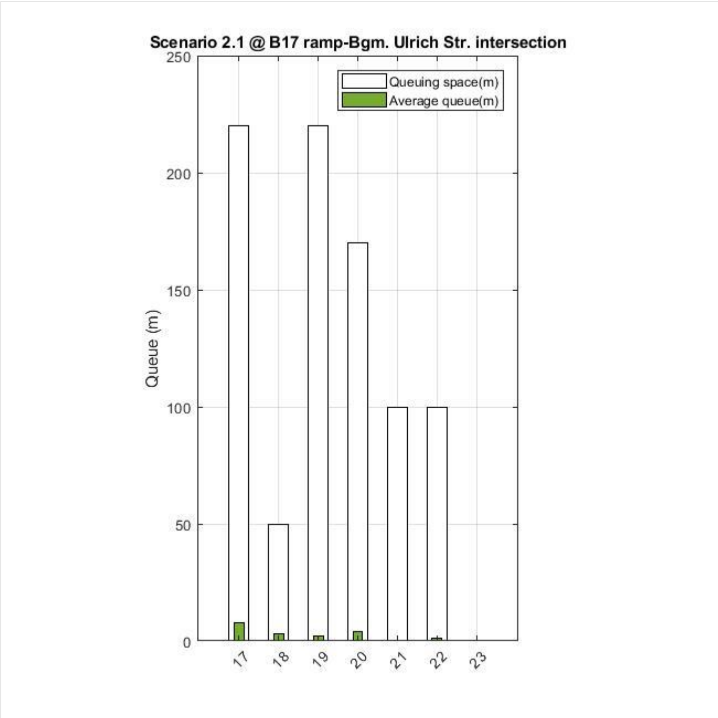
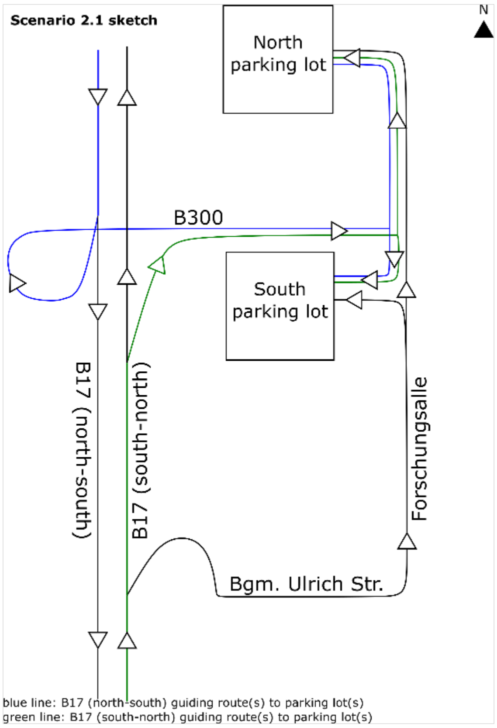
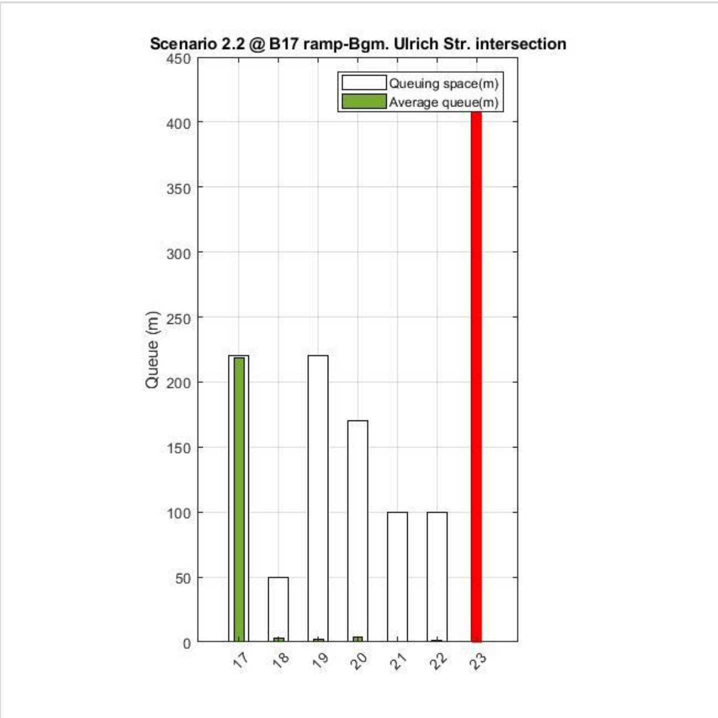


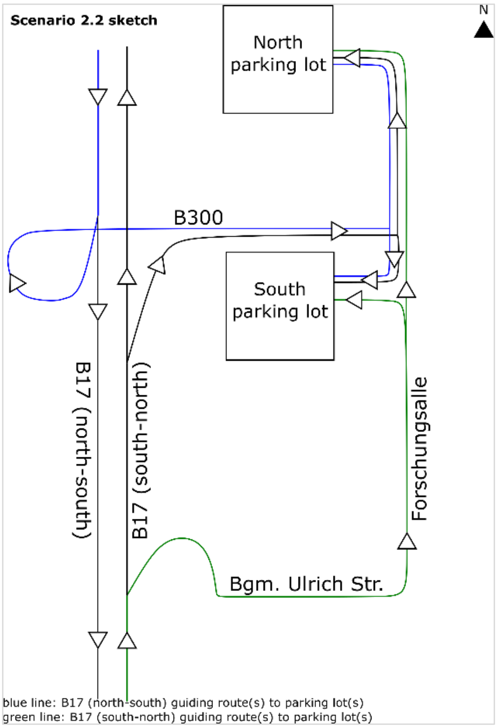
Figure 62: Scenario 2.5 and scenario 2.6 results at Messe intersection

top-left: Queue results for scenario 2.5 at queue detectors (5-16) at Messe intersection/ **top-right:** Scenario 2.5 sketch/ **middle-left:** Queue results for scenario 2.6 at queue detectors (5-16) at Messe intersection / **middle-right:** Scenario 2.6 sketch/ **bottom:** Location of queue detectors (5-16) on map









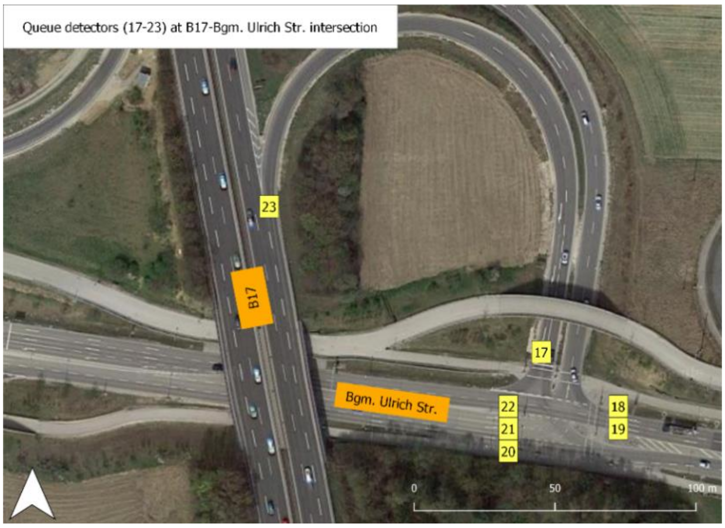
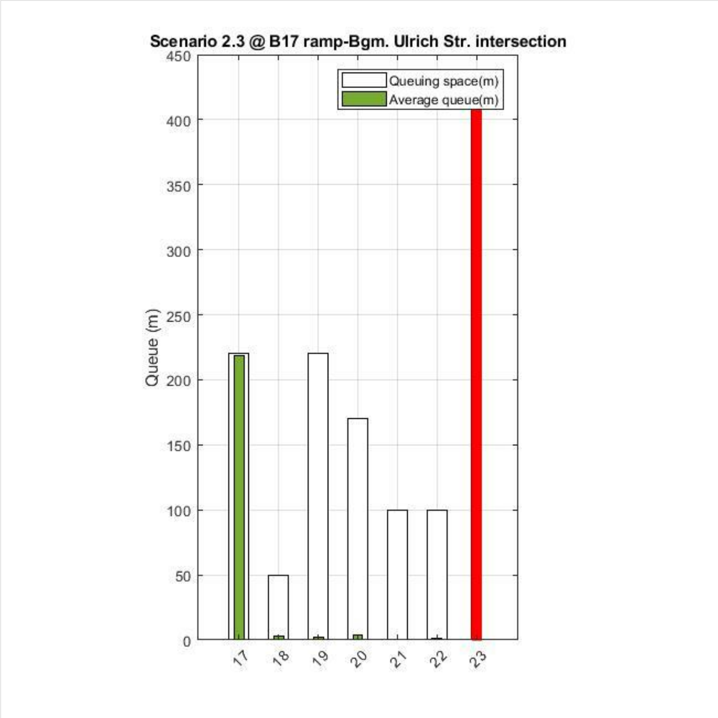
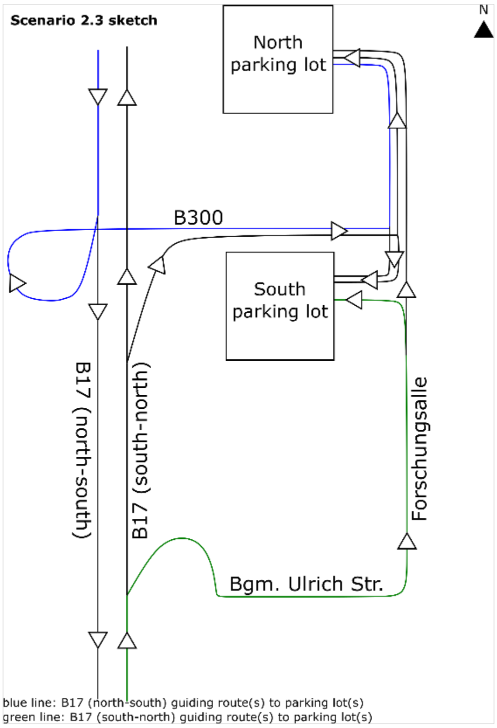
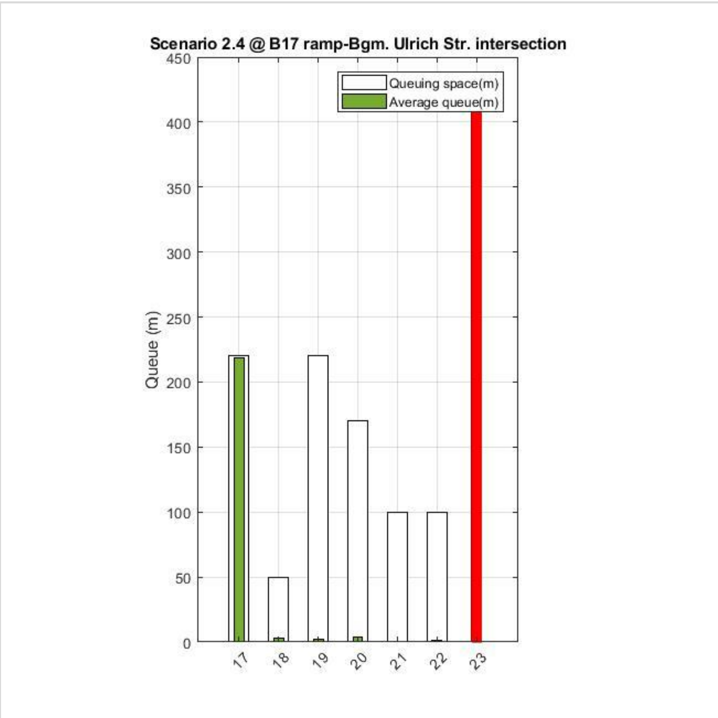


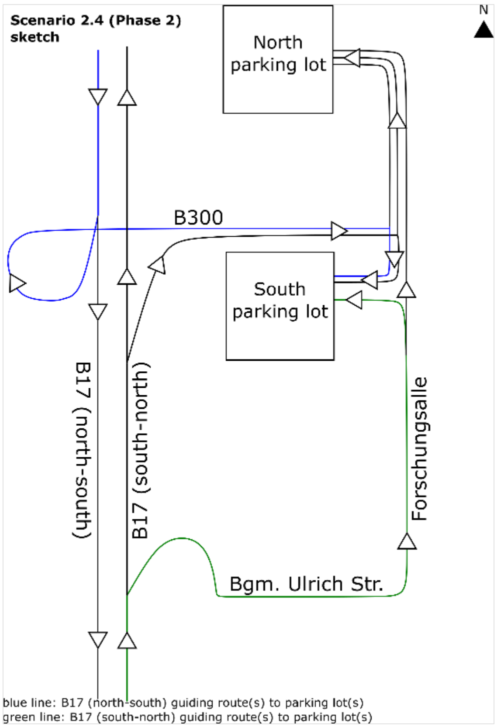
Figure 63: Scenario 2.1 and scenario 2.2 results at B17 ramp/Bgm. Ulrich Str. intersection

top-left: Queue results for scenario 2.1 at queue detectors (17-23) at B17 ramp/Bgm. Ulrich Str. intersection/ **top-right:** Scenario 2.1 sketch/ **middle-left:** Queue results for scenario 2.2 at queue detectors (17-23) at B17 ramp/Bgm. Ulrich Str. intersection / **middle-right:** Scenario 2.2 sketch/ **bottom:** Location of queue detectors (17-23) on map









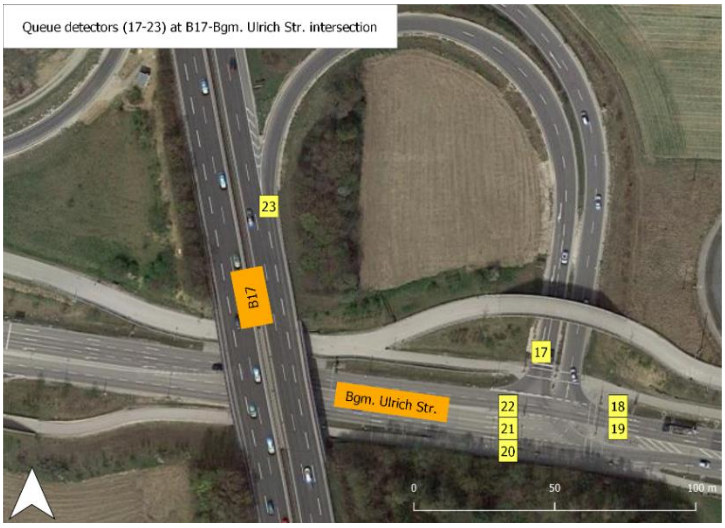
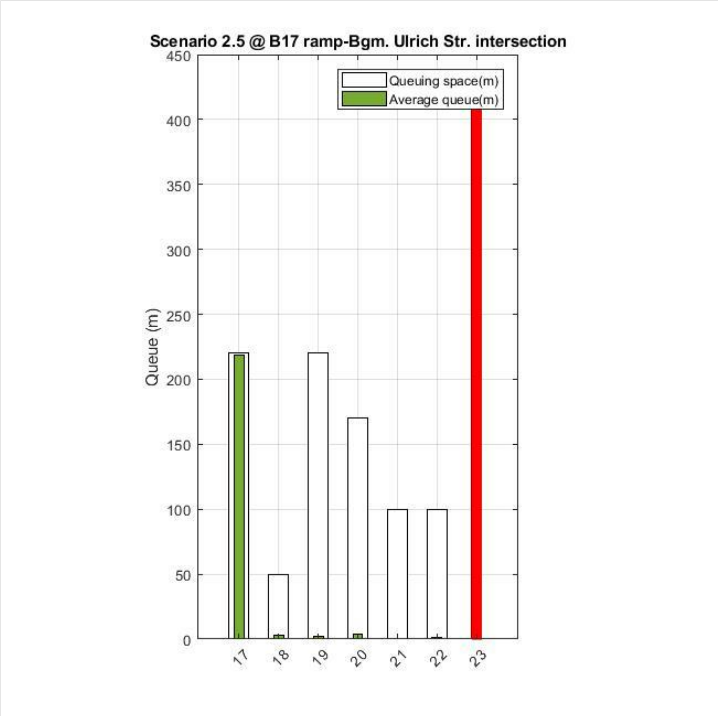
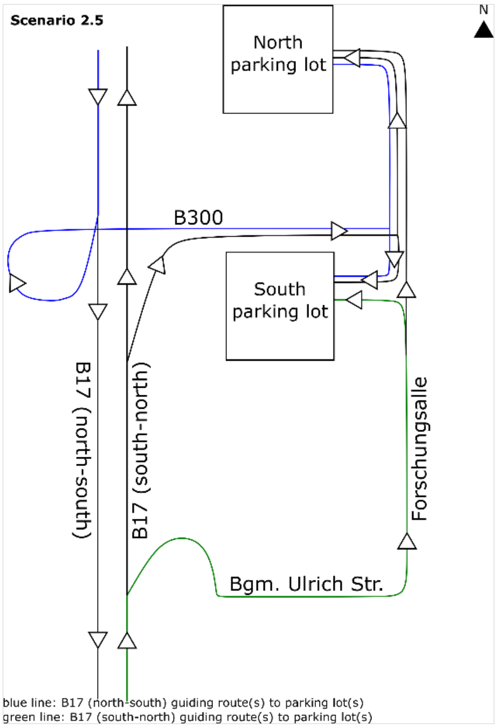
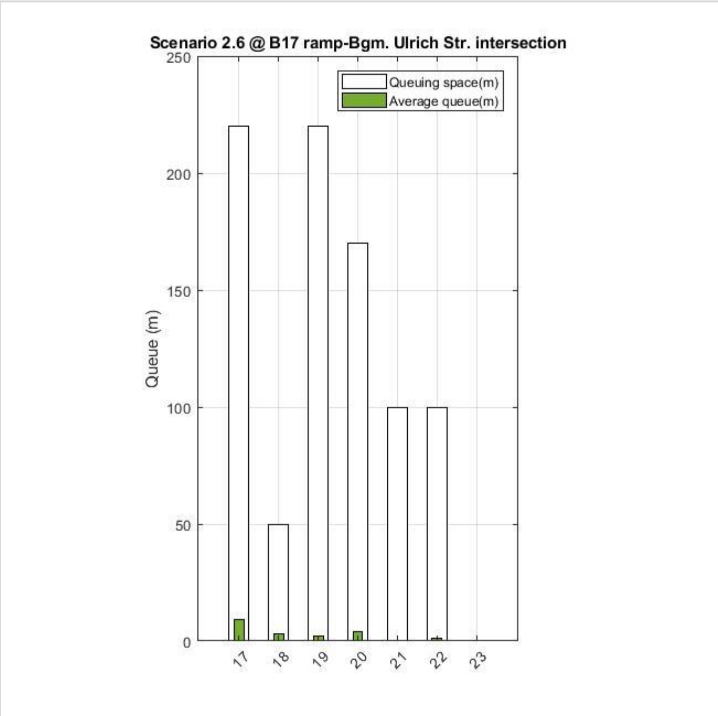


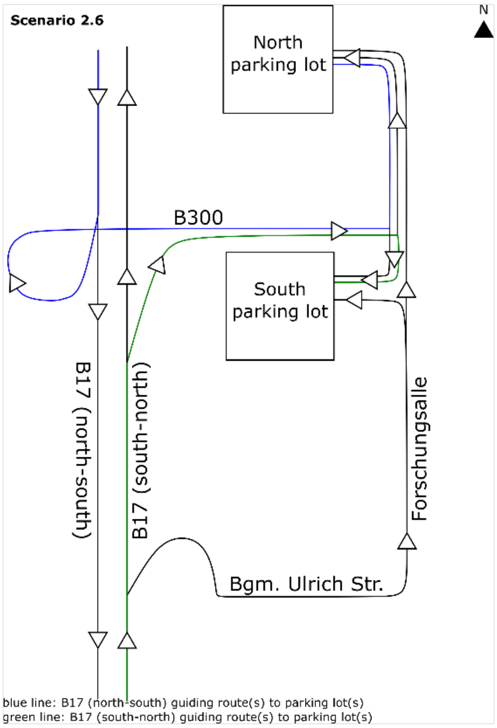
Figure 64: Scenario 2.3 and scenario 2.4 results at B17 ramp/Bgm. Ulrich Str. intersection

top-left: Queue results for scenario 2.3 at queue detectors (17-23) at B17 ramp/Bgm. Ulrich Str. intersection/ **top-right:** Scenario 2.3 sketch/ **middle-left:** Queue results for scenario 2.4 at queue detectors (17-23) at B17 ramp/Bgm. Ulrich Str. intersection / **middle-right:** Scenario 2.4 sketch/ **bottom:** Location of queue detectors (17-23) on map









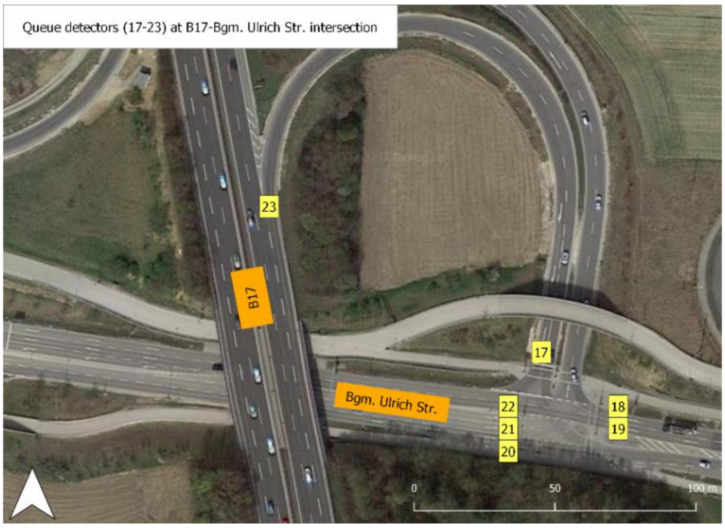


Figure 65: Scenario 2.5 and scenario 2.6 results at B17 ramp/Bgm. Ulrich Str. intersection

top-left: Queue results for scenario 2.5 at queue detectors (17-23) at B17 ramp/Bgm. Ulrich Str. intersection/ **top-right:** Scenario 2.5 sketch/ **middle-left:** Queue results for scenario 2.6 at queue detectors (17-23) at B17 ramp/Bgm. Ulrich Str. intersection / **middle-right:** Scenario 2.6 sketch/ **bottom:** Location of queue detectors (17-23) on map

Appendix: Average maximum queue length for different Scenarios

		Scen.														
		D1	D2	1.1	1.2	1.3	1.4	1.5	1.6	2.1	2.2	2.3	2.4	2.5	2.6	queuing space
Detector No.	1	326	326	326	326	326	325	325	315	326	0	31	26	0	325	275
	2	300	68	68	93	173	0	0	29	73	0	270	269	0	270	280
	3	510	510	510	510	510	510	510	459	510	0	0	0	0	510	0
	4	510	84	84	86	105	57	57	51	82	81	353	309	86	442	0
	5	94	42	42	42	42	42	42	42	42	42	42	42	42	42	100
	6	95	42	42	42	42	42	42	42	42	42	42	42	42	42	100
	7	95	0	0	0	0	0	0	0	0	0	0	0	0	0	100
	8	319	318	318	319	319	319	319	319	319	319	319	319	319	319	90
	9	319	318	318	319	319	319	319	319	319	319	319	319	319	319	300
	10	79	53	53	54	52	53	53	52	53	52	53	52	52	52	100
	11	75	37	37	39	41	42	42	38	57	130	58	117	58	59	25
	12	76	42	42	41	44	44	44	41	58	129	58	117	58	60	90
	13	76	42	42	41	44	44	44	41	58	129	58	117	58	60	90
	14	510	372	372	381	390	278	278	262	372	138	62	314	144	475	150
	15	206	369	369	384	391	301	301	315	357	164	458	411	170	475	300
	16	67	321	321	237	338	216	216	166	303	108	480	459	108	482	115
	17	46	65	65	67	66	66	66	75	62	249	249	249	249	67	220
	18	156	54	54	54	54	54	54	54	54	54	54	54	54	54	50
	19	156	41	41	41	41	41	41	41	41	41	41	41	41	41	220
	20	74	71	71	71	71	71	71	71	91	91	91	91	91	91	170
	21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100
	22	34	19	19	19	19	19	19	19	18	18	18	18	18	18	100
	23	0	0	0	0	0	0	0	0	0	510	510	510	510	0	0

Appendix: Customized signal program

In Sprint 3 of this research project, for the first time, the traffic from B17 (south-north) was guided to Messe parking lots via Forschungsallee. At that time, the network did not include the background traffic on Forschungsallee. However, the traffic jams were diverted to the southern part of the network. Therefore, new signal programs were calculated for the two intersections, based on RiLSA.

Figure 66 and Figure 67 show the queue results for the queue counters in *base* scenario and *guidance via Forschungsallee* scenario. The green window, red window, and yellow window include queue counters results at B17-B300 interchange ramps, Messe intersection, and B17 eastern ramp/ Bgm. Ulrich Str., respectively.

Figure 68 and Figure 69 show the new signal programs at the intersections in the study area.

Figure 70 shows that by introducing customized signal programs in the guidance via Forschungsallee scenario, the average queue length results will be reduced to less than 30 meters in the whole network.

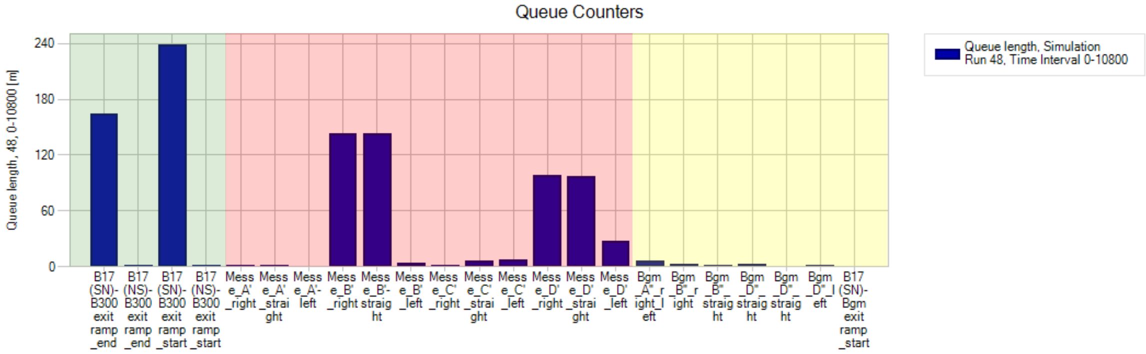


Figure 66: Base scenario (Sprint 3)

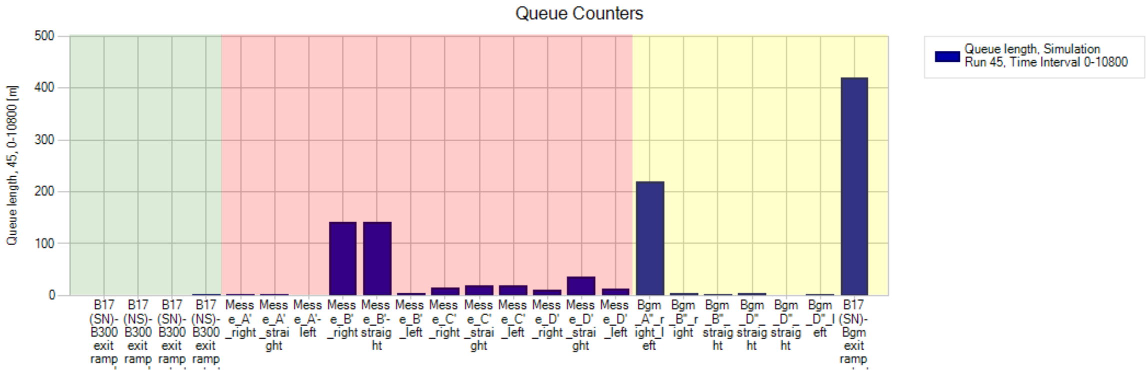


Figure 67: Guidance via Forschungsallee scenario (Sprint 3)

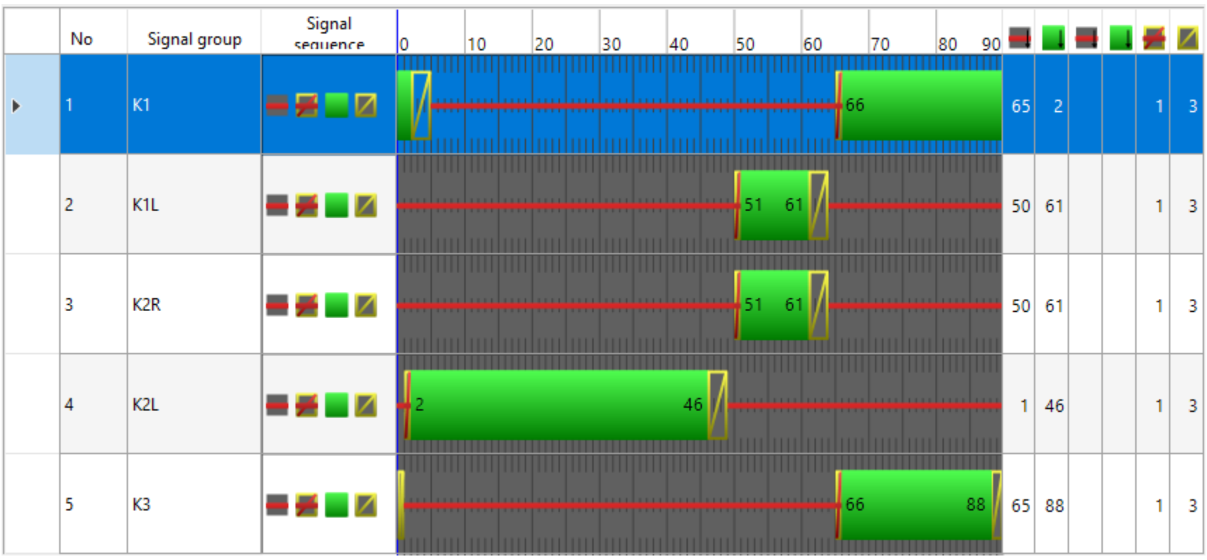


Figure 68: New signal program at B17 eastern ramp/ Bgm. Ulrich Str. inersection

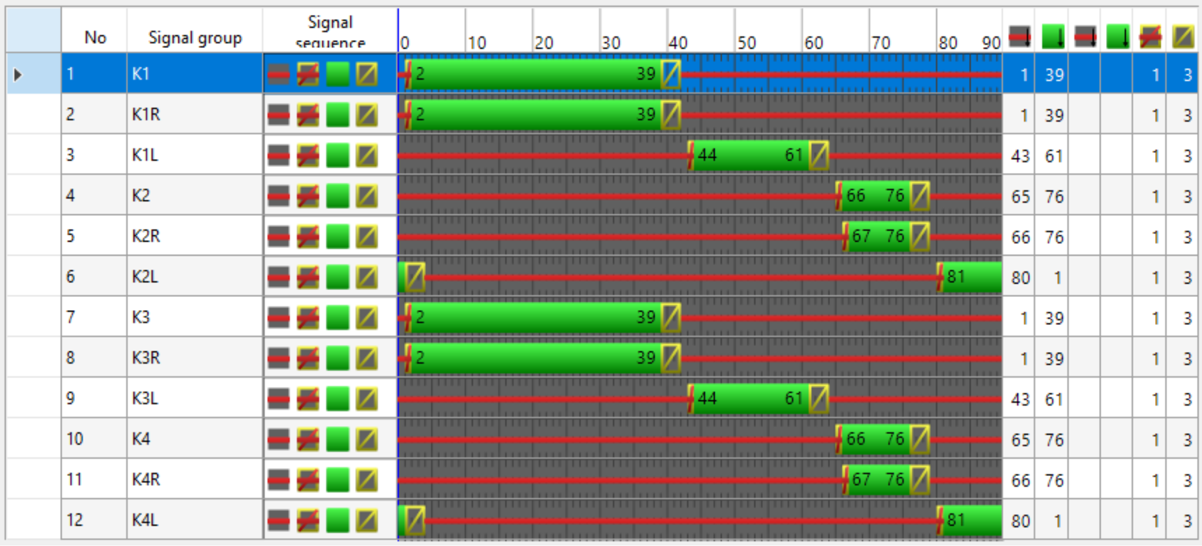


Figure 69:New signal program at Messe intersection

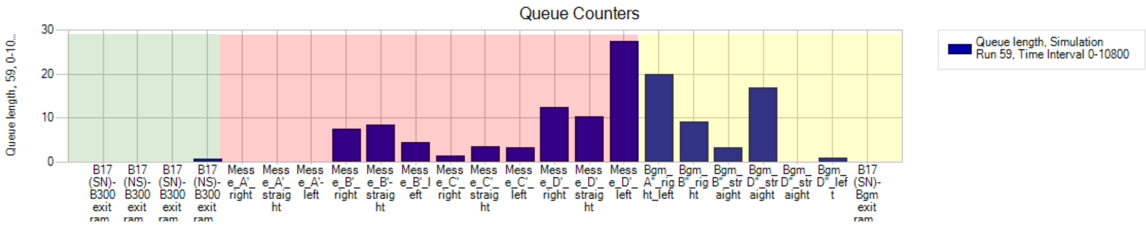


Figure 70: Guidance via Forschungsallee and customized signal program scenario

References

1. **Agile Project Management For Dummies Cheat Sheet. [Online] https://www.dummies.com/careers/project-management/agile-project-management-for-dummies-cheat-sheet/.**

2. *Statistik Augsburg Interaktiv.* [Online] [Cited: 9 9, 2020.] https://statistikinteraktiv.augsburg.de/Interaktiv/.

3. Schlothauer-Wauer. *Augsburg Ergebnisbericht Verkehrsgutachten Messe in Augsburg.* 2019.

4. *Event traffic management design guidelines.* s.l. : State of Queensland (Department of Transport and Main Roads), 2018. Guidline.

5. Li, Peng. *INTEGRATED SPECIAL EVENT TRAFFIC MANAGEMENT STRATEGIES IN URBAN TRANSPORTATION NETWORK.* s.l. : The University of Wisconsin-Milwaukee, 2016.

6. *Traffic Management During a Big Sport Event: A Case Study in Kolkata City.* Ghosh, Kaniska, Singh, Navneet and Maitra, Bhargab. 2019, Journal of The Eastern Asia Society for Transportation Studies, Vol. 13.

7. *Travel trends among young adults in Germany: Increasing multimodality and declining car use for men.* Kuhnimhof, Tobias, et al. 2012, Journal of Transport Geography, Vol. 24, pp. 443-450.

8. *Infrastructure Development in Germany Under Stagnating Demand Conditions A New Paradigm?* Zumkeller, Dirk, Chlond, Bastian and Manz, Wilko. 1, 2004, Transportation Research Record: Journal of the Transportation Research Board, Vol. 1864.

9. *Status Quo statt Verkehrswende. Narrative urbaner Mobilität in Deutschland.* Neebe, Mirjam and Kallenbach, Theresa. 2019.

10. *Straßennutzungsgebühren: Eine Lösung zur Vermeidung von Staus?* Frondel, Manuel. 3, 2019, Perspektiven der Wirtschaftspolitik, Vol. 20, pp. 218-225.

11. Müller, Rainer. *Dynamische Routeninformation im städtischen Umfeld am Beispiel Graz.* 2003.

12. *Key performance indicators for traffic management and intelligent transport systems.* Kaparias, I., Bell, M. G. H. and Tomassini, M. 6, 2011, ISIS, Vol. 14.

13. *Getting to the game: travel to sports stadia in the era of transit-oriented development.* Burke, Matthew and Woolcock, Geoffrey. 7, 2009, Sport in Society , Vol. 12, pp. 890-909.

14. Burke, Matthew and Evans, Rick. *Public Transport Access to Proposed Stadium Sites.* 2009.

15. Baskar, L D, et al. *Traffic control and intelligent vehicle highway systems: A survey.* 2011. pp. 38-52. 3115278.66.7.

16. Ligêza, Antoni. *Logical Foundations for Rule-Based Systems.* s.l. : Springer, Berlin, Heidelberg, 2006.

17. Dynamisches Verkehrsleitsystem Messe/Stadion/ARENA - Verkehrsplanung Nürnberg. [Online] https://www.nuernberg.de/internet/verkehrsplanung/verkehrsleitsystem.html.

18. Spreeuwenberg, Silvie. *Development of the rule based approach to traffic management by the Dutch road authorities.*

19. *Comparison of VISSIM and CORSIM traffic simulation models on a congested network.* Bloomberg, Loren and Dale, Jim. 1, 2000, Transportation Research Record, Vol. 1727, pp. 52-60.

20. *Calibration of microscopic traffic simulation models: Methods and application.* Balakrishna, R., et al. 1, 2007, Transportation Research Record, Vol. 1999, pp. 198-207.

21. Boyles, Stephen D. *A Planning Tool for Active Traffic Management Combining Microsimulation and Dynamic Traffic Assignment.* The University of Texas At Austin. 2018.

22. *Without traffic jams to the concert. Groundbreaking traffic control system for the greater Nuremberg area.* JUELICH, Frank, KOELLE, Mathias and KORDA, Christian. 7/8, 2002, International Transport, Vol. 54.

23. *Das neue Verkehrsnetz-Steuerungssystem VnetS der Landeshauptstadt Muenchen [THE NEW CONTROL SYSTEM FOR THE TRAFFIC NETWORK OF THE STATE CAPITAL MUNICH].* Behr, Erwin and Michael, Ganser. 8, 2000, Straßenverkehrstechnik, Vol. 44.

24. *Evaluation of traffic management strategies for special events using probe data.* Villiers, Claude, Nguyen, Long D. and Zalewski, Janusz. s.l. : Elsevier Ltd, 9 1, 2019, Transportation Research Interdisciplinary Perspectives, Vol. 2. 10.1016/j.trip.2019.100052.

25. Wulfhorst, Ing Gebhard and Assmann, Christian. Chair of Urban Structure and Transport Planning System Modelling Workshop.

26. Weimer, Gregor. *Messe Augsburg parking management.* [interv.] Sara Moghavem Ghaffari. 2020.

27. Krog, Stefan. Augsburg: Warum es bei der afa 2020 kein Verkehrschaos geben soll | Augsburger Allgemeine. *Augsburger Allgemeine.* [Online] 2020. https://www.augsburger-allgemeine.de/augsburg/Warum-es-bei-der-afa-2020-kein-Verkehrschaos-geben-soll-id56531991.html.

28. Shuttle-Service zum FCA-Spiel: Mit dem Bus vom Parkplatz der Messe Fußball-Arena | Augsburger Allgemeine. *Augsburger Allgemeine.* [Online] 2012. https://www.augsburger-allgemeine.de/augsburg/Mit-dem-Bus-vom-Parkplatz-der-Messe-Fussball-Arena-id18954301.html.

29. Hoermann, Michael. Augsburg: FCA-Spiel und afa - gehen an der Messe die Parkplätze aus? | Augsburger Allgemeine. *Augsburger Allgemeine.* [Online] 2018. https://www.augsburger-allgemeine.de/augsburg/FCA-Spiel-und-afa-gehen-an-der-Messe-die-Parkplaetze-aus-id50779241.html.

30. Marks, Ina. Augsburg: Doch Parkplatz-Chaos an der afa 2020: Veranstalter übt Kritik | Augsburger Allgemeine. *Augsburger Allgemeine.* [Online] 2020.

https://www.augsburger-allgemeine.de/augsburg/Doch-Parkplatz-Chaos-an-der-afa-2020-Veranstalter-uebt-Kritik-id56575756.html.

31. Atterdal, Fridtjof. Verkehr: Bei vielen Messen wird Parken zum Problem | Augsburger Allgemeine. *Augsburger Allgemeine.* [Online] 2019. https://www.augsburger-allgemeine.de/augsburg/Bei-vielen-Messen-wird-Parken-zum-Problem-id53450946.html.

32. —. Augsburg: Parkplätze an der Messe sorgen bei Autofahrern für Ärger | Augsburger Allgemeine. *Augsburger Allgemeine.* [Online] 2019. https://www.augsburger-allgemeine.de/augsburg/Parkplaetze-an-der-Messe-sorgen-bei-Autofahrern-fuer-Aerger-id53432506.html.

33. Gastl, Thomas. *Traffic Management System at Messe Augsburg.* 2020.

34. Kaths, Heather and Amini, Sasan. Introduction to Traffic Flow Simulation. 2020.

35. Busch, Fritz. Traffic Flow Models.

36. PTV Vissim and PTV Viswalk Help. [Online] 2020. [Cited: 9 5, 2020.] https://cgi.ptvgroup.com/vision-help/VISSIM_2020_ENG/Content/0_TitelCopyright/Index.htm.

37. *Measuring Traffic.* Bickel, Peter J, et al. 4, 2007, Vol. 22, pp. 581-597.

38. Busch, Fritz. Traffic Control on Motorways.

39. *TRAFFIC QUEUE LENGTH MEASUREMENT USING AN IMAGE PROCESSING SENSOR.* Higashikubo, M, Hinenoya, T and TAKEUCHI, K. 1996.

40. *A method for queue length estimation in an urban street network based on roll time occupancy data.* Ma, Dongfang, et al. 2012, Mathematical Problems in Engineering, Vol. 2012. 10.1155/2012/892575.

41. FGSV. *FGSV Guidelines for Traffic Signals-RiLSA ROAD AND TRANSPORTATION RESEARCH ASSOCIATION STEERING COMMITTEE TRAFFIC CONTROL AND TRAFFIC SAFETY Guidelines for Traffic Signals RiLSA Edition 1992 (with minor modifications).* 2003.

42. Busch, Fritz. Traffic Flow Models (Models for delay and stops).