Otto-von-Guericke-Universität Magdeburg

Fakultät für Informatik

Simulation Project 2018

Project Report - Tramline Jakobstraße

Team SIMTECH: | *Contact:*

Aleksei Baidarov | baidarov@st.ovgu.de

Daniel Bokelmann | daniel.bokelmann@st.ovgu.de

Pham Huu Quang | huu.pham@st.ovgu.de

Sai Vivek | sai.jeevangekar@st.ovgu.de

Sharath Siluveru | sharath.siluveru@st.ovgu.de

Zeynep Ece Ergin | zeynep.ergin@st.ovgu.de

Supervisor: | *Contact:*

Tim Dittmar | tidittma@isg.cs.uni-magdeburg.de

Abstract

The following report presents the simulation of a prospective tram line on the 'Jakobstraße' in Magdeburg, Germany. The resulting model, implemented using the AnyLogic software-suite, is based on several stages, among them abstract modeling, real-world data collection and further data mining activities. The model is considered to be an accurate approximation of the planned future state and thus is expected to lend the responsible planning commission of the city of Magdeburg valuable support for further decision-making.

Acknowledgements

Our thanks go to the city of Magdeburg, and especially to its representative Mrs Frosch-Teichmann, for providing us with this opportunity to work on a real-world task and entrusting us with real-world data.
We would also like to express our gratitude to our supervisor Tim Dittmar and his co-lecturers, Dr. Claudia Krull and Pascal Krenckel, for guiding and supporting us through this valuable experience.
Further thanks go to Prof. Horton for his "Introduction to Simulation"-lecture that provided us with the technical skills and the initial motivation for doing this project.

Contents

List of Figures

List of Tables

1 Introduction

1.1 Task

The task given to the team was to answer one deceptively simple question regarding the 'Jakobstraße' in Magdeburg:
'What effect would a new tram line have'?
To restrict the many possible interpretations, the simulation of the new line has to show the situation assuming that six trams go in any direction per hour and the alternative scenario of the redirection of all trams using 'Breiter Weg' to Jakobstraße in case of emergency or maintenance. The rest was up to the newly formed team, which decided that focusing on the impact the prospective tram line would have on the current situation of motorized traffic, would be in the customer's best interest.

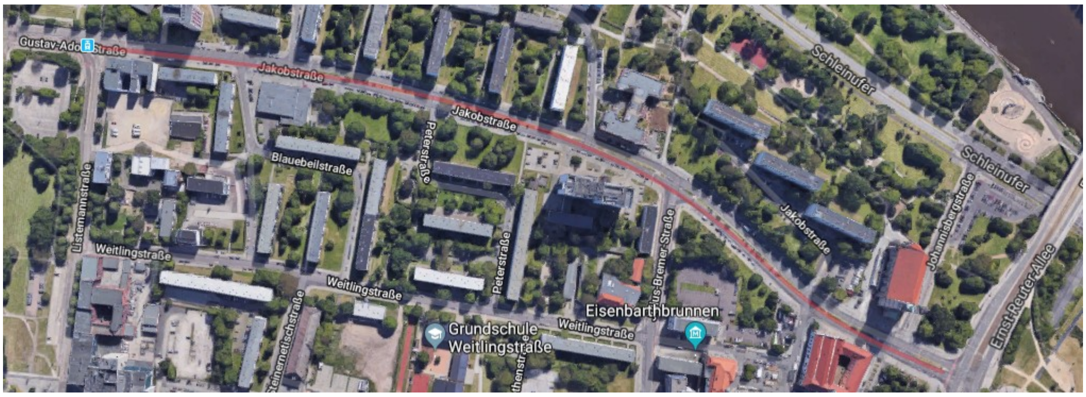

Figure 1: Top-down view of the simulation object - Jakobstraße

1.2 Team

In order to tackle the task given and to distribute the resulting workload, the team's responsibilities were subdivided into roles. Their breakdown is as follows:

Team Member	**Role**
Aleksei Baidarov	Input Data Analyst
Daniel Bokelmann	Project Manager
Pham Huu Quang	Chief Software Architect
Sai Vivek	Experiment Designer
Sharath Siluveru	Conceptual Model
Zeynep Ece Ergin	Validation&Quality Control

2 Conceptual Model

2.1 Overview

Conceptual Modeling is the process of abstracting a model from a real or proposed system after a conceptualization or generalization process in the mind. Conceptual models are often abstractions of things in the real world. Models make us to gain insight in the system, to get ideas to improve the design and to locate the design errors and other shortcomings. Models help to ensure completeness and improve the correctness of the design. Before we show the actual model, we discuss about the different events, which can occur and in the end we tell about the conflicts we had and assumptions which have to be made.

2.2 Assumptions

We have assumed that every user of Jakobstraße is following StVO rules, according to the observations we made. Outcome of our Observations are:

- No speeding
- No accidents
- Infinite patience

For cars and trams we assumed

- Traffic lights
- No trucks, busses and bicycles
- No pedestrians as they are represented by traffic signals.

We Excluded "Breiter Weg" and Seasonal influences.

2.3 Petri net

We used Petri net to model our system. A Petri net is a collection of directed arcs connecting places and transitions. A Petri net may be identified as a particular kind of bipartite directed graph populated by three types of objects. These objects are...

- ...places, some type of resource (illustrated as circles);
- ...transitions, consume and produce resources (rectangles);

- ...and tokens, one unity of a certain resource (illustrated as black dots, tokens live in the places).

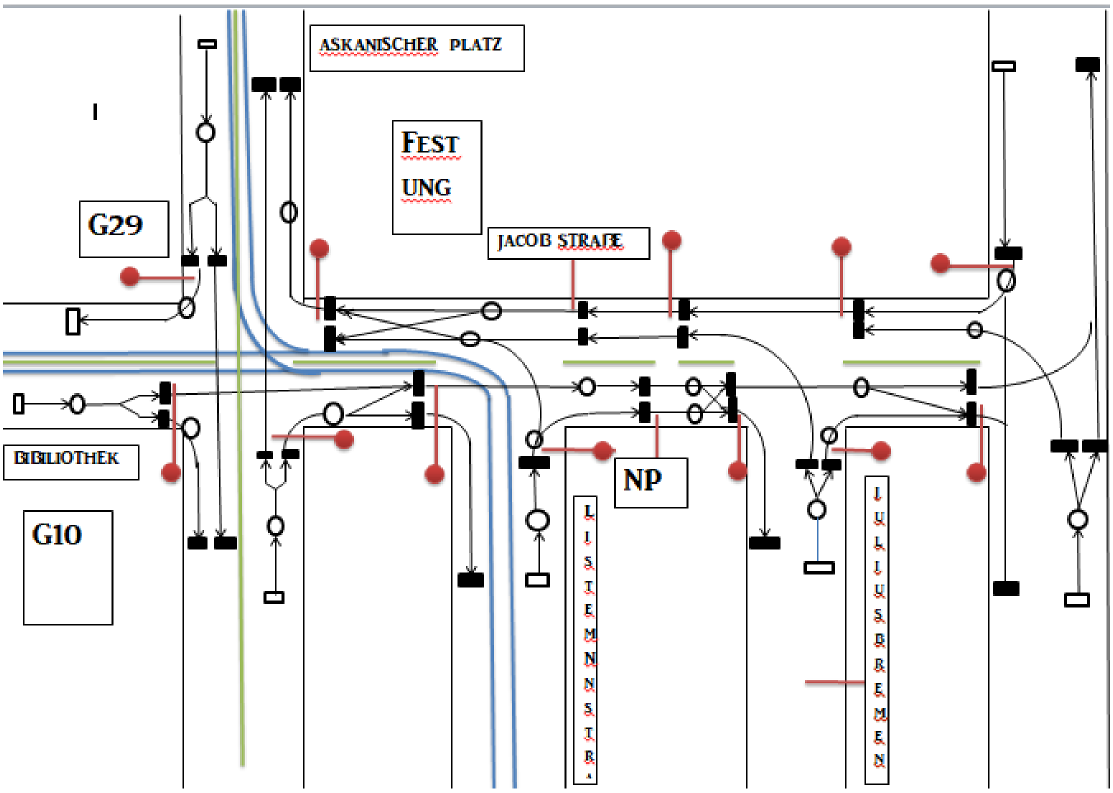

Figure 2: Conceptual model of Jakobstraße.

A source transition generates the cars in each road and a sink transition demolishes the car at the end of the road. A decision transition makes the decision to take one of the lanes or a free lane to cross the junction.

3 Data Analysis

3.1 Overview

Data analysis is an important step that mainly serves for two purposes:

- Provide the input for our simulation model: we need to collect all the data that is required in order to create the model and transform it into the shape that is suitable for usage in Anylogic.
- Provide the basis for validation: we need to measure some real-world output variables in order to be able to compare them to values of the output variable of our simulation model and find out if our model represents the real-world correctly or not.

In our opinion, there five important nodes on Jakobstraße that we have to consider (see Figure 3):

1. Intersection of Jakobstraße and Listemannstraße
2. Intersection of Jakobstraße and Julius-Bremer-Straße
3. Intersection of Jakobstraße and Bei der Hauptwache
4. Intersection of Jakobstraße and Johannisbergstraße
5. Intersection of Jakobstraße and Ernst-Reuter-Allee

Taking assumptions from the Conceptual Model step into account, we have decided that in order to build the model we need the following data.

Input data:

- Traffic volumes (number of cars coming into and going out of the system per hour) for all important nodes (1, 2, 3, 4 and 5).
- Turning probabilities in every possible direction for inner nodes (2, 3 and 4).
- Traffic lights signal timings (red/green timings, pedestrian interarrival time, pedestrian waiting time).
- Length of Jakobstraße and its segments between traffic lights and intersections.
- Speed limit for cars.

Figure 3: The most important nodes of Jakobstraße.

Output data:

- Traveling time of cars in both direction (from node 1 to 5 and the the other way around).
- Queue length at traffic lights (at the end of red phase).

3.2 Methods

Thanks to City of Magdeburg, we have been provided a lot of data, so there was no need to measure traffic volumes and turning probabilities at nodes 2 and 4, which saved us a lot of time. Of course, since traffic volumes were measured by City of Magdeburg in 2012, we have to make an assumption that traffic volumes at Jakobstraße have not changed drastically since then. Additionally, we assume that all cars move with the speed of 50 km/h. To estimate the length of the street we used Google Maps.

Then we have measured the following quantities:

- Turning probabilities at node 3.
- Traffic light timings at the intersection with Listemannstraße, intersection with Mühlenstraße (near NP), intersection with Julius-Bremer-Straße and intersection with Johannisbergstraße (including pedestrian interarrival time and pedestrian waiting time).
- Pedestrian interarrival time and waiting time (time between pressing the button and signal switch to green) at the mentioned above traffic lights.
- Traveling time of cars in both direction (from node 1 to 5 and the the other way around).
- Queue length at traffic lights (at the end of red phase).

To estimate turning probabilities at the node 3 (intersection of Jakobstraße and Bei der Hauptwache) we manually counted numbers of cars traveling in each direction for both streets and then counted how many cars continued to move straight or made a turn. We have repeated this procedure two times: for the morning rush hour (from 8.30 to 9.30) and non-rush hour (from 10.30 to 11.30) on Wednesday, 9.05.2018.

To get traffic lights information we have manually measured the lengths of red and green signal, pedestrian interarrival and waiting times using stopwatch. We have collected the data for about one hour period for each traffic light between 11.00 and 16.00 on Wednesday, 9.05.2018.

To measure traveling times for cars we made video recordings of both nodes of interest (the intersections of Jakobstraße with Listemannstraße and Ernst-Reuter-Allee) at the same time and then calculated the traveling time for each car that appears on both videos as timestamps difference. The data was collected on for both directions (from South to North and North to South) for 30-minute intervals first during the morning rush hour (from 8.30 to 9.30) and then during non-rush hour (from 15.00 to 16.00). We have repeated this procedure on two different days (Wednesday, 23.05.2018 and Wednesday, 30.05.2018).

And then we have measured queue lengths at two traffic lights: at Johannisbergstraße and near the crossroad at Julius-Bremer-Straße (see Figure 4). These positions have been chosen by us because they have the largest load in terms of traffic volumes. The data was collected on Wednesday, 23.05.2018.

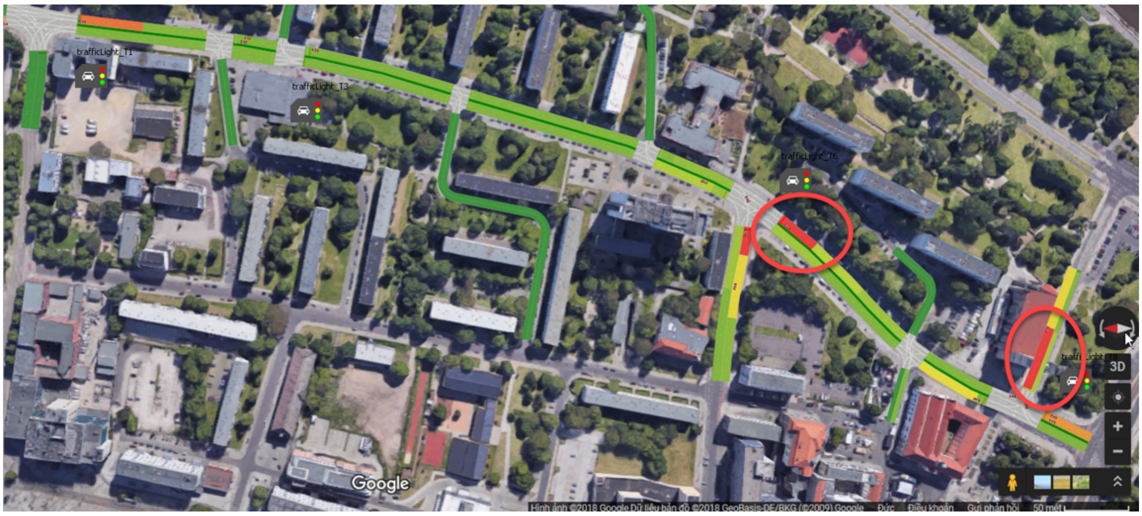

Figure 4: Positions where queue lengths were measured.

3.3 Results

1. Traffic volumes.

   As was mentioned above, we have been provided the the detailed data for traffic volumes at nodes 2 and 4 (Jakobstraße - Julius-Bremer-Straße and Jakobstraße - Johannisbergstraße intersections), so we have used it in order to calculate traffic volumes instead of of measuring the same data again. The data given to us was presented in the form of tables containing the numbers of different vehicles in 15-minute intervals (see Figure 5) from 6.00 to 19.00. Since our model simulates only cars and trams, we did not include other types of traffic, such as trucks, heavy trucks and motorbikes, directly, but took them into account implicitly as car-equivalents using the following formula:

   $Cars = 0.5 \cdot KRAD + 1.0 \cdot PKW + 2.0 \cdot LKW + 4.0 \cdot LZ,$

   where $KRAD$, PKW, LKW and LZ are numbers of motorbikes, regular cars, trucks and heavy trucks respectively. We also did not take bikes and buses into account since they do not have much influence on our model.

Zeitintervall	RAD	KRAD	PKW	LKW	LZ	BUS	FZ	KFZ	SV	PKW-E	FZ/H	KFZ/H	SV/H	PKW-E/H
001 06:00 - 06:15	3	0	66	1	0	1	71	68	2	70,0	0	0	0	0,0
002 06:15 - 06:30	4	0	81	1	0	2	88	84	3	85,5	0	0	0	0,0
003 06:30 - 06:45	7	1	108	3	1	1	121	114	5	122,5	0	0	0	0,0
004 06:45 - 07:00	14	0	129	0	2	3	148	134	5	141,0	428	400	15	419,0
005 07:00 - 07:15	7	0	123	5	1	2	138	131	8	141,5	495	463	21	490,5
006 07:15 - 07:30	22	2	138	4	1	3	170	148	8	163,5	577	527	26	568,5
007 07:30 - 07:45	20	3	153	4	2	1	183	163	7	181,0	639	576	28	627,0
008 07:45 - 08:00	19	1	160	8	1	2	191	172	11	193,0	682	614	34	679,0
009 08:00 - 08:15	10	1	133	4	1	2	151	141	7	151,5	695	624	33	689,0
010 08:15 - 08:30	14	0	133	5	0	2	154	140	7	152,5	679	616	32	678,0
049 18:00 - 18:15	14	0	192	0	0	2	208	194	2	199,0	874	825	11	851,0
050 18:15 - 18:30	7	0	143	0	0	2	152	145	2	146,5	772	724	8	745,0
051 18:30 - 18:45	14	1	145	0	0	2	162	148	2	153,0	707	654	8	675,0
052 18:45 - 19:00	19	2	148	0	0	1	170	151	1	159,5	692	638	7	658,0
S01 06:00 - 19:00	698	52	8797	174	26	105	9852	9154	305	9698,0				
Gesamt	698	52	8797	174	26	105	9852	9154	305	9698,0				
DTV								11000						

Figure 5: Structure of the tables that have been provided to us.

Our initial idea was to simulate the whole day from 6.00 to 19.00 (although later during the implementation stage we had to change our minds and simulate only two hours: one rush hour and one non-rush hour because we did not have enough data to accurately simulate the whole day), so considering the assumptions from the previous paragraph, we converted the given tables to simpler ones, that contain only the number of car equivalents per hour ($Cars\_h$) and time interval (see Figure 6).

	Zeitintervall	Cars_h
0	6-7	406.5
1	7-8	639.0
2	8-9	632.0
3	9-10	660.5
4	10-11	647.0
5	11-12	706.5
6	12-13	687.0
7	13-14	697.5
8	14-15	788.0
9	15-16	890.5
10	16-17	989.5
11	17-18	901.5
12	18-19	629.5

Figure 6: Structure of tables after processing.

Then for each section of the street we used two values: the number of $Cars$ during evening rush hour to simulate rush hour and average number of cars during non-rush hours to simulate normal (non-rush) hour.

For nodes 1, 3 and 5 (Jakobstraße - Listemannstraße, Jakobstraße - Bei der Hauptwache and Jakobstraße - Ernst-Reuter-Allee intersections) we only had numbers of cars per 24 hours, hence our approach for traffic volumes at these nodes was different. While analyzing the data given to us, we have noticed that for nodes 2 and 4 the number of cars in 24-hour period (DTV: Durchschnittlicher täglicher Vehrkehr) is 20% higher than the number of cars in 6.00-19.00 period. Then, assuming that traffic volume distribution for nodes 1, 3 and 5 follows the same pattern as for nodes 2 and 4 (see Table 1), we could easily estimate the numbers of cars on per hour basis for each node.

Time interval	Percentage of cars
6-7	4.5%
7-8	6.8%
8-9	6.5%
9-10	7.0%
10-11	7.1%
11-12	7.5%
12-13	7.3%
13-14	7.5%
14-15	8.5%
15-16	9.8%
16-17	10.8%
17-18	7.5%
18-19	7.3%

Table 1: Cars distribution on per hour basis (as percentage of total amount in 24 hours) for nodes 1, 3 and 5.

Again, we have used two values for each segment of the street: the number of cars in the evening rush-hour to simulate the rush-hour and average number of cars in non-rush hours to simulate the normal (non-rush) hour.

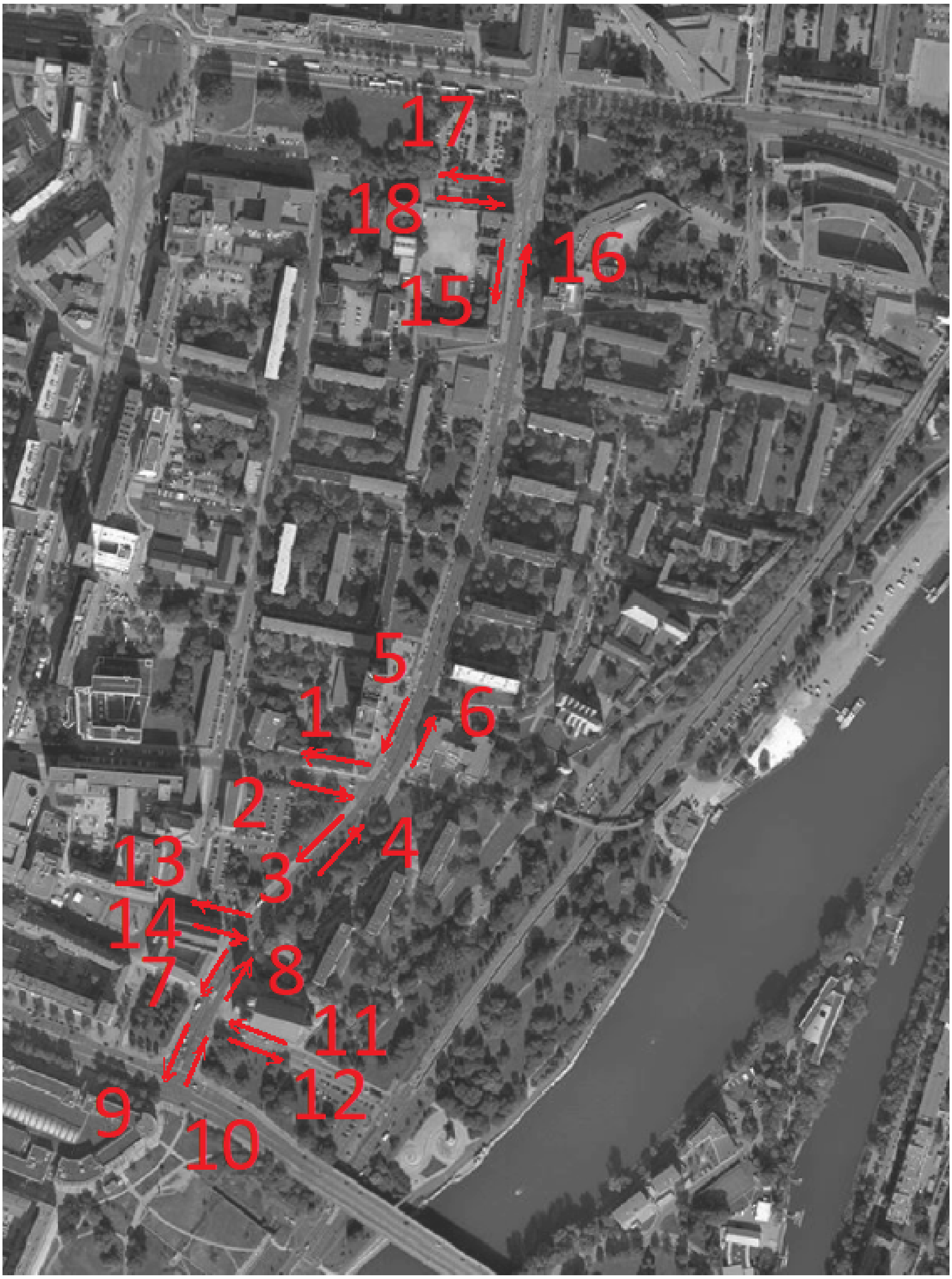

Figure 7: Directions for which we estimated traffic volumes.

1		2		3		4		5		6	
Zeitintervall	Cars_h	Zeitintervall	Cars_h	Zeitintervall	Cars_h	Zeitintervall	Cars_h	Zeitintervall	Cars_h	Zeitintervall	Cars_h
6-7	105	6-7	44	6-7	152	6-7	105	6-7	163	6-7	148.5
7-8	158.5	7-8	108.5	7-8	260.5	7-8	158.5	7-8	255	7-8	216
8-9	156	8-9	98	8-9	235.5	8-9	156	8-9	225	8-9	232.5
9-10	149.5	9-10	135	9-10	267	9-10	149.5	9-10	224	9-10	236
10-11	135	10-11	127	10-11	269.5	10-11	135	10-11	229.5	10-11	232.5
11-12	123	11-12	156	11-12	325	11-12	123	11-12	257	11-12	243.5
12-13	126.5	12-13	177	12-13	327.5	12-13	126.5	12-13	236.5	12-13	226
13-14	120	13-14	181	13-14	324.5	13-14	120	13-14	222.5	13-14	245
14-15	150	14-15	190	14-15	327.5	14-15	150	14-15	260.5	14-15	302.5
15-16	178	15-16	225	15-16	376.5	15-16	178	15-16	266.5	15-16	323.5
16-17	174	16-17	239.5	16-17	465	16-17	174	16-17	349	16-17	345.5
17-18	175	17-18	227.5	17-18	381	17-18	175	17-18	263	17-18	337.5
18-19	110	18-19	153	18-19	265.5	18-19	110	18-19	182.5	18-19	252
mean	143.1153846		158.5769231		305.9230769		143.1153846		241.0769231		257
stdev	25.01429079		56.59536427		77.86415686		25.01429079		44.88543108		55.68662317

Figure 8: Traffic volumes for directions 1-6.

7		8		9		10		11		12	
Zeitintervall	Cars_h	Zeitintervall	Cars_h	Zeitintervall	Cars_h	Zeitintervall	Cars_h	Zeitintervall	Cars_h	Zeitintervall	Cars_h
6-7	158	6-7	235	6-7	203	6-7	363	6-7	152	6-7	235
7-8	259	7-8	329	7-8	349	7-8	552	7-8	280.5	7-8	413.5
8-9	260	8-9	327	8-9	309	8-9	513.5	8-9	245	8-9	382.5
9-10	298	9-10	330	9-10	393	9-10	565.5	9-10	285	9-10	425.5
10-11	277	10-11	391	10-11	379	10-11	644	10-11	301	10-11	452
11-12	343	11-12	343	11-12	424.5	11-12	624	11-12	292	11-12	491.5
12-13	283	12-13	325.5	12-13	377	12-13	588.5	12-13	293.5	12-13	462.5
13-14	320.5	13-14	386	13-14	458	13-14	626.5	13-14	326	13-14	429
14-15	358.5	14-15	418.5	14-15	514.5	14-15	680.5	14-15	408	14-15	514
15-16	438.5	15-16	458.5	15-16	652	15-16	749	15-16	487	15-16	564
16-17	486.5	16-17	460.5	16-17	720	16-17	817.5	16-17	546	16-17	669.5
17-18	406	17-18	394.5	17-18	596	17-18	716	17-18	465	17-18	596.5
18-19	328	18-19	362.5	18-19	519	18-19	573	18-19	412.5	18-19	432
mean	324.3076923		366.2307692		453.3846154		616.3846154		345.6538462		466.7307692
stdev	85.7621562		61.6494172		144.1112351		114.4459759		110.3978383		107.415396

Figure 9: Traffic volumes for directions 7-12.

13		14		15		16		17		18	
Zeitintervall	Cars_h	Zeitintervall	Cars_h	Zeitintervall	Cars_h	Zeitintervall	Cars_h	Zeitintervall	Cars_h	Zeitintervall	Cars_h
6-7	65	6-7	65	6-7	195	6-7	238	6-7	61	6-7	63
7-8	97	7-8	97	7-8	201	7-8	356	7-8	91	7-8	94
8-9	93	8-9	93	8-9	280	8-9	343	8-9	87	8-9	90
9-10	100	9-10	100	9-10	301	9-10	368	9-10	94	9-10	97
10-11	101	10-11	101	10-11	305	10-11	374	10-11	95	10-11	98
11-12	107	11-12	107	11-12	322	11-12	394	11-12	100	11-12	103
12-13	103	12-13	103	12-13	312	12-13	381	12-13	97	12-13	100
13-14	107	13-14	107	13-14	323	13-14	396	13-14	101	13-14	104
14-15	121	14-15	121	14-15	367	14-15	448	14-15	114	14-15	118
15-16	139	15-16	139	15-16	420	15-16	514	15-16	131	15-16	135
16-17	153	16-17	153	16-17	462	16-17	566	16-17	144	16-17	148
17-18	134	17-18	134	17-18	405	17-18	495	17-18	126	17-18	130
18-19	104	18-19	104	18-19	313	18-19	382	18-19	97	18-19	100
mean	109.5384615		109.5384615		323.5384615		404.2307692		102.9230769		106.1538462
stdev	22.64072799		22.64072799		77.2081768		84.41677741		21.42608044		21.99183998

Figure 10: Traffic volumes for directions 13-18.

2. Turning probabilities

   After processing the data, provided by City of Magdeburg, to estimate turning probabilities at nodes 2 and 4 (see Figure 11) and collecting the data for node 3 (see Figure 12), we have got the following results (see Tables 2, 3 and 4).

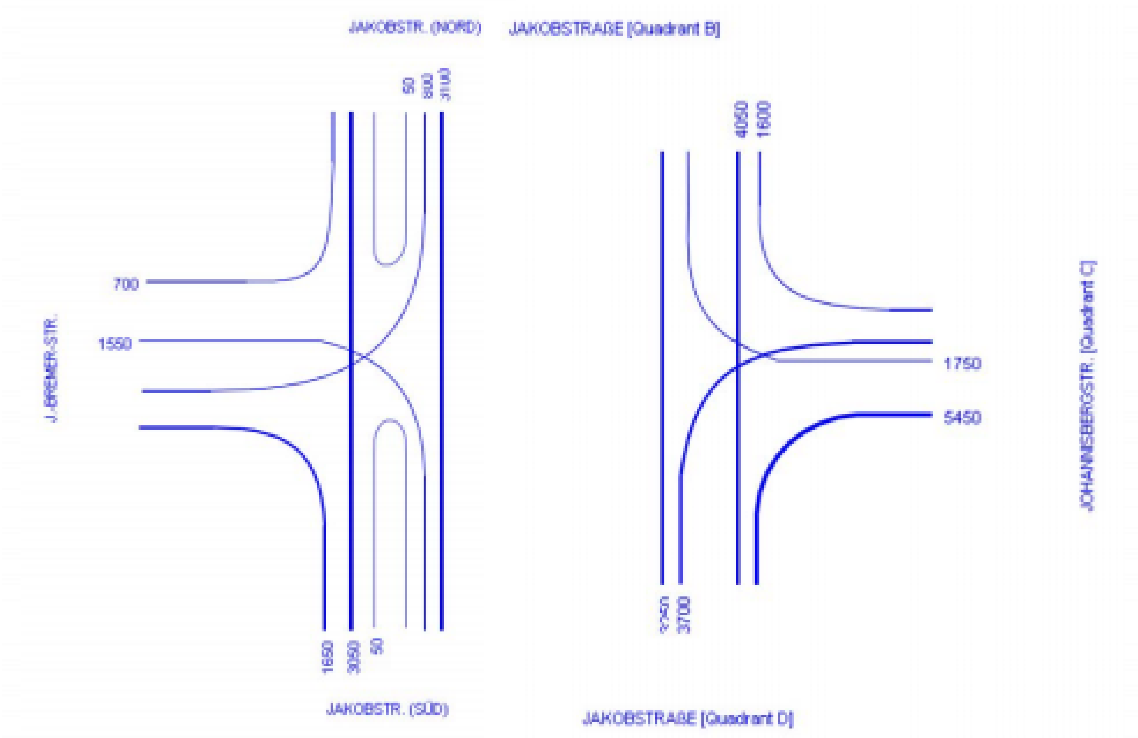

Figure 11: Data used to estimate turning probabilities for nodes 2 and 4.

Timeframe	Lane	Direction in Lane	No in diagram	Number of cars	Total no. Cars in lane
0845-0900	Hauptwache inbound Jakobstraß	South turn	1	7	10
		North turn	2	3	10
	Jakobstraße (North-South)	Turning right	3	3	62
		Straight	4	59	62
	Jakobstraße (South-North)	Turning left	5	8	96
		Straight	6	88	96
0900-0915	Hauptwache inbound Jakobstraß	South turn	1	12	17
		North turn	2	5	17
	Jakobstraße (North-South)	Turning right	3	4	77
		Straight	4	73	77
	Jakobstraße (South-North)	Turning left	5	20	92
		Straight	6	72	92
1045-1100	Hauptwache inbound Jakobstraß	South turn	1	13	21
		North turn	2	8	21
	Jakobstraße (North-South)	Turning right	3	7	101
		Straight	4	94	101
	Jakobstraße (South-North)	Turning left	5	16	97
		Straight	6	81	97
1100-1115	Hauptwache inbound Jakobstraß	South turn	1	14	18
		North turn	2	4	18
	Jakobstraße (North-South)	Turning right	3	8	106
		Straight	4	98	106
	Jakobstraße (South-North)	Turning left	5	14	98
		Straight	6	84	98

Figure 12: Data collected to estimate turning probabilities for node 3.

Probabilities	Jakobstraße North	Jakobstraße South	Julius-Bremer-Straße
Jakobstraße North	0.013	0.803	0.184
Jakobstraße South	0.660	0.010	0.330
Julius-Bremer-Straße	0.327	0.673	-

Table 2: Turning probabilities at node 2.

Probabilities	Jakobstraße North	Jakobstraße South	Bei der Hauptwache
Jakobstraße North	-	0.936	0.064
Jakobstraße South	0.849	-	0.151
Bei der Hauptwache	0.303	0.697	-

Table 3: Turning probabilities at node 3.

Probabilities	Jakobstraße North	Jakobstraße South	Johannisbergstraße
Jakobstraße North	-	0.650	0.350
Jakobstraße South	0.426	-	0.574
Johannisbergstraße	0.302	0.698	-

Table 4: Turning probabilities at node 4.

3. Traffic lights timings, pedestrian interarrival times and waiting times

   After collecting data for traffic lights at intersections with Listemannstraße, Mühlenstraße (near NP), Julius-Bremer-Straße and Johannisbergstraße we have got the following results (see Tables 5, 6, 9 and 8)

Listemannstraße	Measurements	Mean value
Length of green signal (sec)	13, 11, 10, 11, 11, 9, 10, 15, 11, 12, 10, 10, 9, 9, 8, 11, 27, 10, 10, 9, 11, 19, 11, 6, 6, 11, 10, 9, 12, 14	11.2
Length of red signal (sec)	89, 92, 124, 73, 34, 85, 90, 28, 105, 32, 106, 73, 107, 90, 65, 41, 49, 90, 70, 107, 61, 78, 95, 113, 100, 88, 77, 40, 61	78.0
Pedestrian interarrival times (sec)	80, 163, 39, 72, 97, 68, 99, 67, 43, 206, 211, 23, 156, 64, 101, 143, 129, 159, 122, 67, 126, 142, 51	105.6
Pedestrian waiting times (sec)	48, 70, 11, 59, 7, 35, 35, 12, 25, 3, 8, 57, 30, 66, 45, 19, 61, 10, 6, 45, 18, 30, 42	32.3

Table 5: Traffic light at Listemannstraße.

Mühlenstraße	Measurements	Mean value
Length of green signal (sec)	15, 16, 16, 17, 13, 17, 15, 16, 15, 15, 16, 16, 15, 16, 16, 14, 13, 16, 14, 14, 16	15.3
Length of red signal (sec)	111, 170, 130, 39, 39, 112, 119, 37, 33, 61, 39, 43, 37, 30, 52, 59, 40, 101, 58, 98	70.4
Pedestrian interarrival times (sec)	126, 184, 147, 36, 50, 31, 122, 135, 28, 54, 95, 55, 52, 59, 168, 68, 8, 66, 55, 117, 73, 110	83.6
Pedestrian waiting times (sec)	6, 7, 8, 7, 28, 30, 7, 6, 32, 27, 8, 8, 14, 8, 7, 7, 7, 6, 7, 6, 9	11.7

Table 6: Traffic light at Mühlenstraße (near NP).

Julius-Bremer-Straße	Measurements	Mean value
Length of green signal (sec)	17, 13, 18, 14, 12, 15, 19, 16, 12, 16, 10, 13, 13, 16, 12, 12, 14, 11, 13, 14, 11, 18, 15, 13, 13, 12, 15, 15, 11, 13, 11, 13, 20, 20, 12, 11, 18, 11, 13, 10, 11, 12, 17, 15, 13, 14, 22, 12, 14, 17, 11, 20, 19, 17	14.2
Length of red signal (sec)	63, 38, 38, 40, 38, 40, 40, 38, 37, 50, 39, 38, 68, 39, 41, 44, 47, 61, 61, 44, 38, 46, 42, 34, 38, 42, 38, 43, 37, 44, 38, 38, 42, 40, 41, 39, 43, 36, 39, 40, 48, 38, 48, 38, 39, 63, 40, 33, 38, 39, 40, 39, 40	42.4
Pedestrian interarrival times (sec)	44, 166, 52, 18, 149, 21, 487, 136, 247, 113, 190, 97, 186, 31, 91, 81, 202, 113, 104, 87, 39, 24, 107, 60	118.5
Pedestrian waiting times (sec)	9, 15, 20, 18, 21, 30, 9, 34, 30, 27, 7, 24, 16, 14, 39, 14, 20, 5, 34	20.3

Table 7: Traffic light at Julius-Bremer-Straße.

Johannisbergstraße	Measurements	Mean value
Length of green signal (sec)	13, 13, 13, 9, 10, 6, 9, 5, 6, 6, 15, 14, 8, 40, 14, 8, 12, 6, 6, 7, 6, 6	10.5
Length of red signal (sec)	75, 78, 74, 81, 102, 68, 105, 83, 75, 96, 99, 75, 37, 105, 75, 83, 69, 47, 87, 48, 81	78.2
Pedestrian interarrival times (sec)	18, 66, 58, 51, 84, 60, 30, 193, 186, 142, 192, 79, 55, 337, 238	119.3
Pedestrian waiting times (sec)	67, 74, 52, 60, 83, 21, 4, 79, 22, 78, 3, 3	45.5

Table 8: Traffic light at Johannisbergstraße.

4. Traveling time of cars

   Analysis of video recordings gave us the following results.

Northwards direction, rush hour

- Traveling times (in seconds): 91, 77, 79, 76, 111, 98, 89, 78, 89, 107, 109, 70, 114, 98, 88, 97, 68, 98, 87, 87, 118, 78, 92, 150, 117, 86, 76, 54, 94, 86
- Average traveling time (in seconds): 92.1

Southwards direction, rush hour

- Traveling times (in seconds): 100, 63, 80, 62, 87, 120, 98, 136, 137, 131, 115, 109, 107, 117, 85, 78, 102, 97, 94, 88, 92, 80, 133, 113, 111, 80, 114, 115, 73, 118
- Average traveling time (in seconds): 101.2

Northwards direction, normal hour

- Traveling times (in seconds): 106, 95, 101, 99, 94, 98, 98, 95, 71, 95, 100, 76, 114, 116, 112, 97
- Average traveling time (in seconds): 98.0

Southwards direction, normal hour

- Traveling times (in seconds): 89, 94, 104, 103, 89, 99, 52, 105, 62, 72, 90, 123, 103, 105, 91, 100
- Average traveling time (in seconds): 92.6

5. Queue lengths (rush hour)

Near Julius-Bremer-Straße

- Queue length (number of cars): 8, 10, 6, 12, 7, 8, 8, 10, 7, 6, 9
- Average queue length (number of cars): 8.3

Johannisbergstraße

- Queue length (number of cars): 11, 14, 15, 21, 28, 17, 8, 12, 18, 12, 15, 13, 11, 8, 20, 16, 6, 0, 8, 12, 12, 9
- Average queue length (number of cars): 13.0

4 Simulation Program

4.1 Overview

After having the conceptual model and all the data needed, we create a base simulation program to represent the current situation at Jacob Straße. Even though the program can be created to be as complicated as the real world, that will require a lot of data collected. Therefore we try to make it simple, while still cover all the traffic hotspot along the road.

After this step, the base simulation program will be edited and extended by other team group in the validation and experiment steps. For that purpose, we modularized the program and applied a clear structure for it to be easy to understand and maintain. Part of the future steps are already implemented in the program like: the codes for counting queue length, delay time of all cars traveling Jacob Straße, calculating confident interval of those data etc...

4.2 Assumptions

Five roads (belong to four crossroads) are ignored, namely Blauerbeilstraße, Mühlenstraße, Peterstraße, Neustädter Straße, and side road of Jacob Straße. The criteria of this decision is:

- They have low traffic rate
- They have no traffic light
- The density of traffic inflow and outflow are equal.

4.3 Methods

To satisfy the modularization requirement, we choose the "Pipe and Filter" structure for our program. This structure will ensure:

- Separation of independent segments: The program is separated into several parts and several modules. All modules are independent from each other, and therefore ensure the modularization
- Exhibition of concurrence processing: Each module functions independently at the same time, and that process is transparent for monitoring.

- Easy to extend by reusing and adding segments: A modules is a combination of a certain numbers of (program) parts, and can be constructed from the existed or newly added segments.

4.4 Results

4.4.1 Accuracy

We care about every detail while creating the simulation program to ensure the accuracy. By doing that, we can be certain of the result when doing all the experiments, and therefore the quality of our claim and recommendation.

Figure 13: Accuracy by details.

4.4.2 Clear structure

The simulation program is straight forward, easy to understand just by looking at at. In the below picture is two program modules.

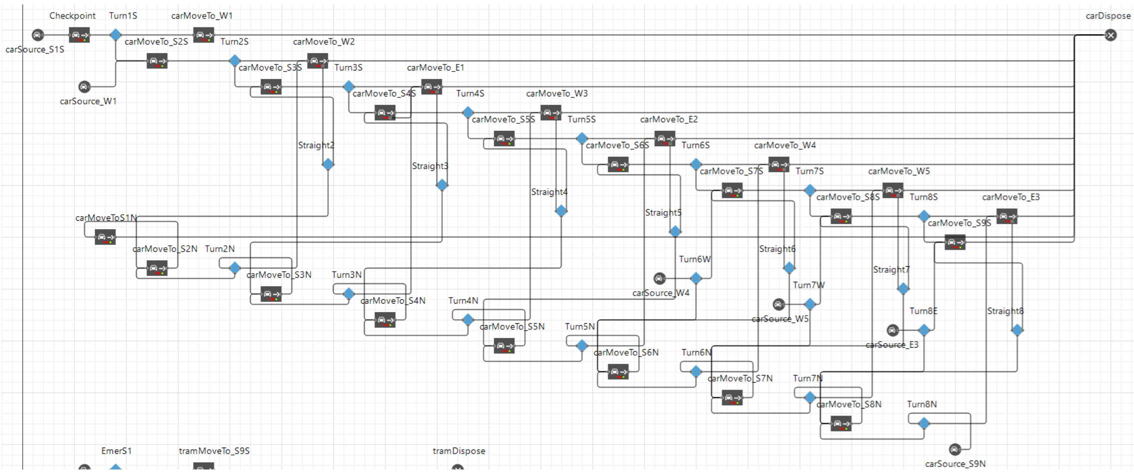

Figure 14: Easy to understand structure

4.4.3 Smooth operation

The program is created with as small event as possible to ensure the lightweight of the code. It can runs an infinite amount of time error-free.

4.4.4 Prepared for next steps

The modification needed for all the next stages of the simulation program is thought of, and prepared ahead to simplified the implementation of them. Below is the code for counting queue length.

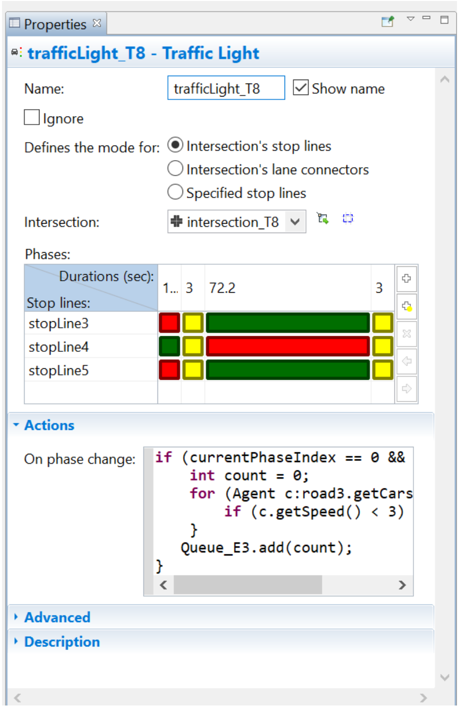

Figure 15: Queue length counting code

5 Validation

5.1 Overview

Validation is the process of determining if a simulation model and its associated data are an accurate representation of the real world with respect to quantities of interest. It focuses on the concord between observed behaviour of the real system with behaviour of the simulation model of the system and on detecting whether the differences are acceptable according to point of interest.

In this section, output data which is used to validate data is given, modifications made on the model are explained, real and simulated data are compared and the limitations and assumptions which cause the differences are given.

5.2 Output Data

On behalf of output analysis, two different parameters are considered, i.e, queue length and traveling time.

First of all, for queue lengths, it is focused on the traffic lights on Johannisbergstraße and at the crossroad of Julius-Bremer-Straße due to high traffic volume. Calculation is done by counting number of cars waiting for each red traffic light. The average queue lengths obtained from the real world are given in Validation Results section of the report.

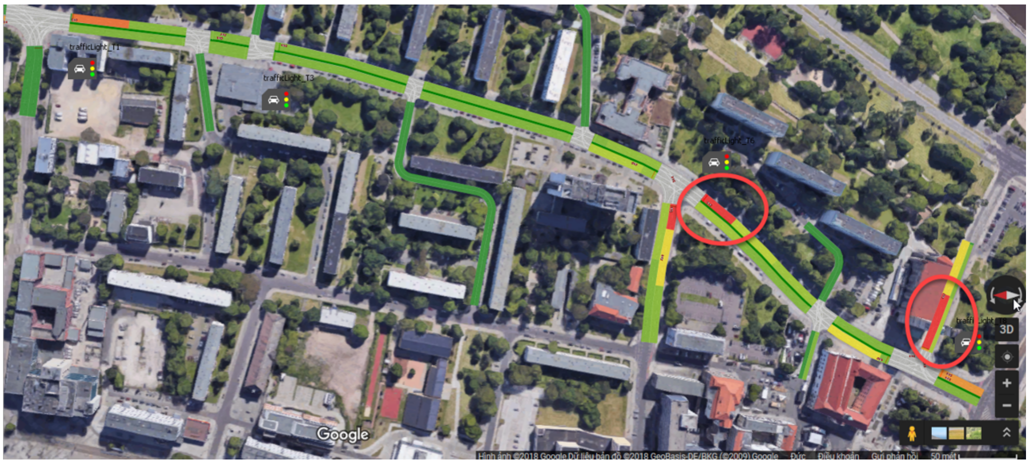

Figure 16: Queue Lengths Interested

Secondly, for traveling time, road completion time of cars are observed. Two cameras are settled at the beginning and end of Jakobstraße and cars are recorded for 30 minutes in rush hours and 30 minutes in non-rush hours. To report the timings, cars which can be seen in both videos are taken and the timings are noted. The average of traveling time is given in Validation Results section.

5.3 Modifications

In order to have a simulation model which is closer to real world, some modifications made in the model. In this section of the report, some of these changes will be shared.

First of all, The biggest change done in validation part of the project is modeling time. Due to having two certain peak times, car sources which are five in the simulation model have to synchronize with each other. Modeling time which was planned as 12 hours is changed to 2 hours as 1 rush hour and 1 non-rush hour to be able to synchronize car sources for peak times.

Secondly, observed mistakes on turning lanes are corrected.

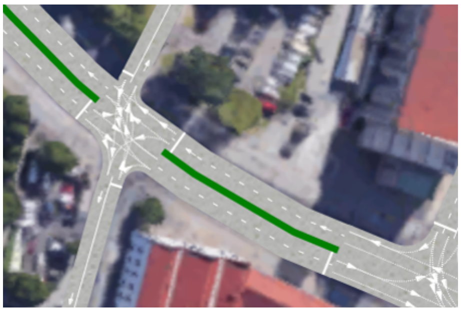

Figure 17: Turning Lanes Near Bei der Hauptwache

Thirdly, for some of traffic lights, some discrepancies were realized and changed after new calculations.

Additionally, in order to have a simulation model which is closer to real life, some modifications on traffic light phases are made. Phases for traffic lights, which were two as green and red, are changed to four phases. As observed at the crossroads, between the changes of traffic lights, there are some gaps for safety reasons. With adding 2 more red phases in model, it is aimed to have these gaps.

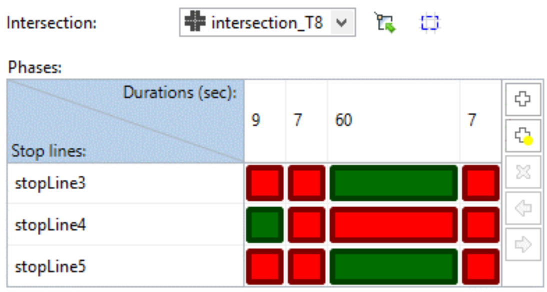

Figure 18: Example for Traffic Light Phases

Lastly, the mistakes done by calculating pedestrian arrival timings on Mühlenstraße was realized and interarrival rate is corrected with a new calculation. The mistake originated in counting all the pedestrians who came to the traffic light instead of the one came when the traffic light is red for pedestrians.

5.4 Validation Results

After the corrections, the model is run for 1000 times with different random value from same distributions. In the run, 0,005 for level of significance and 99% for confidence level are used.

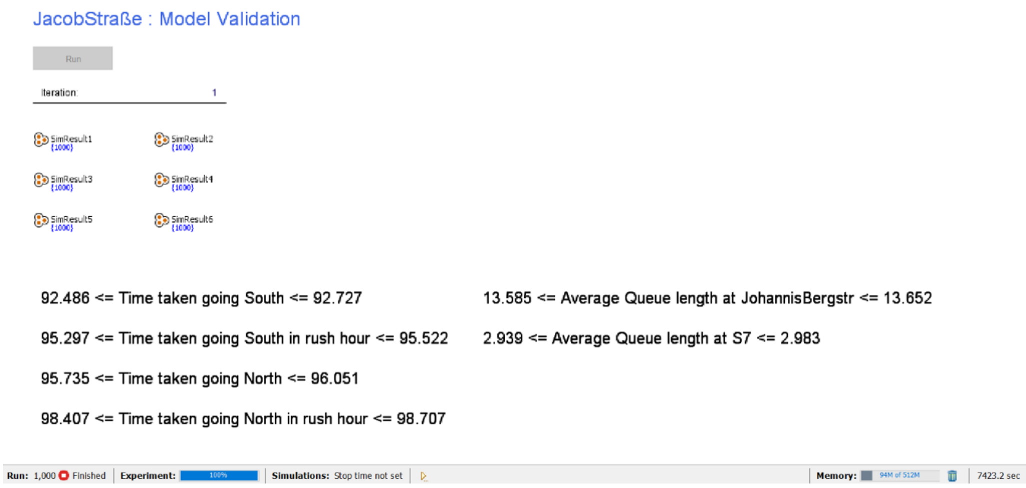

Figure 19: Results of Validation Experiments

Average queue lengths from real world and confidence interval boundaries from simulation model can be seen below.

	Johannisbergstraße	Near Julius-Bremer-Straße
Average of Real World Data	13	8,273
Confidence Interval Lower Bound (Simulation Model)	13,585	2,939
Confidence Interval Upper Bound (Simulation Model)	13,652	2,983

Figure 20: Average Real Data & Confidence Interval

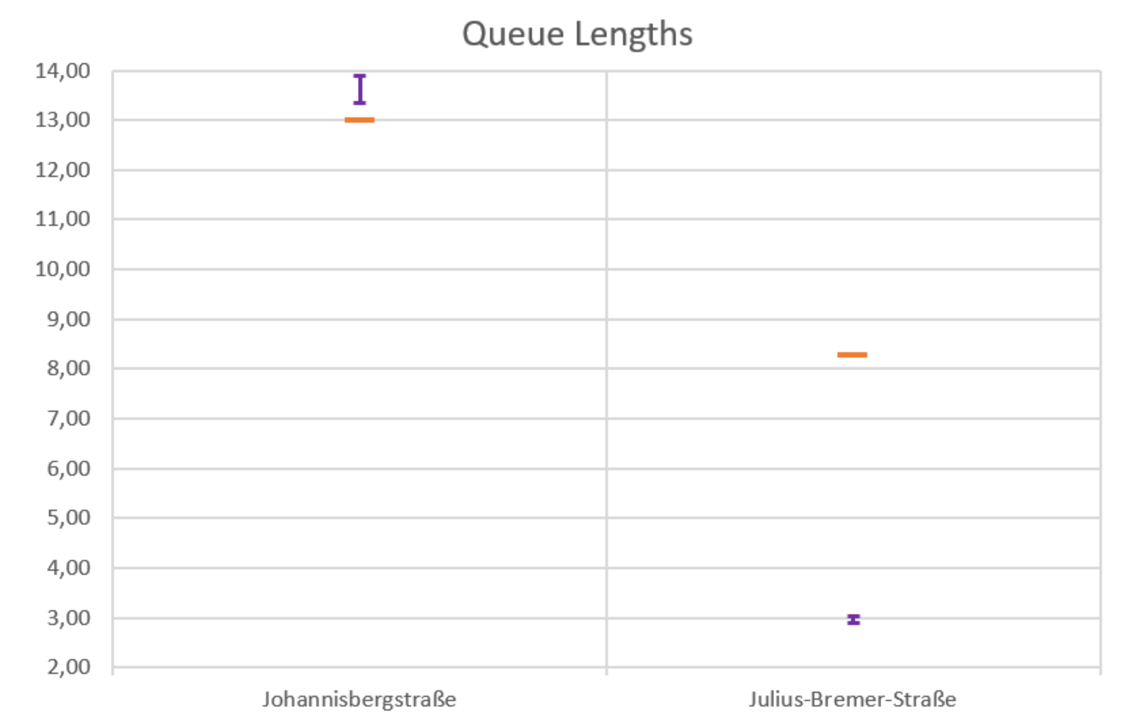

Figure 21: Comparison of real and simulated data for queue lengths

Average traveling time from real world and confidence interval boundaries from simulation model can be seen below.

	Non-Rush Hours		Rush Hours	
	North ⬇ South	South ⬇ North	North ⬇ South	South ⬇ North
Average of Real World Data	92,5625	97,9375	101,16666 67	92,066666 67
Confidence Interval Lower Bound (Simulation Model)	92,486	95,735	95,297	98,407
Confidence Interval Upper Bound (Simulation Model)	92,727	96,051	95,522	98,707

Figure 22: Average Real Data & Confidence Interval

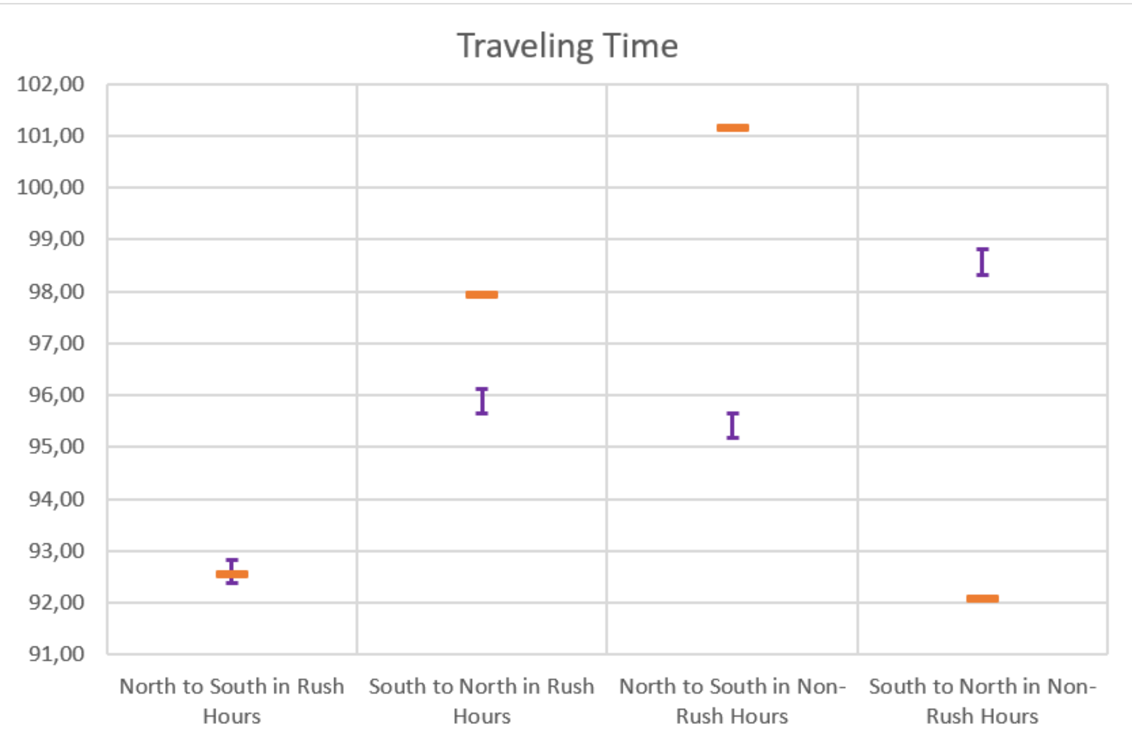

Figure 23: Comparison of real and simulated data for queue lengths

5.5 Limitations & Assumptions

While simulating the real world, due to lack of the knowledge and randomness of real world, the model has some assumptions and limitations.

First of all, due to lack of information about traffic light timings and algorithms, stable numbers are used for timings except Mühlenstraße. Especially in the result of validation experiments for queue lengths, the differences originated by that mostly. The reason of having bigger difference at traffic light near Julius-Bremer-Straße than Johannisbergstraße is number of traffic light which cars need to pass. More specifically, while cars which are created in the model are going directly to the queue on Johannisbergstraße, cars are needed to pass three traffic lights for the queue near Julius-Bremer-Straße and this causes bigger difference.

Secondly, the effects of pedestrians are added to the model only on Mühlenstraße. Beside the effects on traffic lights, pedestrians random behaviours are not included in the system.

Thirdly, traffic lights are not separated for turnings.

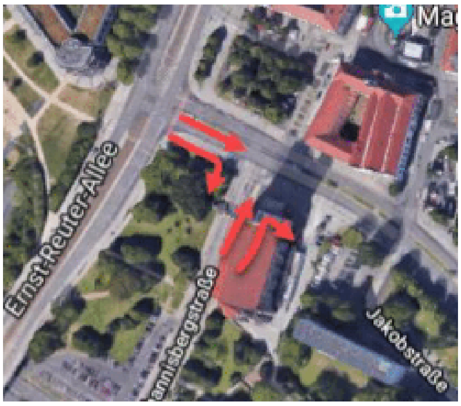

Figure 24: Example of traffic lights which are separated for turnings

Forth of all, the lack of knowledge about behaviour of cars which are chosen for calculation of traveling time also causes the difference between real and simulated data.

Additionally, the effects of busses, bicycles and streets with low traffic volumes, i.e. Blaubeilstraße, Peterstraße, Mühlenstraße, Neustädter Straße, are not added to the model.

Lastly, turnings probabilities are also stable. The changes during the day in rush or non-rush hours are not added to the model.

6 Experiments

6.1 Overview

Experimentation means testing empirically a causal hypothesis. On the basis of the hypothesis, you design the experiment in such a way that your object of study has a chance, either to behave according to your hypothesis or not. We performed several experiments on Jakobstraße. The results of the conducted experiments are shown below.

6.2 Experiments and results

We conducted several different experiments on the model of Jakobstraße, four of which will be shown. Note: As each variant of each experiment was run a thousand times to arrive at the results, the confidence intervals were quite small. The diagrams thus show the average value between the boundaries of the intervals for ease of reading.

Figure 25: Static view of baseline model

Experiment 1a - Stop Julius-Bremer- Straße

In this experiment, we added tram stop at Julius-Bremer-Straße in both directions. The waiting time for the tram at the stop is assumed to be constant at 25 seconds. For this, we used stop lines,traffic lights and simulated 6 trams per hour in each direction and calculated the queue lengths and average travel time.

In case of emergency, we simulated a diversion path (36 tracks per an hour in each direction - adding lines M1, M2, M5, M9, M10).

After simulating for 1 hour during Non-rush hour and then 1 hour during rush hour with 1000 simulation runs each, we obtained the results, which are shown below

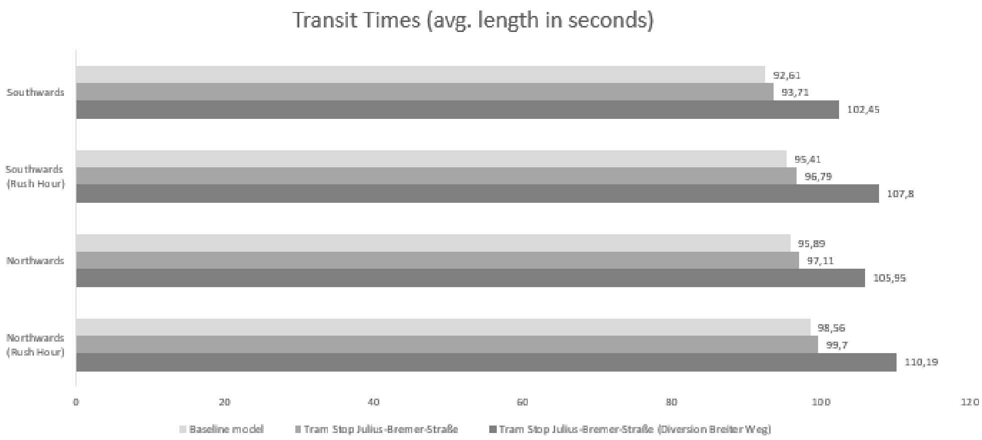

Figure 26: Simulation Results - Comparison of avg. transit time

In this experiment, the average travel time (seconds) is calculated and compared with actual travel time (in seconds) in both directions after adding a tram stop at Julius-Bremer-Straße, with the following results

Southwards

The average travel time taken from North to South(Non-rush hour) is 93.71 sec, the actual travel time is 92.61 sec. It clearly shows that the time difference is relatively very less. And In case of diversion average transit time increased to 102.45 sec.

During rush hour the average travel time is calculated at 96.79 sec.While 95.41 sec is the average travel time in the baseline model. In case of emergency, the value jumped to 107.8 sec.

After the comparison, we can conclude that there is no significant change in the overall average travel time during both Non-rush hour and rush hour.

Northwards

The average travel times during non-rush hour and rush hour are 97.11 seconds and 99.7 seconds respectively. While the average travel times for the baseline model are 95.89 seconds and 98.56 seconds respectively. In case of emergency the time changed to 105.95 seconds and 110.19 seconds respectively. Comparison of average travel time northwards is done, showing a slight increase of the travel time during both non-rush hour and rush hour.

Queue length

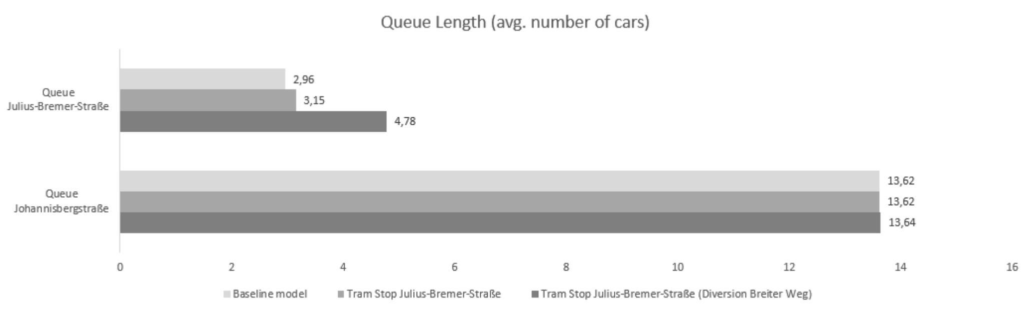

Figure 27: Simulation Results - Comparison of avg. transit time

After the introduction of new tram stop at Julius-Bremer-Straße, the average queue length at Julius-Bremer-Straße is increased from 2.96 to 3.15 avg (avg no.of cars) which is comparatively less. The average queue length for diversion at Breiter Weg has slightly increased.

Average queue lengths at Johannisberger Straße before and after the introduction of tram stop at Julius-Bremer-Straße are 13.62 and 13.62 respectively. In case of diversion, it has a slight increase to 13.64 car units. We can say that the average queue length at Johannisberger Straße is almost same and is affected only very little by the rest of the system.

Conclusion

After the comparison of average travel time and average queue length in both non-rush hour and rush hour.There is no drastic change can be seen in the average travel time and average queue length.Even though there is a small increase in travel time and queue length, that will not have major effect on the system.

Experiment 1b - Alternative positioning of single tram stop

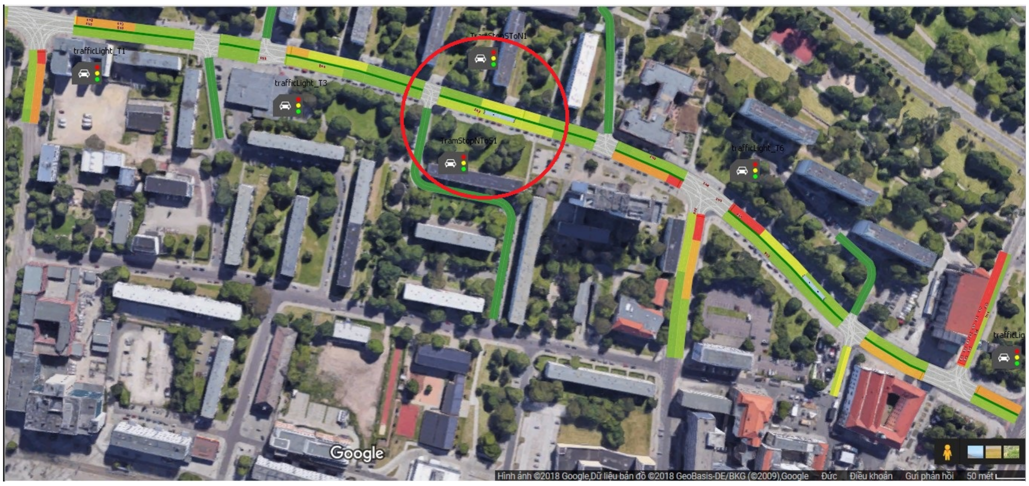

Figure 28: 1st Experiment - Alternative positioning of single tram stop

In this experiment,the placement of the tram stop is changed to a different location and the average travel times is calculated.

Southwards

The average travel times during Non-rush hour and rush hour are 94.02 seconds and 97.23 seconds respectively. While the average travel times for the baseline model are 92.61sec and 95.41 sec respectively. In emergency cases,the travel time is 104.3 seconds and 110.18 seconds respectively. Finally, the average travel time Southwards is calculated, noted small increment in the travel times when compared to baseline model.

Northwards

The average travel times during Non-rush hour and rush hour are 96.56sec and 99.05sec respectively.While the average travel times for the baseline model are 95.89sec and 98.56 sec respectively.In emergency cases,the travel time is 104.04sec and 106.81 sec respectively.The average travel time Northwards is calculated and when compared to baseline model,there was an increment in the travel times.

Queue length

After the placement of tram stop at a different location, the average queue length at Julius-Bremer-Straße is stable 2.96 (no.of cars). However, the average queue length for emergency path has increased to 3.23 (no.of cars).

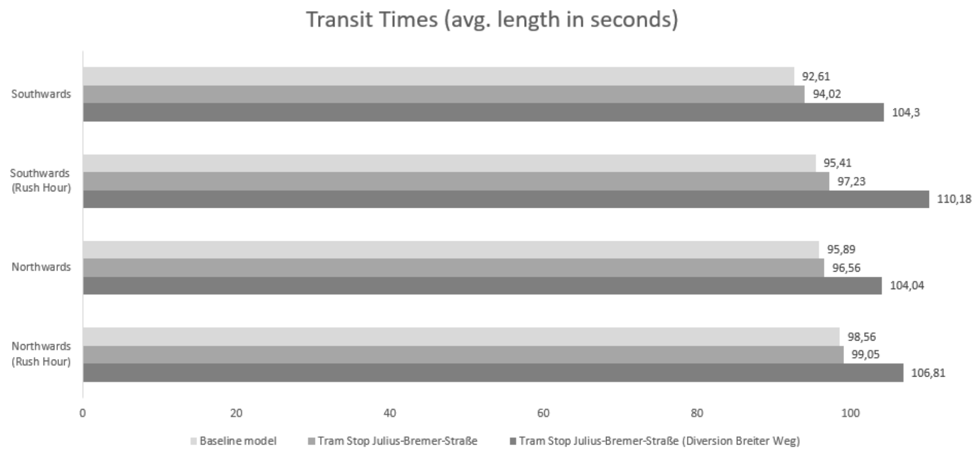

Figure 29: 1st Experiment - Comparison of avg. transit time

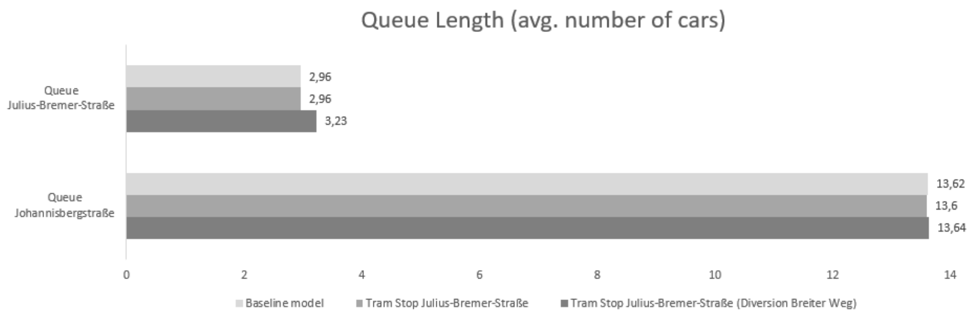

Figure 30: Simulation Results - Comparison of avg. queue length

Average queue lengths at Johannisberger Straße after placing the tram stop at different location does not change. In case of diversion, there is a slight increase in queue length to 13.64 (no.of cars).

Conclusion

After the comparison of average travel time and average queue length in both Non-rush hour and rush hour.Average queue length is constant.There is no change in the average queue length.The average travel time has increased in comparison with baseline model. Even though there is a minute increase in queue length during emergency situation, that will not have a great influence on the system.

Experiment 2 - 2 stops

In this experiment,we decided to introduce one more stop at peter Straße apart from the stop which is at Julius-Bremer-Straße for more even distribution of stops.We expected it to give a higher index values than single stop. We calculated the queue lengths and average travel time after introducing a new tram stop. Here are the results

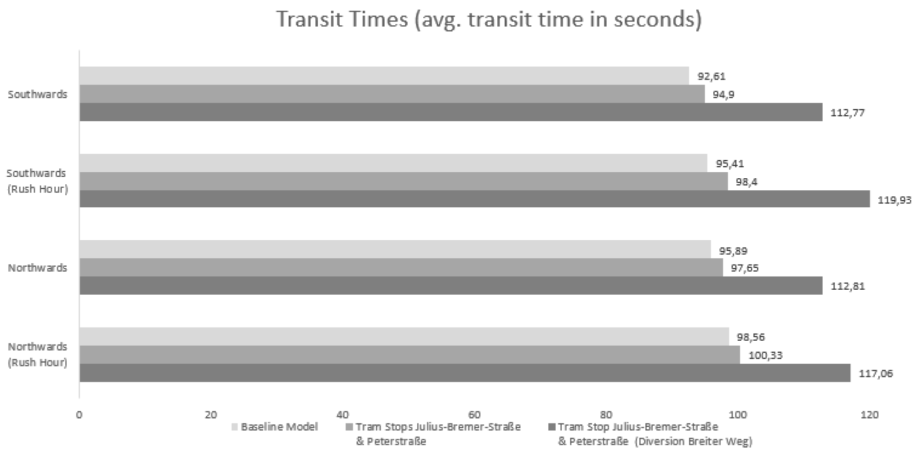

Figure 31: 2nd Experiment - Comparison of avg. transit time

Southwards

The average travel times during Non-rush hour and rush hour are 94.9sec and 98.4sec respectively.While the average travel times for the baseline model are 92.61sec and 95.41 sec respectively.In case of emergency the travel time to 112.77sec and 119.93 sec respectively.Finally,the average travel time southwards is calculated,the travel times during both Non-rush hour and rush hour are increased to some extent but the difference is very small.

Northwards

The average travel times during Non-rush hour and rush hour are 97.65sec and 100.33sec respectively.While the average travel times for the baseline model are 95.89sec and 98.56 sec respectively.In case of diversion the travel time ha gone up to 112.81sec and 117.06 sec respectively.Finally,the average travel time northwards is calculated,the travel times during both Non-rush hour and rush hour are increased by a very small margin.

Queue length

After the addition of second tram stop at Peterstraße, the average queue length at

Julius-Bremer-Straße is increased from 2.96 to 3.12(no.of cars)which is small. The average queue length for diversion path has increased to 4.61.

Average queue lengths before and after at Johannisberger Straße after adding second stop at Peterstraße are 13.62 and 13.63 respectively. In case of diversion, it has a slight increase to 13.63 car units. We can say that the average queue length at Johannisberger Straße is almost equal and has negligible effect on the system.

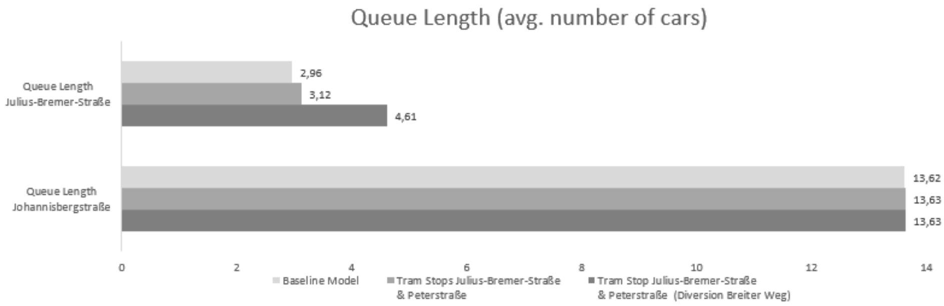

Figure 32: 2nd Experiment - Comparison of avg. transit time

Conclusion

After examining the results,it is concluded that the average travel time and average queue length are increased.

Experiment 3 - ”Left Turn” into Listemannstraße

For experiment 3,we decided to introduce a left turn at Listemannstraße.So far we have only straight ahead in South-North direction.We wanted to test alternative lines and calculated the effect of average queue lengths and waiting times

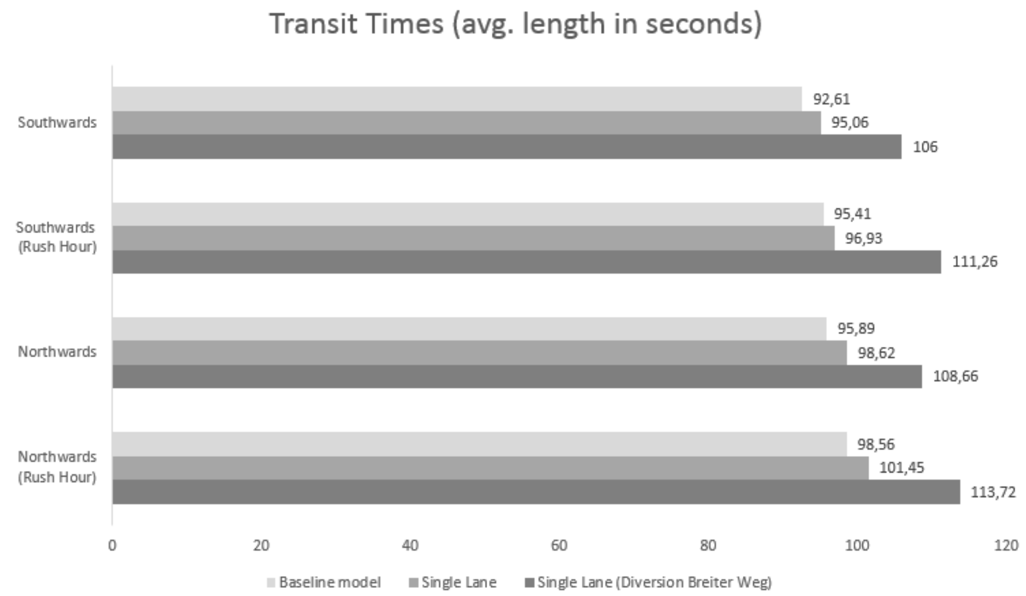

Figure 33: 3rd experiment - Transit Times

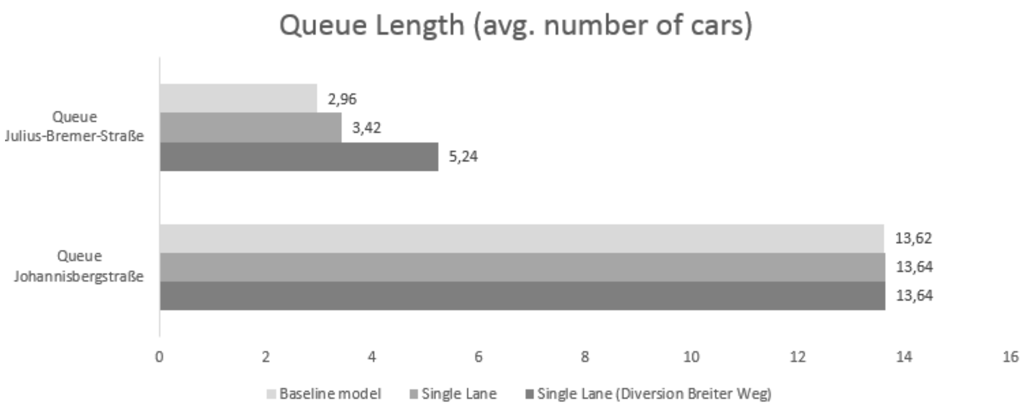

Figure 34: 3rd experiment - Queue Lengths

Conclusion The average travel time and average queue length re calculated and noted small increase.

Experiment 4 - Exclusive tram route

For this experiment, we came up with an idea to introduce an exclusive tram route .And then calculated the effect of average queue length and average travel time for the model in both directions in Non-rush hour and rush hour.

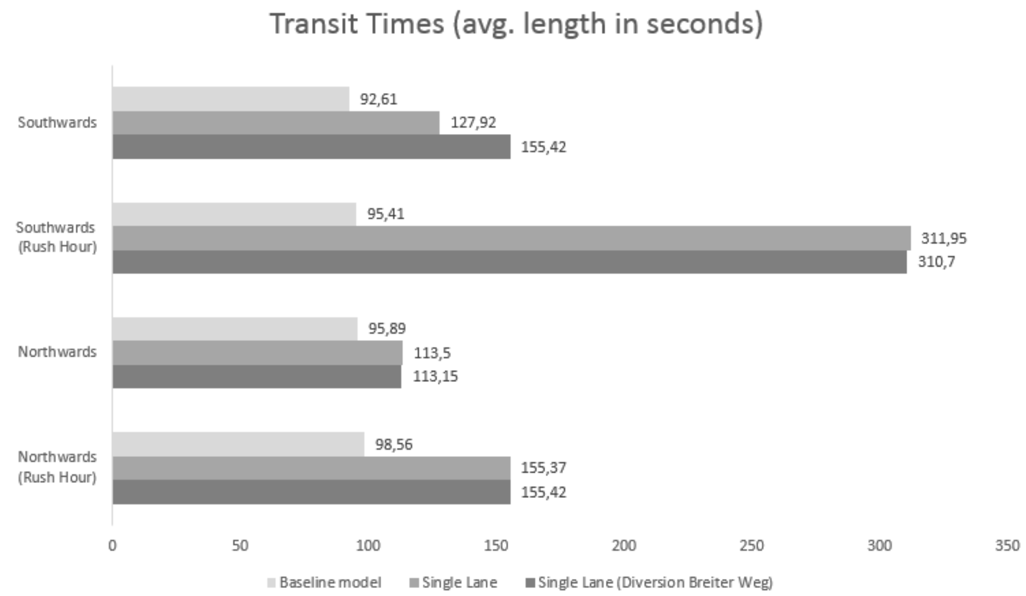

Figure 35: 4th experiment - Transit Times

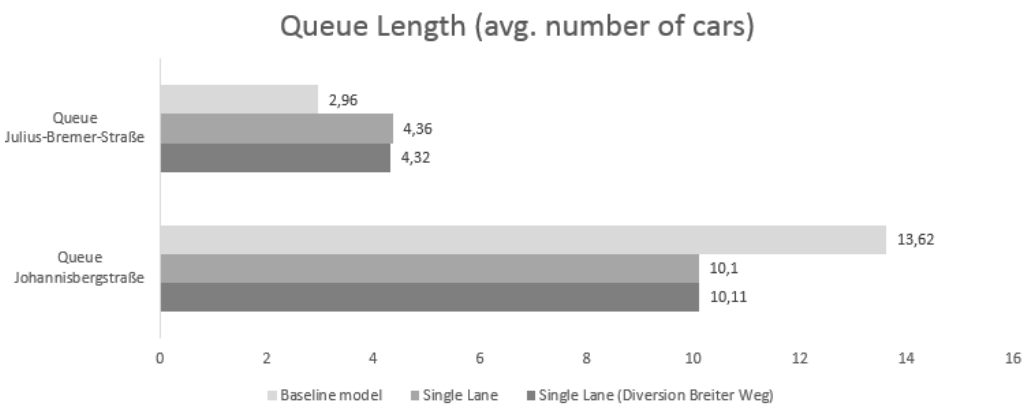

Figure 36: 4th experiment - Queue Lengths

Conclusion After calculating the outcomes of experiment 4,the average travel time has increased by a large number and average queue length increased at Julius-Bremer-Straße and decreased at Johannisberger Straße.

7 General

7.1 Costs

As in most projects, and in software-related ones especially, the most expensive component is people respectively their opportunity costs. Though final numbers aren't fixed yet at the time of writing, the overall cost shouldn't quite reach the projected budget (42.000 Euros without buffer). As our consulting services are calculated with an hourly rate of 100 Euros, this spells out to about 390 hours. Assuming efforts being distributed evenly, this corresponds to about 65 hours for each of the 6 team members over the course of 11 weeks, which again is less than 6 hours per week and thus less than a common (German) workday.

Milestone	Plan	Actual	Plan Running Total	Actual Running Total
Team	42	46	42	46,00
Plan	30	28,5	72	74,50
Concept	54	30,75	126	105,25
Data	66	84	192	189,25
Model	78	56	270	245,25
Validation	54	44	324	289,25
Experiment	48	63,5	372	352,75
Report	48	39,25	420	392

Table 9: Breakdown of total costs

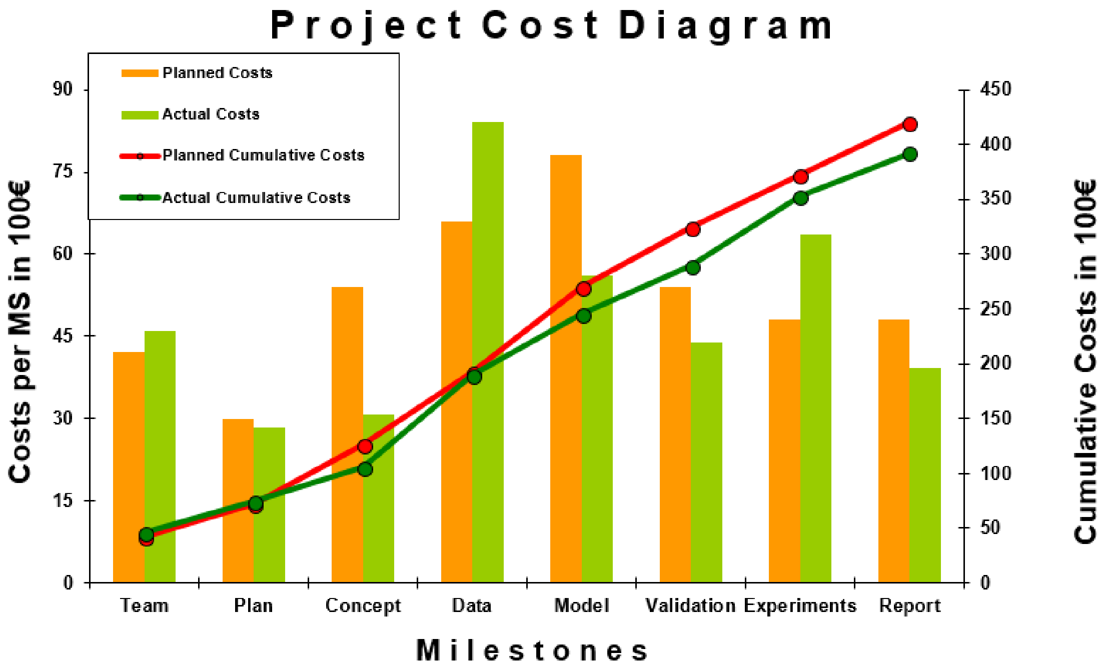

Figure 37: Comparison of planned and actual costs over project's course

7.2 Planning

Though there were minor deviations from the plan, the major goals have all been met in the allocated time with the allocated budget and people during the course of the project. To give an idea at which milestones the progress slightly deviated from the norm, refer to the following diagram:

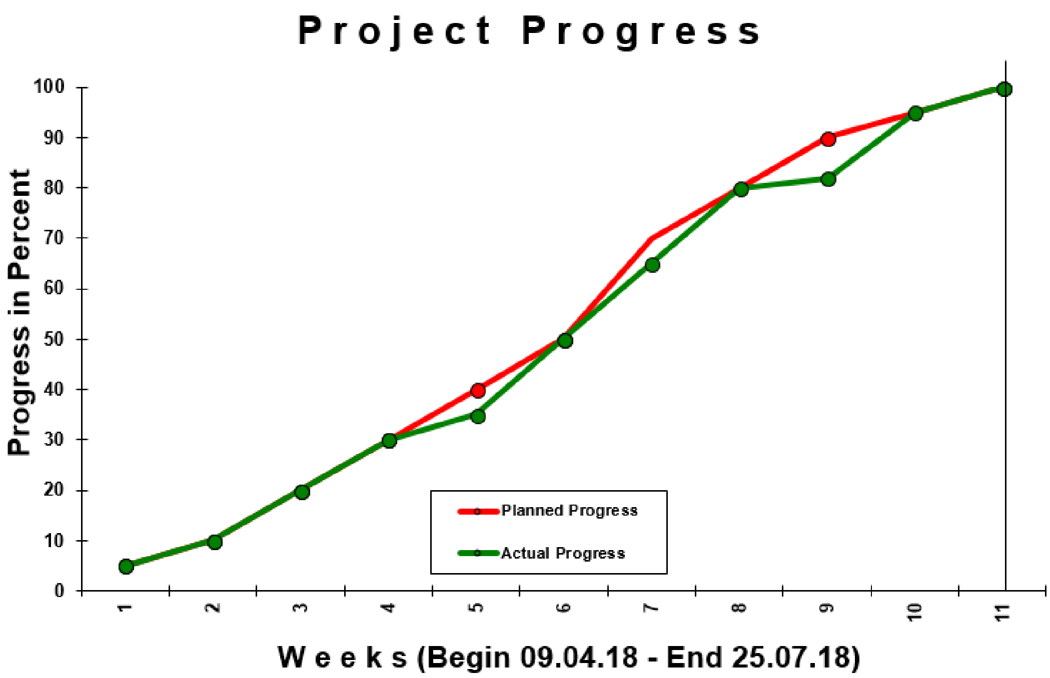

Figure 38: Comparison of planned and actual progress over project's course

Note: The 'sagging' segments of the figure coincide with milestones that take a fortnite instead of a single week, be it because of national holidays like 'Pentecost' in week 5 or 'Whit Monday' in week 7 or for scheduling reasons.

8 Recommendation

The overall recommendation, judging from the outcome of the experiments, would be that building a tram line through Jakobstraße doesn't have a great impact on the actual traffic situation as long as both lanes in each direction stay open to all vehicles. This verdict does not cover changes in external parameters like general traffic volume, throughput of other parts of the road network etc. and is limited in scope to the simulated quantities.
Nevertheless, we as a team wouldn't object to the tram line being built given the simulation results.

9 Team

In this second part of the report, some more informal observations and opinions on the project's course will be voiced. As such, this part is for the team members' and supervisors' use only, excluding the general public.

9.1 Difficulties - expected & unexpected

- Time Management

  Efficient time management was not our strongest ability especially for the first few milestones: our first meetings were not as effective as expected, so we had to arrange additional ones and spend too much time for finding out what to do instead of actually doing anything.

- Cost Tracking

  It is always difficult to predict something in advance, especially when one does something for the first time and doesn't know what to expect from the project, what difficulties might suddenly arise and how much time is really needed for different tasks. That's why we could not manage our costs more efficiently and accurately.

- Limitations of tools

  We have also faced several difficulties while working with different tools. For example, Personal Edition of Anylogic have some limitations for simulation length, number of agent types, pedestrian library and others. This difficulty have been overcome by switching to University Edition that was kindly provided to us the University. Our account Dropbox had limited amount of space, so we had to use different storage solutions to share large files (videos). Some members of them had difficulties with editing shared files because they have older version of MS Office. Also we have learned that it's better to convert files that must be presented on different devices to PDF format, because that way they always look the same on different computers and/or software tools, which is not the case when using native MS Office formats.

- Holidays

  Considering limited amount of time that we had to collect data, holidays reduced it even more, since it does not make sense to collect data on holidays and weekends, as it would not accurately represent the situation for normal working days.

- Scheduling of meetings

  As was mentioned above, we had to arrange additional meetings in addition to our regular meetings slot. That was another difficulty, because all of us have different schedules, work, other appointments and so on. That was not a big problem, when the purpose of the meeting was just to discuss things (since we could always use online tools such as Facebook Messenger for that purpose), but was quite difficult when we had to collect data, because some tasks (e.g. recording videos) required more than person to be completed successfully.

- Sickness

  There is always a possibility that someone suddenly gets sick or doesn't feel well. But since we had time buffers and tried to work as a team, which means to be ready to divide work and responsibilities between all members of the team, that did not influence our performance in a negative way.

- Team Formation

  Since none of us had any experience with projects like this before, most of the team members did not have any preference for any particular team role. But nonetheless it worked out quite well for us, because everyone was involved in every milestone and was not afraid to take the lead/responsibility or propose useful ideas.

9.2 Experiences & Noteworthy events

- Presentations: All the presentation are very important, and somewhat stressful to us. We prepared them in a serious manner. The feedbacks are all very helpful to us and help us improved a lot. It is also a great feeling when our efforts are acknowledged (we won 3 presentation sessions until now).

- Data Collection: while doing data analysis, after many mis-match and error, we realize that some data should be consider noise. An example is when collecting the delay time, we count a police car, which later is confirmed to stop in the middle of the road for pedestrian inspection. Cluster analysis before processing data is what we learned from this. Furthermore, working outdoors is quite different from the usual work environment of a FIN-student.

9.3 What would you do differently next time

- Work with high accountability
- Effective communication
- Mini postmortems at key milestones
- A “pre-mortem” (you assume that a project has failed even before it has started and try to find all potential causes of project failure)
- Manage the budget more closely
- Risk-management: Conflicting goals. If there are any, how to mitigate them? Which goal has the higher priority? These are some questions worth asking right at the start of a project.
- Collecting input and output data at the same time may help to prevent error when validating.

9.4 Evaluation of team

Before diving into the grisly details, several introductory points have to mentioned:

- Team composition

  It has to be mentioned that the composition of the team with its six members happened randomly by lottery, thus ensuring that its members had to find a ’modus operandi’ before actually performing - all phases of ’Tuckmann’s Model’ had to be completed in full.

- Diversity

The team has to be considered as being highly diverse, as there were nearly as many nationalities present as there were team members.

- Lingua Franca

  Taken together with the diversity mentioned, it's also worth mentioning that none of the team members was a natural speaker of English, thus making communication somewhat harder than it would have been otherwise.

- Roles

  The distribution of the roles can be considered to be semi-random, as most team members, apart from the Chief Software Architect, showed no preference for any role.

9.4.1 Leadership

Weak personal leadership, the project's course was rather shaped by the structure imposed on it from the outside. Decisions were arrived at in democratic fashion, that is, by quite often hard-won consensus, which fostered acceptance - the team members adhered to these decisions rather consistently when finally reached.

9.4.2 Organization

As with leadership, organization was more of a team effort, and again as already seen with leadership, this democratic model proved to be surprisingly effective if not efficient, as some decisions were challenged several times over the course of several meetings until a settlement was reached.

9.4.3 Atmosphere

Tense during most meetings, though the resulting impasse was consistently overcome when a certain tipping point was reached, changing into a more open and productive one. Friendly if no stress from the outside was imposed, which was seldom the case.

9.4.4 Division of labor

Below average. At every milestone, the person responsible did coordination as well as manual work with support by one or two other team members - meaning that the workload was unevenly distributed. Data collection was a honorable exception to this, as the whole team 'chipped in'.

9.4.5 Degree of cooperation

To be considered high. Team members could rely on each other in nearly every situation. The limitations as mentioned in the subsection 'Division of labor' have to be taken into consideration, though.

9.4.6 Motivation

Very high, though a little unevenly distributed, this being the main reason for the eventual success of the project despite the shortcomings mentioned. A certain measure of motivation has to be attributed to the timetable, that is the pace was partially imposed from outside the project team.

9.4.7 Competence

Above average, though not stellar averaged over the whole team. Deficiencies were glossed over successfully, though this had a negative impact on efficiency and division of labor.

9.5 Lessons learned

- Student project's are hard. Given that there's normally little in terms of disciplinary tools, slack terms of 'polish of results' and timeliness always creeps in, though it was less than expected in this specific case owing to the high intrinsic motivation of the team. In this case it would be easiest if there'd be more feedback 'rounds' assessing each team member instead of just one at the end.
- Adding members to a team multiplies relationships between its members. This simple observation points to the growing risk of detrimental conflict. Furthermore, the risk of uneven distribution of workload grows with the headcount along with the administrative effort. To counteract this, team's have to be kept as small as possible.
- Problem's are similar to snowballs, not waves. They tend to pick up force rather than petering out. Tackling them as soon as perceived is a must.

- Toolstack used has to be chosen wisely. The toolset as it was used, with 'Facebook Messenger' as a general communication tool, 'Dropbox' for filesharing, 'GitHub' for the simulations model sharing, 'MS Office' for working on some documents and 'Latex' on 'Overleaf' to work on others and at times 'Doodle' for coordinating appointments, should be streamlined. In this special case, at least the functions of Facebook, Doodle and probably Dropbox could have been provided in a unified manner by 'Trello', 'Slack' or an extended use of GitHub.
- In the case of simulation, there's quite often a real object to be modeled. Making every team member a least somewhat familiar with it prevents misconceptions. In this special case, the misconceptions resulting from omitting this step led to several conflicts (concerning scope, actual layout, relative importance of the parts etc.) that could have been prevented from the start. A short walk along 'Jakobstraße' could have doubled as team-building exercise as well.
- Buffers. Though this is common advice, it cannot be stressed enough. Adding large buffers, i.e. 50% of the projected budgets, is a must.

9.6 Comments on course format

- Project work. The course delivers an experience surprisingly close to 'real-world' projects despite its 'sandbox' nature.
- Structure. Well structured course, the rigidity of the schedule greatly helped shaping the project into an appropriate form.
- Presentation slots. To be considered very important given the team composition, as every team member, no matter her or his inclination to do so, was obliged to make and hold a presentation on one's own work.

9.7 Personal notions

- This whole project was very valuable experience, not only regarding simulation but in other aspects of team work as well.
- After completing a real project, we have to revise our knowledge studied from the course "Introduction to Simulation" and understand them clearer. We realize that this course is a high quality lecture with practical value, and we recommended it to our fellow students.