Simulation Project - Summer 2021

Team B

Member	Contact
Prashanth Vaidyanathan	prashanth.vaidyanathan@st.ovgu.de
Harshavardhan Reddy	harshavardhan.bayyapu@st.ovgu.de
Rekha Sundrakrishna	rekha.nuggehalli@st.ovgu.de
Surabhi Katti	surabhi.katti@st.ovgu.de
Rajasekar Dubaguntla	raja.dubaguntla@st.ovgu.de
Md Zahangir Hossain	md5.hossain@st.ovgu.de

Mentors:
Dr.-Ing. Claudia Krull
Pascal Krenckel

29/June/2021, MAGDEBURG

Acknowledgements

Throughout the proceedings of this project, we have constantly been learning. Not only about the technical aspect of a simulation project, but also about communication, collaboration and teamwork. It gives us pleasure to finish this project as a better individual as well as a better teammate, than what we were when we started.

We would first like to thank our mentors Dr. Ing. Claudia Krull and Pascal Krenckel. Their coaching was critical to our project completion. The invaluable advice and suggestions given by them helped us improve every step of the way.

We would also like to thank Prof. Dr.-Ing. habil. Graham Horton for a well taken course of ‘Introduction to Simulation’ during the Winter Semester 2020. This course and his lectures are the reason all of us chose to apply for this project in the current Summer Semester of 2021.

We would like to acknowledge Stadtplanungsamt Magdeburg for allowing us to work on this project and providing us with data from the past for our analysis.

A special thanks to the Faculty of Informatics, Otto Von Guericke University. They ensured continuous development of education and enabled us students to learn from classes and projects even during this pandemic situation.

Finally, we thank our fellow project mates, the other two teams involved. The motivation and inspiration we were able to draw from their work constantly pushed us to try our best. They made this journey all the more thrilling.

Abstract

Traffic problems exist everywhere in the world. To improve the traffic situation of any particular place, incurs a lot of cost - both time and money. This is where simulation comes in. Simulating the traffic system helps us design the model and test it against different scenarios. The resources used are far less than actually implementing real-world changes and it also gives us the ability to predict how things might change with any particular idea. Our team worked towards improving the traffic performance of the node assigned to us - Wilhelmstädter Platz, Stadtfeld Ost, Magdeburg. This report will walk you through our approach to this project. It includes an insight into our conceptual model and our approach to transform given and collected data into knowledge. It also takes a look at the simulation model that was created using the knowledge and conceptual model. It then continues to explain our approach towards validating the model along with four experiments that would be conducted to test traffic performance improvement. This report then concludes analysing the results of the experiment and our recommendation based on different key indicators.

Table of Contents

1. Introduction

The core aim of this project is to improve traffic flow of the node (Wilhelmstädter Platz) by utilizing the knowledge gained about the tools and aspects of simulation, during the 'Introduction to Simulation' course.

1.1 Node Description

The node involves intersection between 5 roads. Two of those are half arms of Gerhart-Hauptmann Straße. The roads and their possible abbreviations in figures are:

1. Olvenstedter Straße (South) [OSS]
2. Olvenstedter Straße (West) [OSW]
3. Ebendorfer Straße [ES]
4. Herder Straße [HS]
5. Gerhart-Hauptmann Straße (main arm and secondary arm) [GH]

Figure 01: Wilhelmstädter Platz

1.2 Special Features of the node

- Two half arms branching from Gerhart-Hauptmann Straße connecting to the node at two different positions.
- There is a tram line running through Olvenstedter Straße.
- There are bus stops in Ebendorfer Straße and Gerhart-Hauptmann Straße main branch.
- Pedestrian crossing present in all roads bound to road signal. Except on Gerhart-Hauptmann Straße secondary branch which is a free crossing.

1.3 Team Goal

We are ‘Team B - Fellowship of the ping’ and our goal for the Simulation Project 2021, is to improve traffic performance metrics for the node of ‘Wilhelmstädter Platz’ at Stadtfeld Ost, Magdeburg. We deliver the proposals in our final project presentation, planned for 29th June 2021. And we aim to achieve this with the support of our dedicated team members. We plan to enable each other to effectively work with a high level of teamwork and communication. All the learnings we take away from this project, whether with each successful milestone or a setback, should help us improve.

We aim to drive this project together to completion on time and with high quality. Individually and collectively, we will use the knowledge we gained in the ‘Introduction to Simulation’ class from the previous semester(s) and apply the concepts learnt there in a practical environment.

Each team member is fully committed to his/her role and has accepted the responsibility of the assigned roles. Though the roles are assigned to create accountability for the type of work, the actual work will still be done using help from everyone in the team. We are also determined to attend each of the team meetings and will be open to put forward our ideas. We have started our journey together and plan to finish it successfully, together, having grown as both individuals and as a team.

1.4 Team Structure

Our team consists of 6 members, each with ownership of a module during the project. While the assigned person is the acting owner, contribution will be from all members of the team across all the milestones. All the roles were divided and taken up during the initial team discussion with consent of all the team members.

Prashanth Vaidyanathan	: Team Lead
Harshavardhan Reddy	: Conceptual Model Designer
Rekha Sundrakrishna	: Data Analyst
Rajasekar Dubaguntla	: Software Architect
Surabhi Katti	: Validation Owner
Md Zahangir Hossain	: Experiments Engineer

1.5 Tools & Platforms used

The main tools used during the projects are mentioned below. Apart from these, there were small usages of other applications such as TeamGantt for Gantt charts.

Informal Communication	: Whatsapp
Formal Communication	: Uni mail
Data Storage	: Dropbox
Documents	: Google Workspace
Simulation	: Anylogic
Project Board	: ClickUp

1.6 Team Member Standards

We created a list of standards that the team members should maintain.

- Punctuality
- Progressive and constructive contribution
- Genuine attempt on completion and quality
- Sincere and Transparent cost reporting

1.7 Project Quality

Our project quality was measured on these different factors:

- Resources utilized: Time and Cost
- Accuracy of the simulation compared to real time data
- Contributions from all the team members
- Identification of optimal signal patterns
- Comparisons with different traffic loads on the experiment results

2. Project Details

This section will walk you through the details of the project and its planning in terms of work packages and deadlines.

2.1 Project Approach

The Project framework we have followed here is Kanban. This helps the team have an appealing visual representation of project progress along with focus on continuous delivery. It also promotes ownership of the work packages along with creating a good balance in workload between the members.

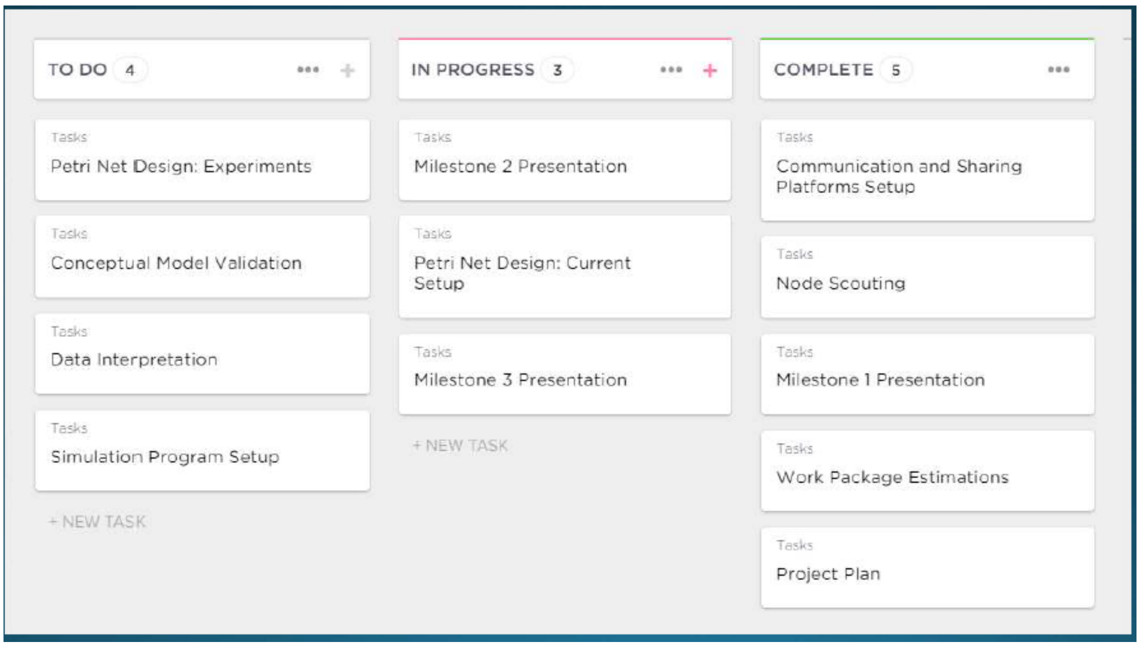

Figure 02: Project Kanban Board

2.2 Operation Structure

The team members each have ownership of one milestone for which they will be responsible and accountable.

Working structure of each work packages:

- Owner
- Principal support engineer
- 2 Support engineers

For each work package, we had an owner who was the critical point of contact for that respective milestone. Then we had a principal support engineer who acted as a deputy for the owner for that milestone in case the owner was unavailable or there were many tasks to be dealt with. Apart from these two, two other members were always available for each milestone in case any help was needed. The other members would pitch in whenever available or got free from working on their own milestone, which usually would be the next one coming up.
This enabled us to reduce workload and dependency on one person for any milestone and also the rotation of all of those roles for each of the milestones ensured that we all had enough time to balance other projects/classes/jobs.

2.3 Project Phases

The project phases were divided based on the milestones that were being followed:

- Team Organization [Owner: Whole Team]
- Project Plan [Owner: Prashanth]
- Conceptual Model [Owner: Harsha]
- Data Analysis [Owner: Rekha]
- Simulation Program [Owner: Rajasekar]*
- Validation [Surabhi]
- Experiments [Zahangir]
- Documentation (consistent phase progress throughout the project)

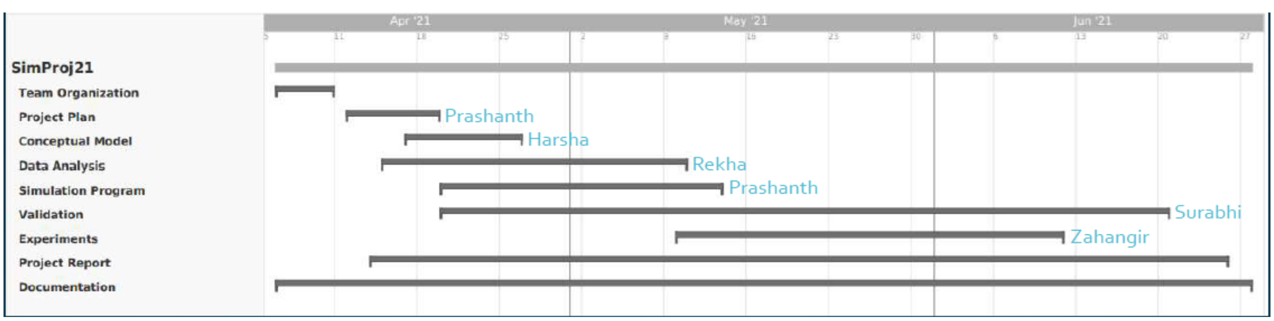

Figure 03: Project Plan Overview

*Rajasekar joined the project after the above plan was created. Thus the owner is different.

2.4 Project Plan

The below is the project plan that was created after discussion between all of the team members and deciding on milestones, deadlines and work distributions.

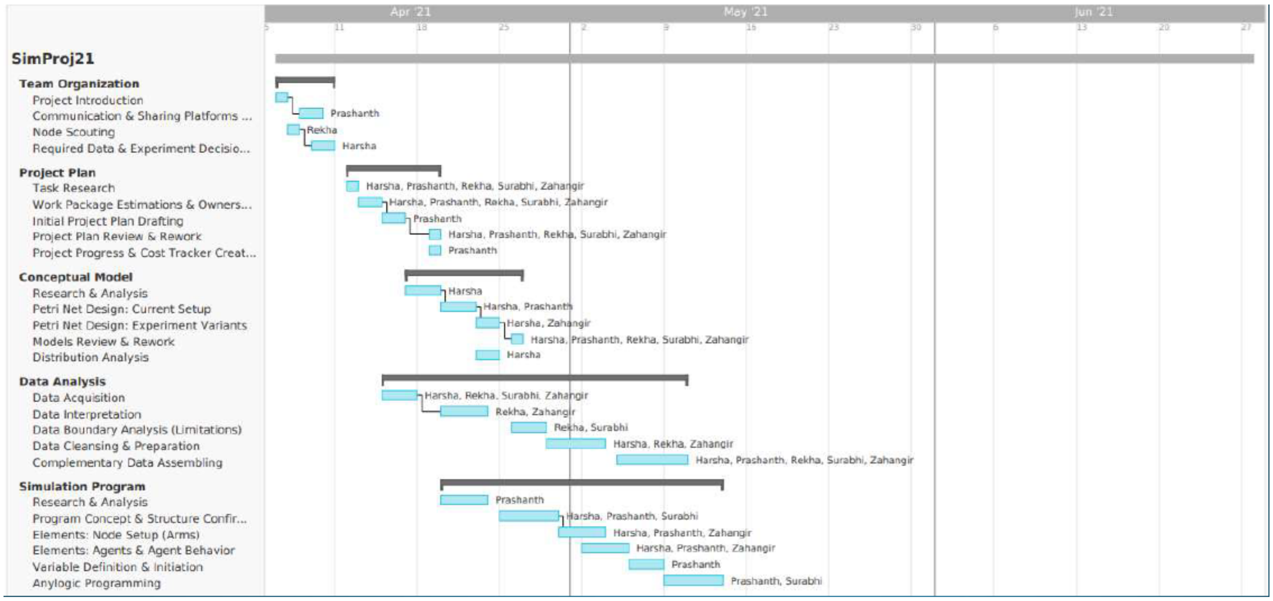

Figure 04: Project Plan - Detailed Part 1

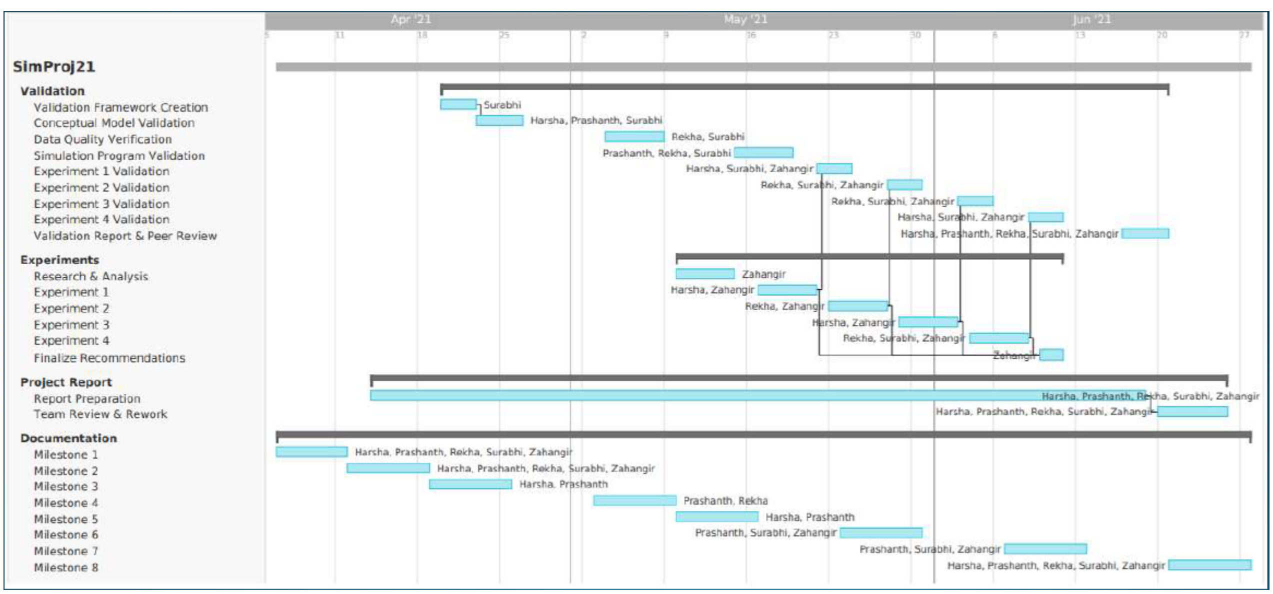

Figure 05: Project Plan - Detailed Part 2

3. Conceptual Model

A conceptual model is a representation of the real system. These models are related to real life scenarios or problems, and give information on what needs to be solved. Petri-net model is the conceptual model that is used in simulation, that defines the states and transactions of the system. Our model describes the functioning of the node that joins the streets Olvenstedter Straße (North west), Ebendorfer Straße, Herderstraße, Olvenstedter Straße (south), Gerhart Hauptmann Straße (5c and 5d). Assumptions were made with justifications to reduce the complexity of real-world scenarios. We look into the other details like the parameters to be measured as inputs and outputs of the simulation model and the types of events described in the model.

3.1 Stochastic Petri Net Model

A petri-net model is used in simulation as a conceptual model. It models all the events and states of the system. This makes the conceptual model easy to convert to simulation. Petri-net is generally recommended for small systems, complexity increases as the model increases.

There are mainly four stochastic Petri-net components, they are tokens, places, transitions and arcs.

3.1.1 Tokens

Represent entities in a system. Represented as dots in Petri-nets. The tokens are located in places. They are created and destroyed by the firing of transactions.

In our system trams, vehicles, pedestrians are tokens

3.1.2 Places

Represent states or locations of a system, which are drawn in circles and are used to store tokens.

3.1.3 Transitions

Represents activities and events which end an activity in a system.They are mainly of two types i) Timed transactions ii) Conditional Transactions

- **Timed Transitions** represent activities and the events in a system, drawn as open rectangles which are used to create and destroy tokens, and also have an associated firing time.
- **Immediate Transitions** represent events (without activities), draws as bars, used to create and destroy tokens, fires immediately when they become enabled, and can also have an associated firing probability.

3.1.4 Arcs

Connects places and transitions, they are of three types i) Input Arcs, ii) Output Arcs, iii) Inhibitor Arcs

- **Input Arcs** join places to transitions, are drawn as arrows, determine which transition to be enabled and which token to be destroyed when fired, can have multiplicity.
- **Output Arcs** join transitions to places, are drawn as arrows, determine where the tokens need to be created when fired, and can have a multiplicity.
- **Inhibitor Arcs** join places to transitions, and are drawn as arrows with circular heads, disable transitions when enough tokens are in place, and can have a multiplicity.

3.2 Events

There are two events i) Primary Events, ii) Secondary Events

Primary Events: The event occurrence is scheduled at a certain point in time. In our system, the primary events are

- Vehicle entry/exit
- Tram entry/exit
- Pedestrians entry/exit
- Change in traffic signal

Secondary Events: events which have certain conditions for their transition to occur. In our system, the secondary events are

- Vehicle movement based on signal change
- Pedestrian movement based on signal change
- Vehicle movement through a pedestrian crossing.

3.3 Assumptions and Simplification

Assumptions that were made are

- The time required for a Pedestrian and a cyclist to cross the pedestrian crossing is the same, because the signal is open for the same duration for both.
- All vehicles follow the traffic rules and signals.
- Traffic signal follow a pattern observed during the sampling process

Simplifications that were made to make design easy are

- Vehicle types: All the vehicles travelling are grouped into these three categories cars, two-wheelers, Heavy Vehicles.
- Pedestrians and Cyclists are grouped into a single group.
- Pedestrians cross only in one direction (the direction should not matter because they cross signal when it is green).
- Gerhart Hauptmann Straße pedestrian crossing is not included (no impact on real world scenario).

3.4 Quantities to be measured:

- **Vehicle inter-arrival time:** is the time difference between two consecutive vehicles entering the system. This provides the type of distribution for the arrival of vehicles into the system. Modelling the system based on this distribution gives the real-time functioning of the system
- **Vehicle turn probabilities:** This is the probability a vehicle which started in a street will turn towards the other streets in the system.
- **Vehicle wait times:** The amount of time a vehicle spends from a point(start) on a street to a certain point(end) on another street in the node. The vehicle wait time helps us in validating whether the simulated system is working similar to the real system.
- **Tram and bus Inter-arrival times:** It's the time difference between two successive trams/bus arrivals. This data is collected from INSA(APP) and is used to schedule tram/bus arrivals in the simulation
- **Traffic signal times:** It is the time taken for a signal to change from one phase to another. This provides the information about the active lanes in the system and helps in determining the respective vehicle queue lengths.
- **Vehicle throughput:** The number of vehicles traveled through the system for a particular amount of time. Helps in validating whether our distributions are generating a similar number of vehicles in the simulated system.

3.5 Quantities for simulation result

- **Vehicle wait time** is the amount of time taken for the vehicle from arrival to departure of the node.
- **Vehicle queue lengths** is the average number of vehicles waiting per red signal per street in the real system.

3.6 Representation of Wilhelmstädter Platz node using Petri-net

The petri-net for this project was developed using PIPE2 software**.** This is with respect to the assigned node for the team which is: Wilhelmstädter Platz, Stadtfeld Ost, Magdeburg. The below depicted figures represent the Petri net of the whole system followed by the Petri net of each of the roads in the node.

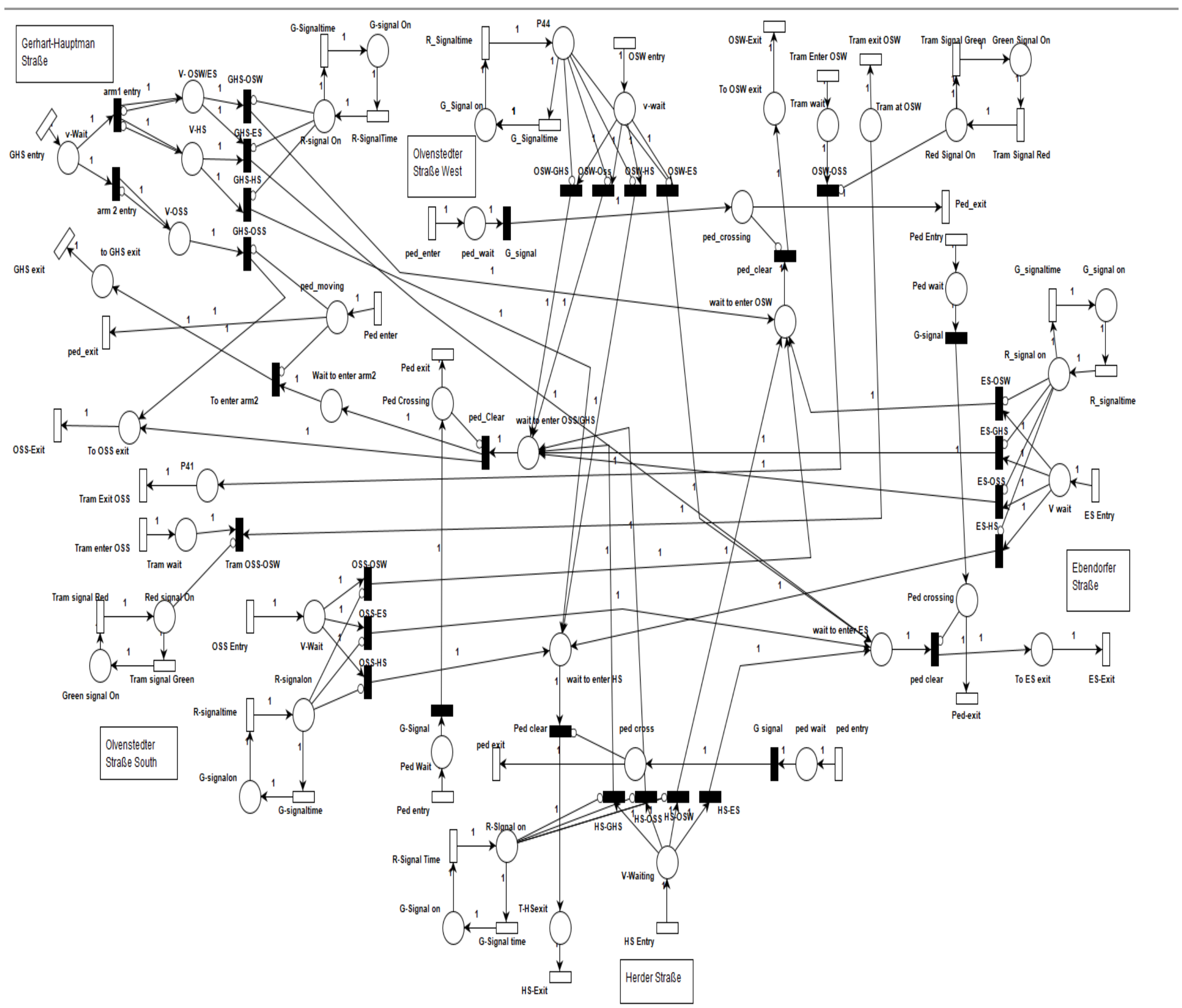

Figure 06: Petri Net of whole node

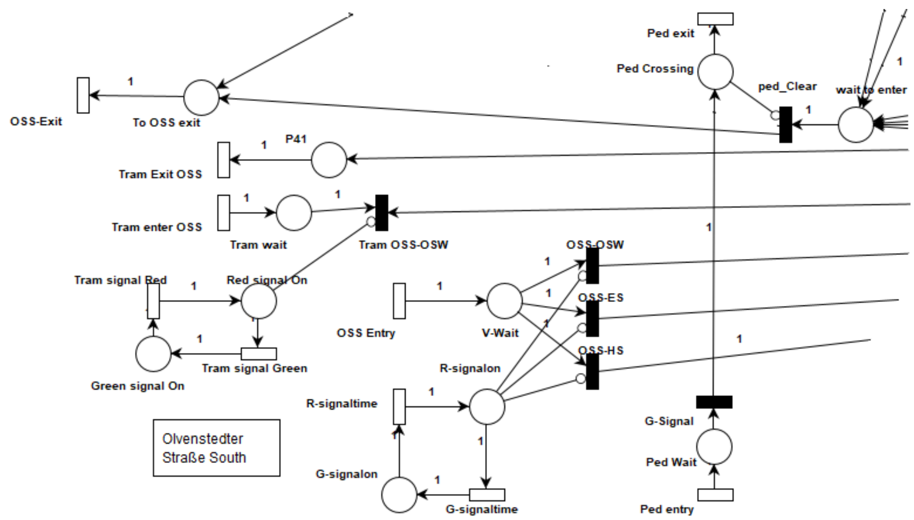

Figure 07: Petri Net for Olvenstedter straße South

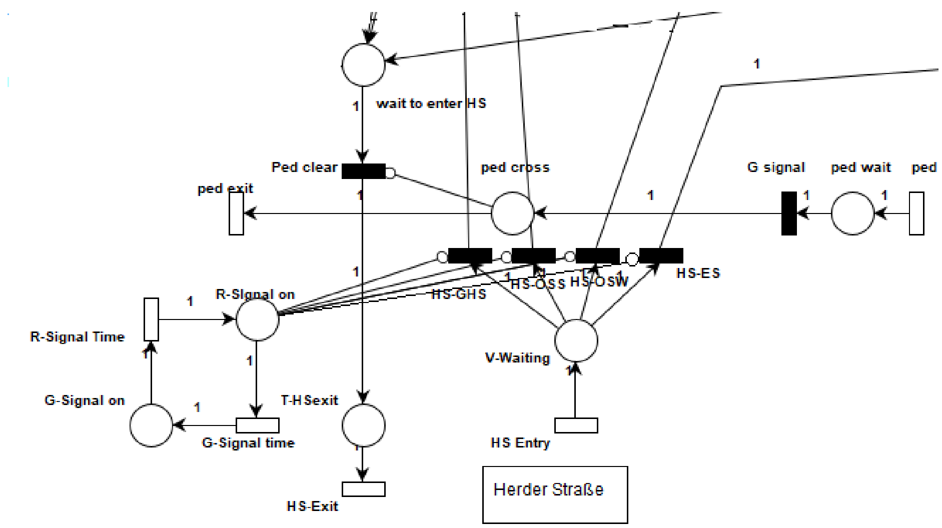

Figure 08: Petri Net for Herder straße

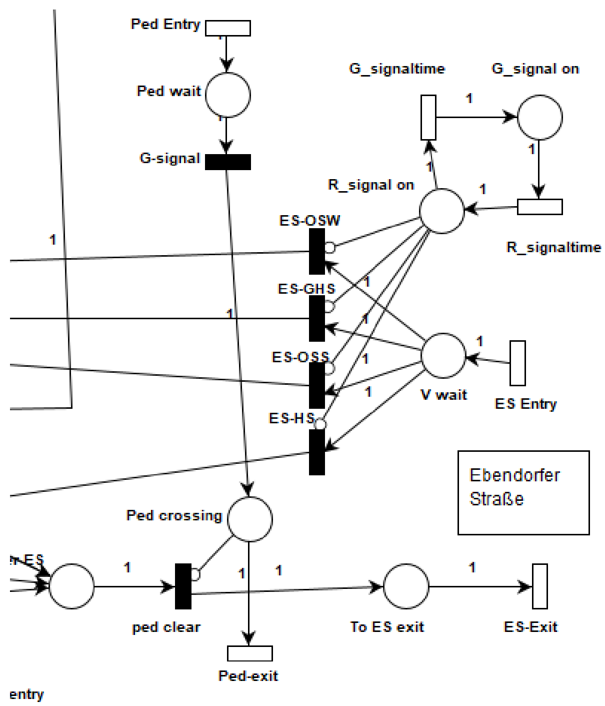

Figure 09: Petri Net for Ebendorfer Straße

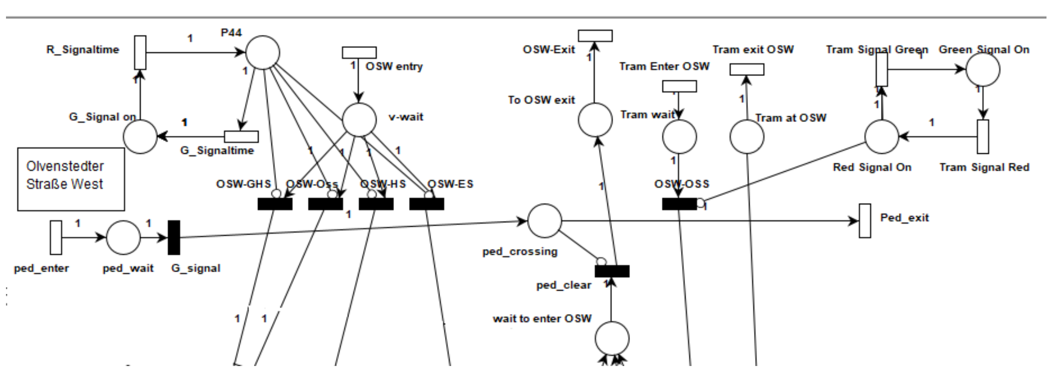

Figure 10: Petri Net for Olvenstedter Straße West

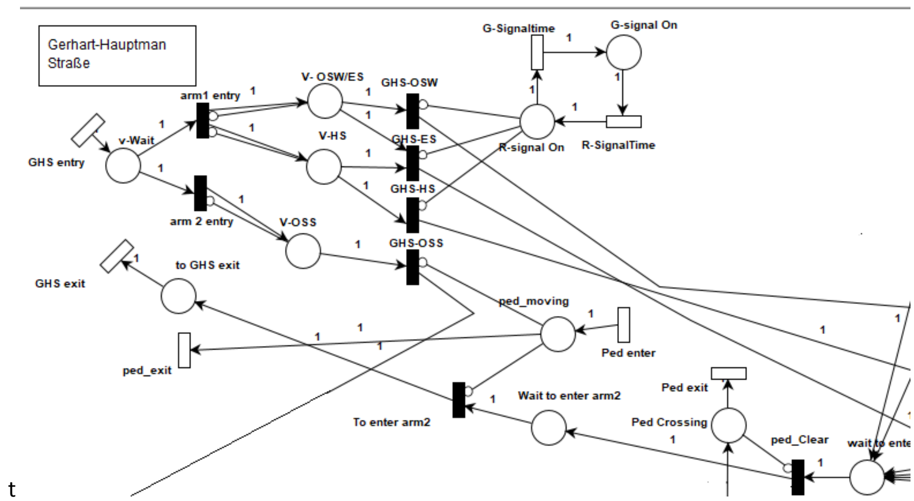

Figure 11: Petri Net for Gerhart-Hauptmann Straße

4. Data Analysis

The main motivation for data analysis is to provide input to the simulation model and check whether the output matches the real time output of the system. The inter arrival time was used as input, and queue length and the average time spent by the vehicle in the node was calculated to validate the output.

4.1 Data Received

The data provided to us by the traffic department of Magdeburg consists of inflow and outflow of vehicles in all of the 5 arms of the node. The data was recorded on a weekday (Tuesday), from 6am to 7pm in 2009. The data contains 52 samples, each sample size being 15 minutes. Sample includes individual vehicle counts, total vehicles, car units and vehicles per hour. Vehicle counts include Cars, Trucks, Buses and other motor vehicles, but does not include any information about Trams, pedestrians or cycles. The basic node and traffic flow representation drawn from the given data is as shown in the figure below.

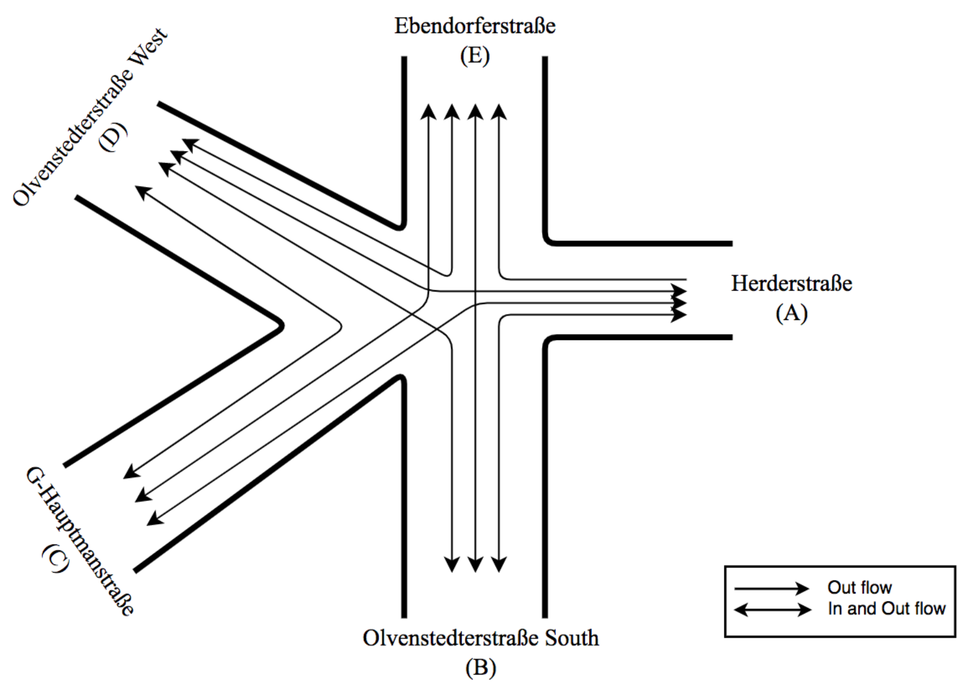

Figure 12: Basic node and Traffic flow representation

4.2 Data Quality

The Data quality will be measured using the below four metrics:

- **Completeness** - the data is complete with respect to vehicle flow in the node and accident statistics, but does not provide inter-arrival times, signal times, pedestrian data or tram frequency.
- **Uniqueness** - there is quite some amount of redundant data, such as motor vehicle count, total vehicle count, vehicle count per hour, total vehicle count per hour which are repetitions of the same data.
- **Validity** - the provided data is more than a decade old and might not be valid for the current condition of the node.
- **Consistency and Accuracy** - the provided data is assumed to be consistent and accurate when it was recorded as it is obtained from a single source.

4.3 Comparison between data collected in 2009 and 2021

There is a significant difference between the vehicle flow data given to us by the traffic department of Magdeburg, collected in the year 2009 and the current node situation. As of in 2021, two major factors affect the Wilhelmstedter platz traffic data, one of which is the ongoing pandemic condition that leads to reduction in the overall traffic density throughout the city and the second one is the Olvenstedter Straße road block due to construction, that restricts the vehicle movement in that direction. This comparison is drawn in the table below for our understanding of the scenario.

Street	Vehicle Outflow (2009)	Load Percentage (%)	Vehicle Outflow (2021)	Load Percentage (%)
Herder Str	92	8.52	67	16.54
Olvenstedter Str South	433	40.12	64	15.80
Gerhart-Hauptmann Str	131	12.14	123	30.37
Olvenstedter Str West	196	18.16	59	14.56
Ebendorfer Str	227	21.03	92	22.71
Total	1079		405	

Table 01: Comparison b/w 2009 and 2021 vehicle flow during peak hours

From the table we can see that there is a large amount of load shift among the roads and the old traffic data does not hold good for the present day scenario. Hence there is a necessity to collect new data from the node.

4.4 Data Collection

For the purpose of analysis, the data was required to be as updated and recent as possible, as significant variations were observed in the traffic behaviour due to factors like construction near the Haupt-bahnhof and the ongoing pandemic. Therefore essential data such as inter-arrival times of the vehicles and signal readings was collected by our team in real time with the help of Excel Macros feature, tram and bus readings were collected conveniently from the INSA app. To get maximum approximation, the data was collected in the morning and evening hours at the time where traffic was at its peak in the node. The signal data had no specific pattern that could be observed as they were affected by tram arrivals and pedestrian crossings at random.

4.4.1 Input Data

The data that was required as input to the simulation model are :

- Inter-arrival time
- Turn probabilities
- Signal phases

4.4.2 Output Data

The data that was output from the model and used for validating the model are :

- Queue length
- Average time spent by the vehicle in the node

The real-time values for the output variables can be found in the validation section.

4.5 Signal phases

In order to design the signals as similar to the real world as possible, we calculated the duration of the signals in each phase during data collection. The traffic phases control the respective stop lines in that particular phase.

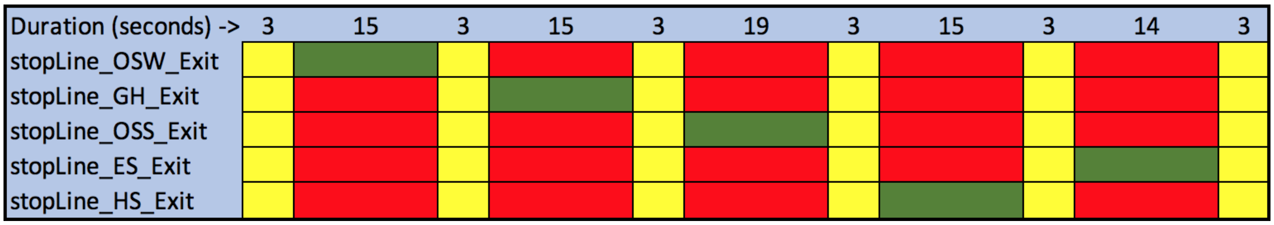

Figure 13: Signal phases

4.6 Probability Distribution Function Estimation

In order to make a right guess of the distribution of cars, we have drawn histograms of number of cars vs inter-arrival time for every cross road in the node. This can be observed in figures 3, 6, 9, 12 and 15. By comparing the histograms obtained, with various probability distribution functions, we guessed that the distribution is exponential. This was done for all the 5 streets and we had all the distributions guessed as exponential. In order to check the correctness of our assumption quantile-quantile plots were drawn, which can be seen in figures 4, 7, 10, 13 and 16. Since the q-q plots obtained approximate to a straight line and the plots pass through the origin, the probability distribution function estimation was found to be correct. We tested our guessed distribution with a chi-square test, that of which can be seen in figures 5, 8, 11, 14 and 17 and its corresponding values in the tables 2, 4, 6, 8 and 10.

Apart from the distribution data, turn probabilities of vehicles in each street were calculated in order to design a system with traffic flow as close to the real world node as possible. These probabilities can be observed in the tables 3, 6, 9, 12 and 15.

Herderstraße (A)

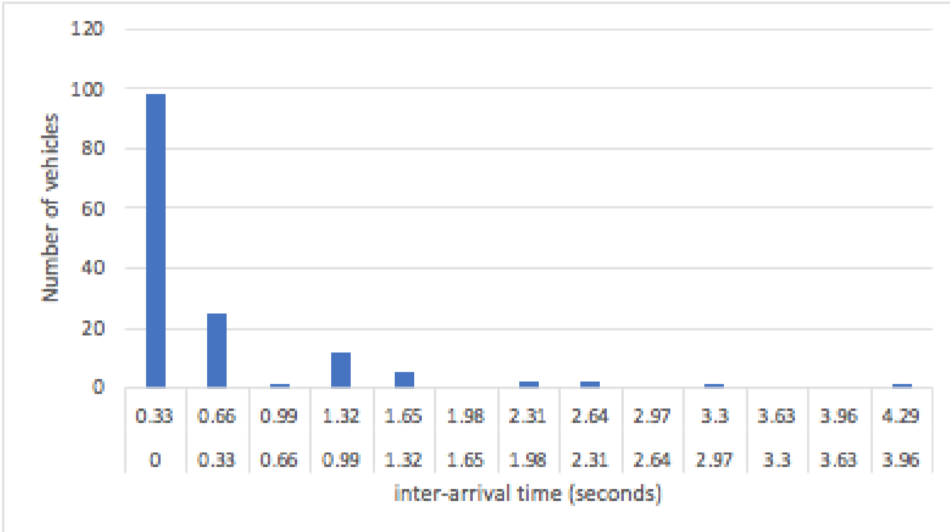

Figure 14: Histogram for vehicle inter-arrival times in Herderstraße

Distribution	Exponential distribution
Mean	Lambda
0.390	2.5644

Table 02: Distribution and parameters of Herderstraße

Olvenstedter Straße (west)	Ebendorfer Straße	Olvenstedter Straße (south)	Gerhart Hauptmann Straße
0.3214	0.25	0.0178	0.4107

Table 03: Turn probabilities of vehicles flowing from Herderstraße

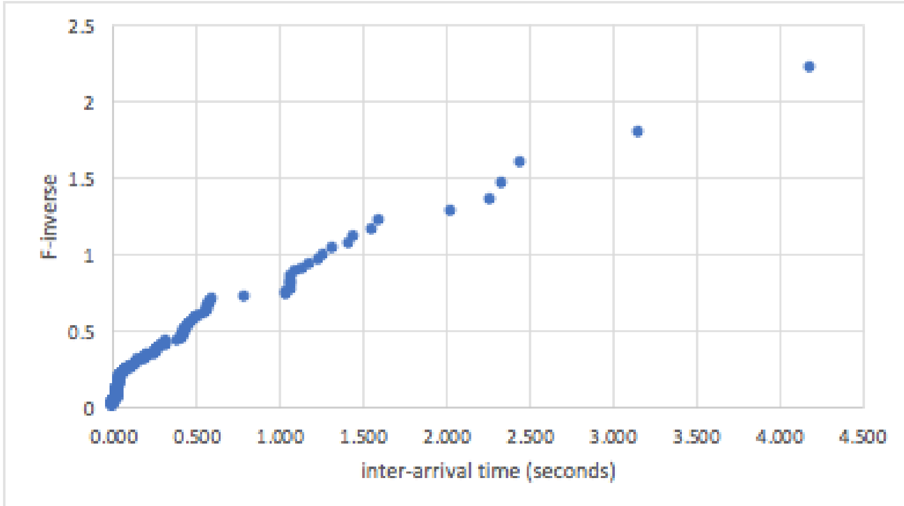

Figure 15: Q-Q plot for Herderstraße

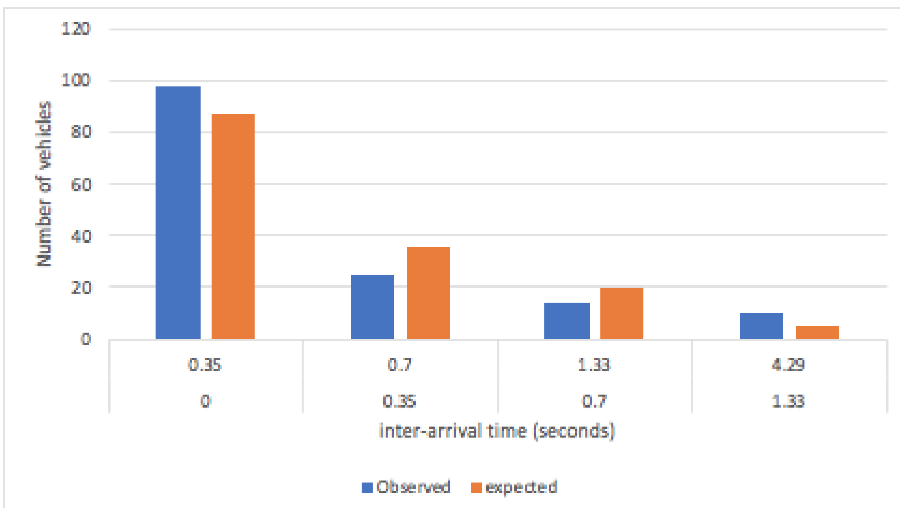

Figure 16: Chi square test for Herderstraße

Number of data points, N	147
Degrees of freedom, f	2
Alpha, a	0.99
χ^2_0	11.5169
$\chi^2_{f,a}$	9.2103

Table 04: Chi square test values for Herderstraße

Olvenstedter Straße South (B)

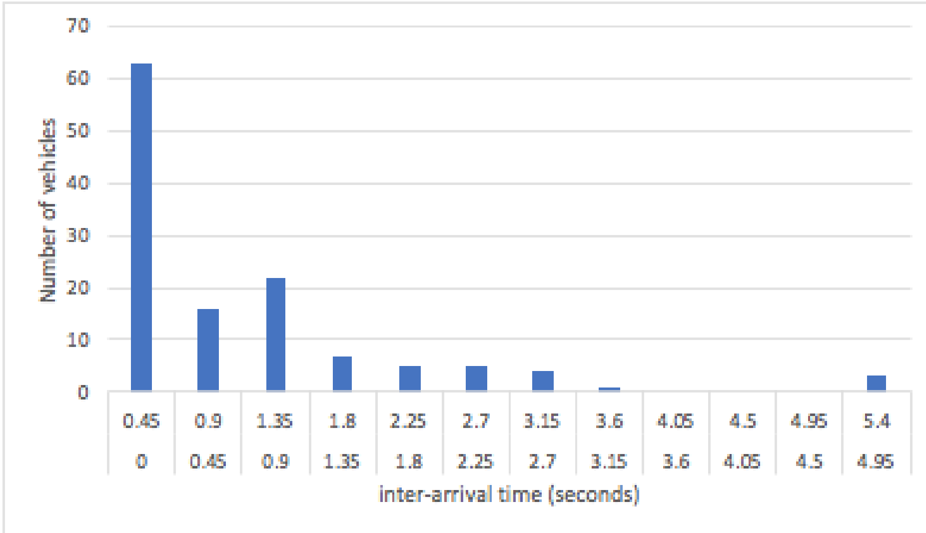

Figure 17: Histogram of vehicle inter-arrival times in Olvenstedter Straße (south)

Distribution	Exponential distribution
Mean	Lambda
0.86	1.1639

Table 05: Distribution and parameters of Olvenstedter Straße (south)

Olvenstedter Straße (west)	Ebendorfer Straße	Herderstraße	Gerhart Hauptmann Straße
0.2619	0.6031	0.1269	0.0079

Table 06: Turn probabilities of vehicles flowing from Olvenstedter Straße (south)

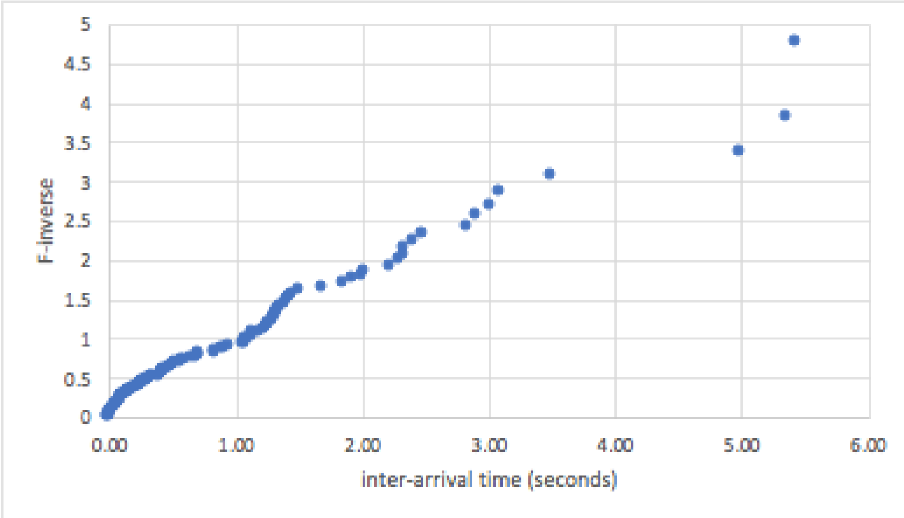

Figure 18: Q-Q plots for Olvenstedter Straße (south)

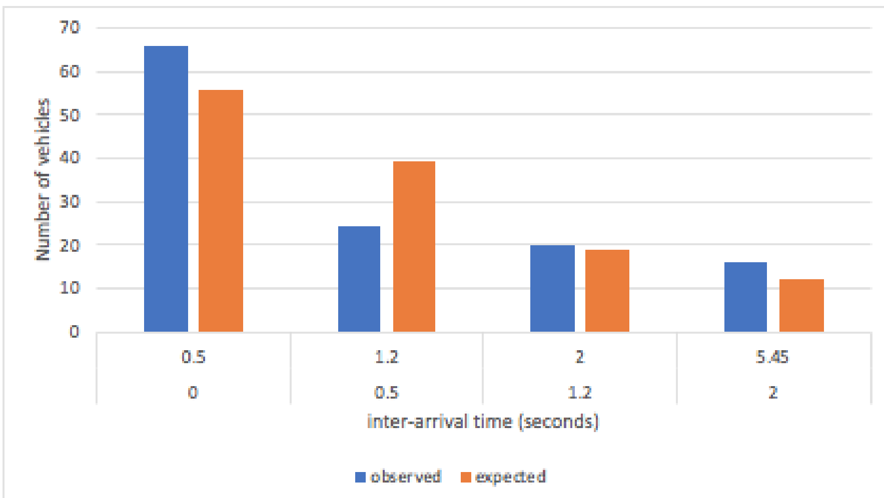

Figure 19: Chi square test for Olvenstedter Straße (south)

Number of data points, N	126
Degrees of freedom, f	2
Alpha, a	0.99
χ^2_0	9.2145
$\chi^2_{f,a}$	9.2103

Table 07: Chi square test values for Olvenstedter Straße (south)

Gerhart-Hauptmann Straße (C)

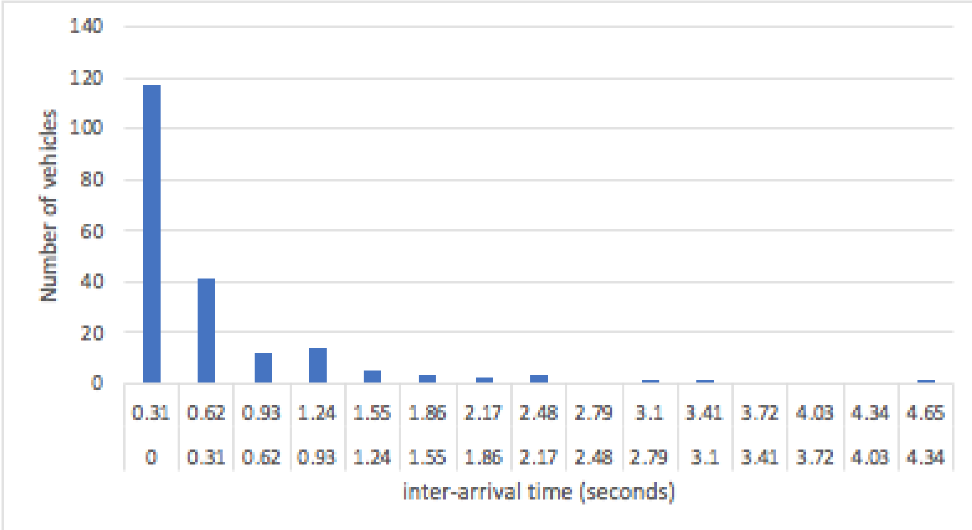

Figure 20: Histogram of vehicle inter-arrival times in Gerhart-Hauptmann Straße

Distribution	Exponential distribution
Mean	Lambda
0.4615	2.1669

Table 08: Distribution and parameters of Gerhart-Hauptmann Straße

Olvenstedter Straße (west)	Ebendorfer Straße	Herderstraße	Olvenstedter Straße (south)
0.0366	0.6788	0.2293	0.0550

Table 09: Turn probabilities of vehicles flowing from Gerhart-Hauptmann Straße

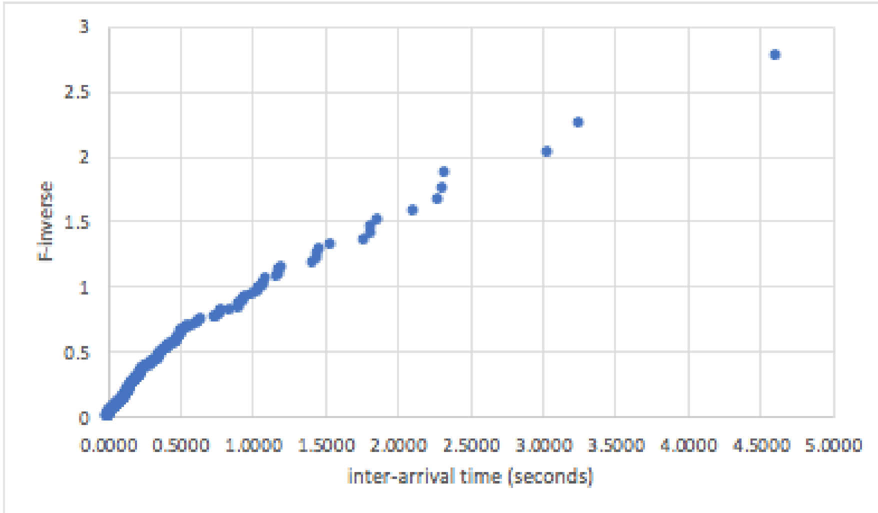

Figure 21: Q-Q plots for Gerhart-Hauptmann Straße

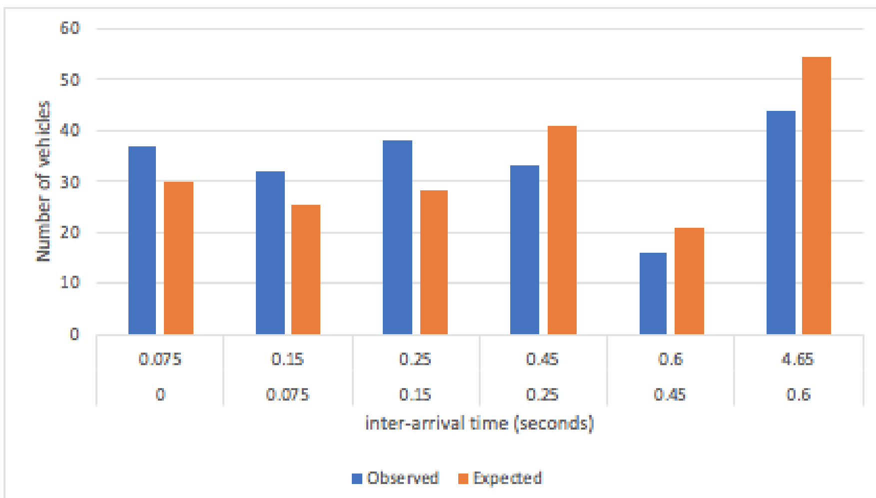

Figure 22: Chi square test for Gerhart-Hauptmann Straße

Number of data points, N	200
Degrees of freedom, f	4
Alpha, a	0.98
χ^2_0	11.4488
$\chi^2_{f,a}$	11.6678

Table 10: Chi square test values for Gerhart-Hauptmann Straße

Olvenstedter Straße West (D)

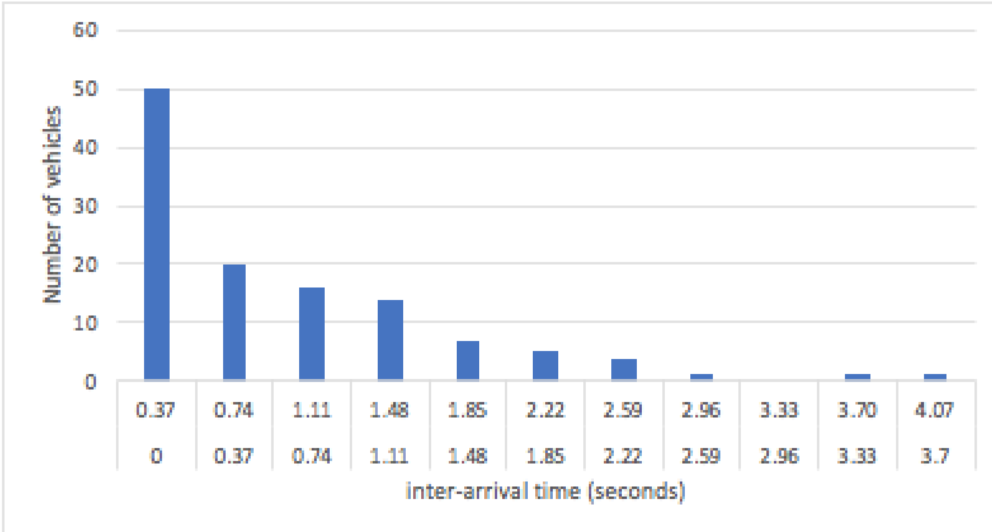

Figure 23: Histogram of vehicle inter-arrival times in Olvenstedter Straße (west)

Distribution	Exponential distribution
Mean	Lambda
0.77	1.3045

Table 11: Distribution and parameters of Olvenstedter Straße (west)

Ebendorfer Straße	Herderstraße	Olvenstedter Straße (south)	Gerhart Hauptmann Straße
0.4227	0.3658	0.1544	0.0569

Table 12: Turn probabilities of vehicles flowing from Olvenstedterstraße (west)

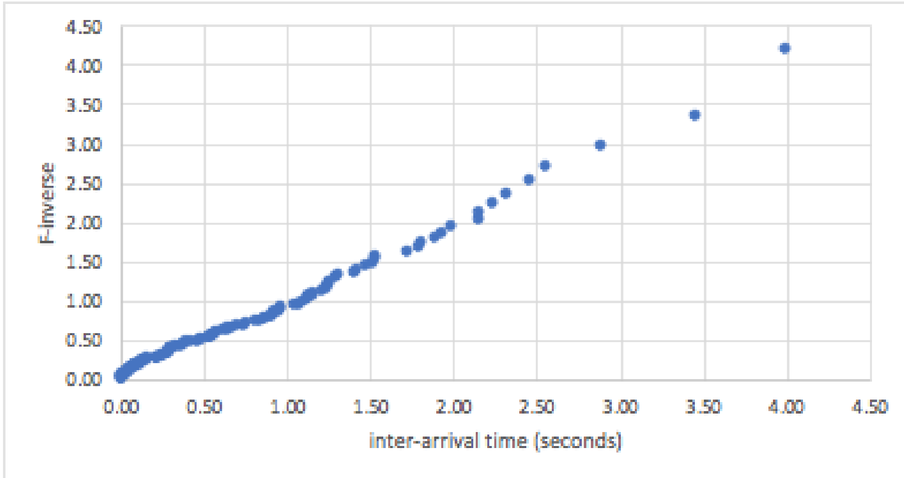

Figure 24: Q-Q plot for Olvenstedter Straße (west)

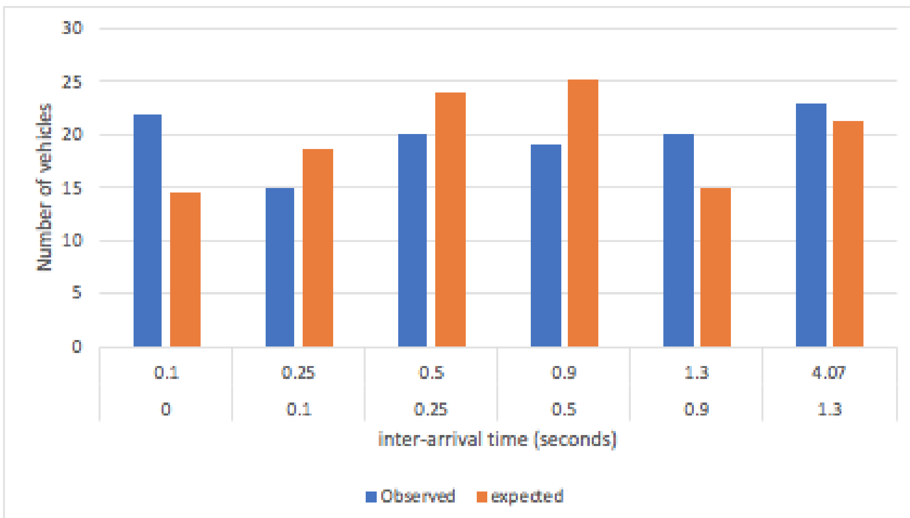

Figure 25: Chi square test for Olvenstedter Straße (west)

Number of data points, N	119
Degrees of freedom, f	4
Alpha, a	0.93
χ^2_0	8.5031
$\chi^2_{f,a}$	8.6664

Table 13: Chi square test values for Olvenstedter Straße (west)

Ebendorfer Straße (E)

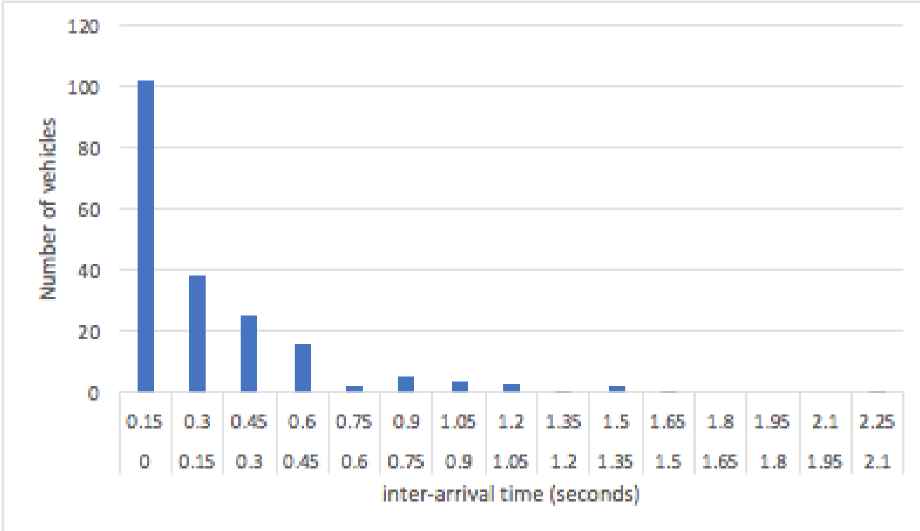

Figure 26: Histogram of vehicle inter-arrival times in Ebendorfer Straße

Distribution	Exponential distribution
Mean	Lambda
0.2562	3.9025

Table 14: Distribution and parameters of Ebendorfer Straße

Olvenstedter Straße (west)	Herderstraße	Olvenstedter Straße (south)	Gerhart Hauptmann Straße
0.2405	0.0168	0.3037	0.4388

Table 15: Turn probabilities of vehicles flowing from Ebendorfer Straße

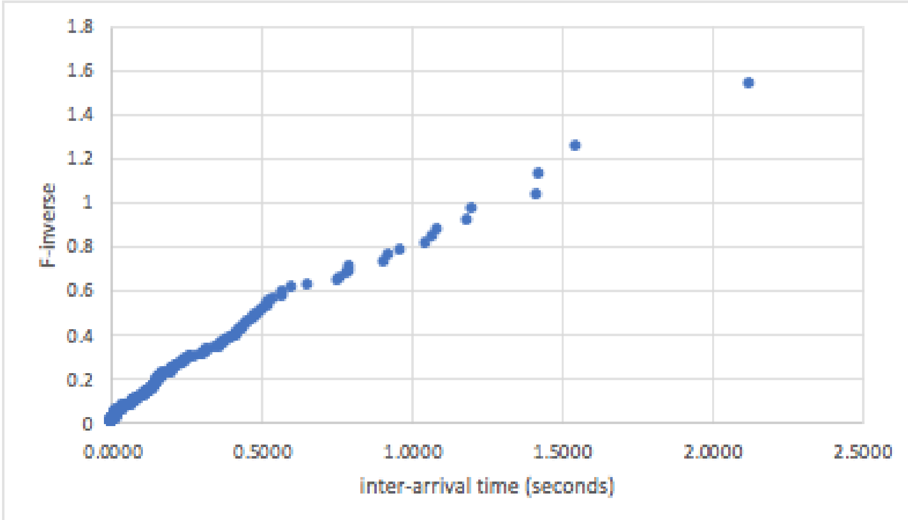

Figure 27: Q-Q plot for Ebendorfer Straße

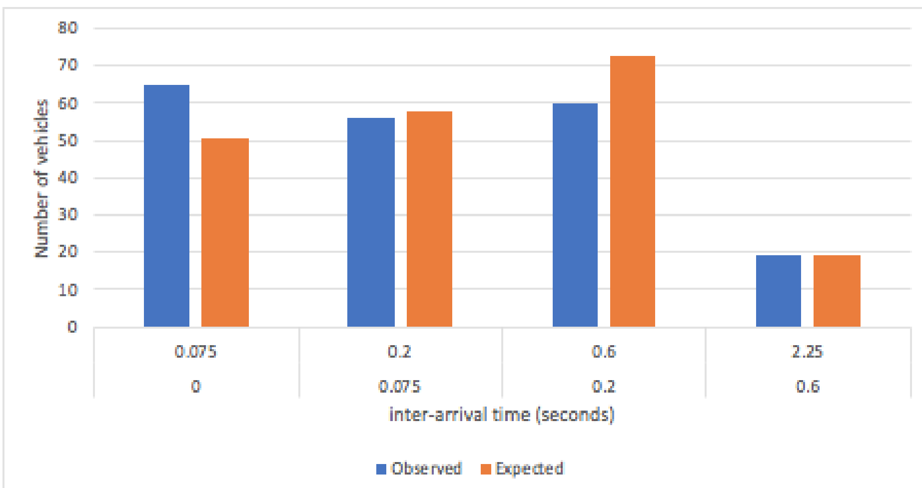

Figure 28: Chi square test for Ebendorfer Straße

Number of data points, N	200
Degrees of freedom, f	2
Alpha, a	0.96
χ^2_0	6.1721
$\chi^2_{f,a}$	6.4377

Table 16: Chi square test values for Ebendorfer Straße

4.7 Difficulties encountered while obtaining the data

- Bringing the team together to agree upon a common time for data collection.
- The team did not anticipate the frequent weather changes that led to delay in the data collection and the members had to spend additional hours into it.
- Recollecting of the data due to inconsistencies in the time of the day.
- Change of recording methods from stopwatch to Excel Macros for more accuracy and precision led to repeated data collection.
- Due to unavailability of all the members and five different cross arms, there was an increase of load on the members that led to small inaccuracies while recording.
- Deciding exactly what type of data was necessary to build the model and how to record the same.

5. Simulation

For simulation, Anylogic Personal Learning Edition (v8.7.2) was used. The libraries used throughout the modelling include:

- Road Traffic Library: For road traffic components such as roads, vehicles. The core library for this project.
- Process Modelling Library: For logic and entities such as agents.
- Pedestrian Library: For simulating pedestrian crossing.
- Presentation Library: For 3D simulation and other presentation entities.
- Space Markup Library: For marking zones for pedestrians to cross inside pedestrian crossings.
- Analysis Library: For analysis and charts to measure data during the simulation.

5.1 Design Approach

The layout of the model was created based on Google maps of the node in the same level of scaling. Extra lanes were added to act as Tram lines since there is no explicit Tram/street car library in Anylogic.

Key Components:

The key components in the simulation include the agents and entities that control the core flow of the traffic.

- Vehicles
- Pedestrians
- Tram
- Bus
- Traffic Signal
- Intersection (Including allowed turns to different roads)

5.2 Program Structure

Two main segments of the Anylogic simulation models were extensively used in this project.

- Agent: These are the core components that make the model run
    - Main: This is the main agent where the design of the node takes place.
    - Cars/Busses/Trams: These are sub agents which act their part inside the main agent.

- Experiment: This segment is to create experiments and test different scenarios.
    - Design experiment: These were the actual experiments performed. Discussed further in the Experiments section.
    - Traffic Variance: These are experiments where we increased the traffic load ranging from 1(current load) to 5(500% of the current load) and analysed the outcomes.

5.3 Program Concept & Model

The simulation program was designed by modelling the roads and the intersections of the node along with implementing the expected behavior of the agents and other elements.

Roads and Intersection: The roads are created using the Road markup element from the Road Traffic Library. Intersections were automatically formed when two or more roads were connected. They could also be manually inserted from the same library.

Tram Lines: Since Anylogic does not have tram lines, extra lanes in the roads were created to act as Tram lines and custom agents of length 20 (for comparison, car's length is 5) were created and instructed to travel only on those specified lanes.

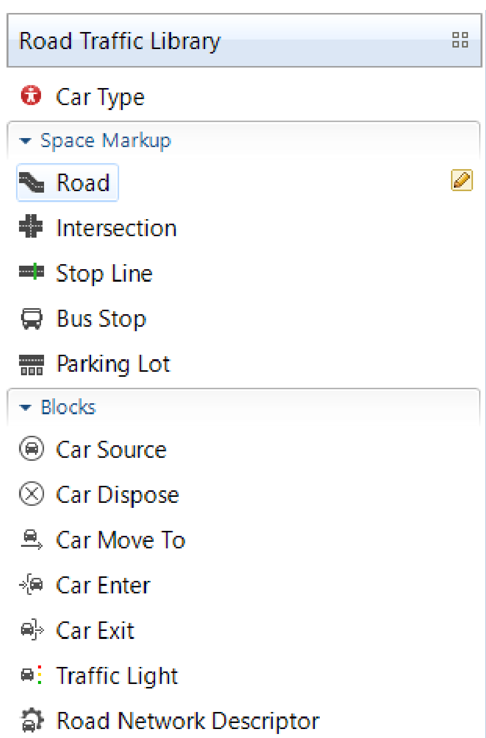

Figure 29: Road Traffic Library of Anylogic.

Traffic Light: Taken from the same Road Traffic Library, the signal was instructed to manage traffic flow of all the roads coming into the intersection (except the half arm of Gerhart-Hauptmann Straße joining into Olvenstedter Straße south side).

Pedestrians: These agents were simulated by using the Pedestrian Library for creation of pedestrians and Space Markup library for marking the area for those pedestrians to travel.

The model was designed to run both on 2D as well as 3D view.

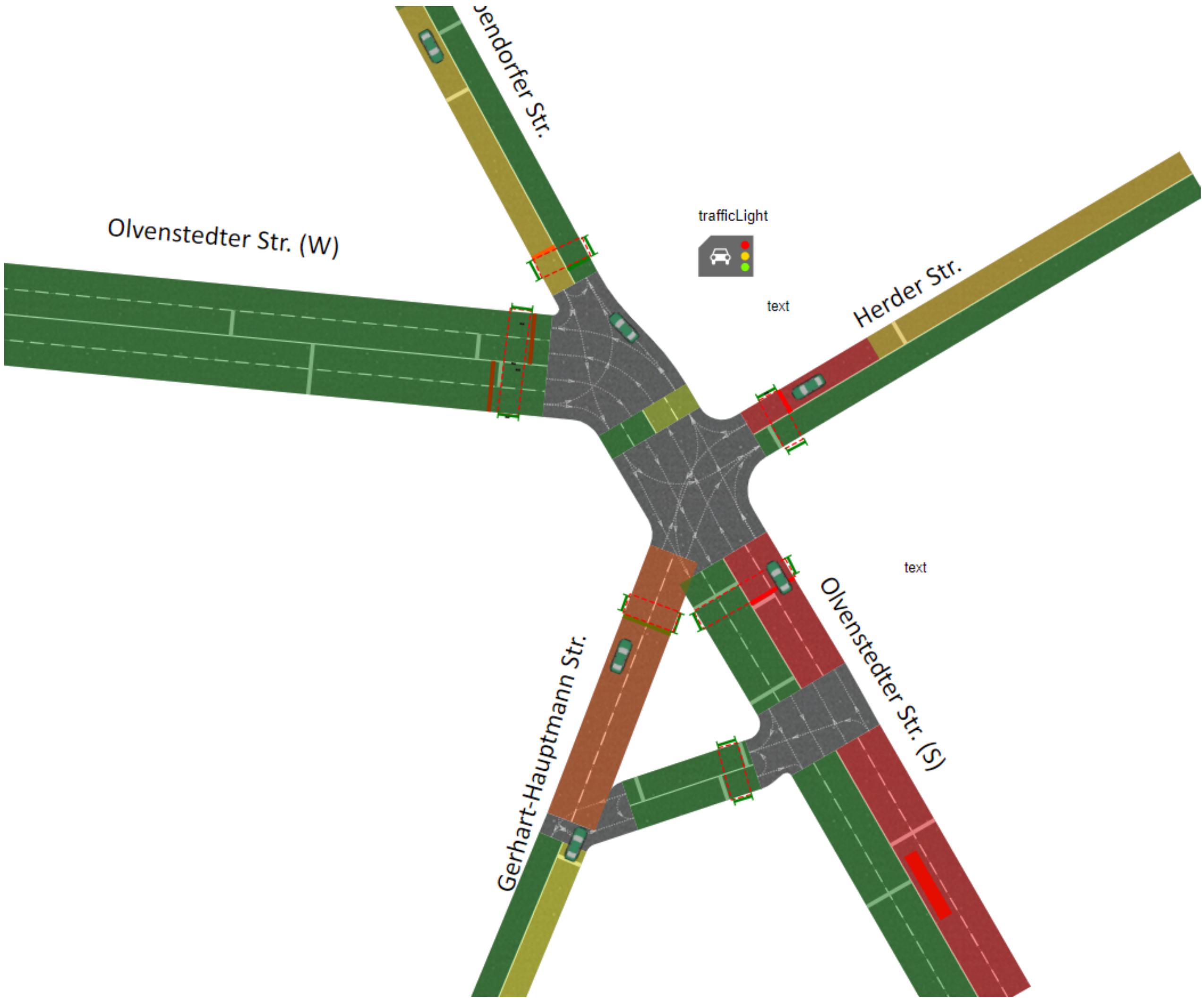

Figure 30: Simulation model 2D version

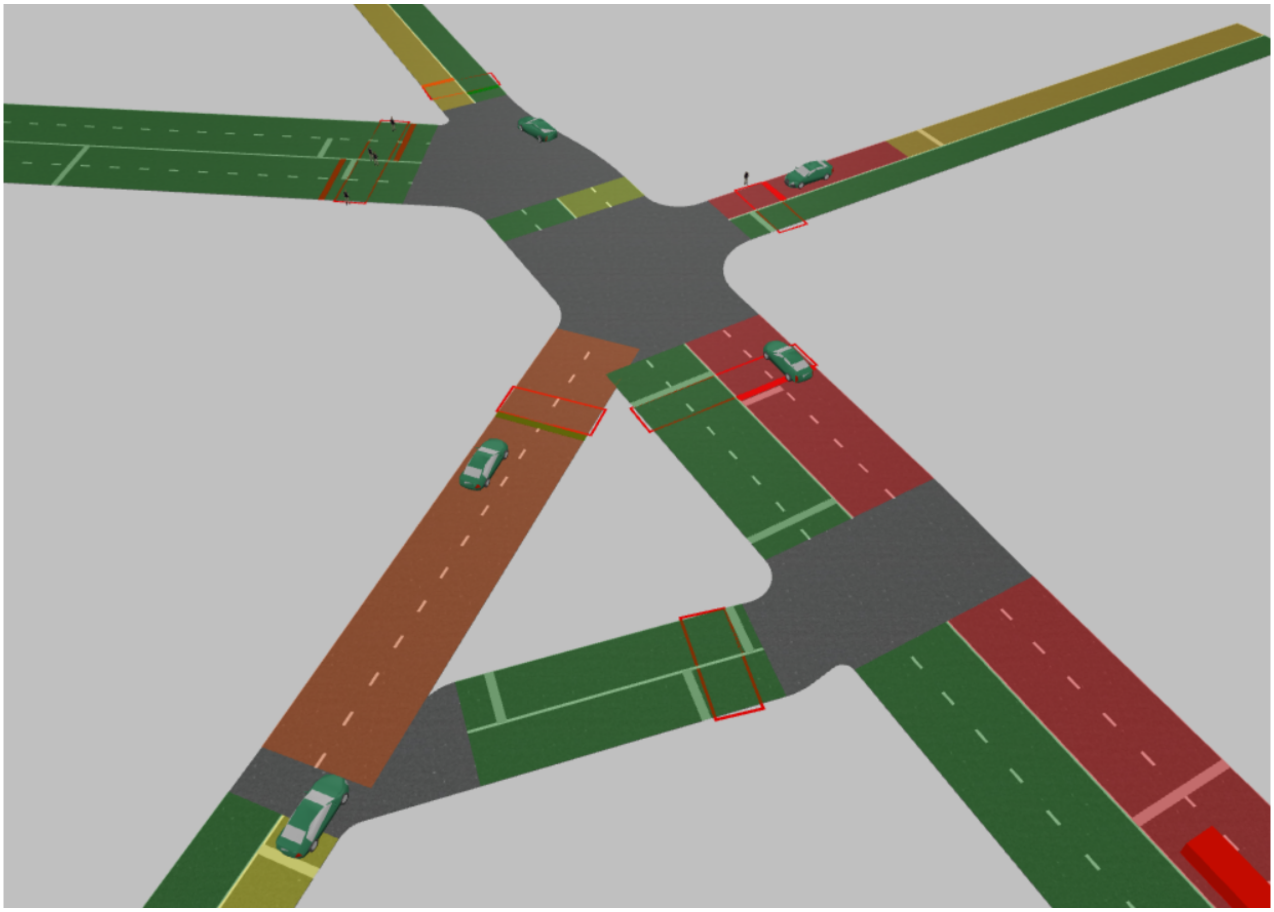

Figure 31: Simulation model 3D version

5.4 Simulation Logic:

The simulation ran on a few predefined logics and rules that the model and the agents followed in order to imitate real world situations.

Stop Line markup:

This is a line markup that is placed on the road in order to control the flow of vehicles. We have used the stop lines to:

- Control traffic when linked with the signal, acting as the boundary of the roads.
- Control incoming cars whenever a pedestrian is still crossing while the signal changes.
- Direct cars and trams in Olvenstedter Straße to stay in their lane.
- Create virtual Tram/Bus stops when combined with a delay block.

SelectOutput5 blocks:

This block takes upto 5 possible probabilities and distributes the output based on them. The probabilities of vehicles going into different destination roads from any source road are given as input. The inbuilt functionality instructs the vehicles to move to those roads based on the given probabilities.

Rectangular node:

This is a space markup entity which can be used to contain agents. In this case, these are used as pedestrian crossing zones and the pedestrians are instructed to stay inside them. The access to these zones are blocked if the pedestrian signal is Red.

5.5 Agent Behavior:

Based on what was expected of each agent, the applied behavior differs.

Cars: Once cars are created, they are forwarded to their destination roads by using the carMoveTo block. Each destination road has a carMoveTo block that will be selected through the SelectOutput5 element based on turn probabilities that have been entered.

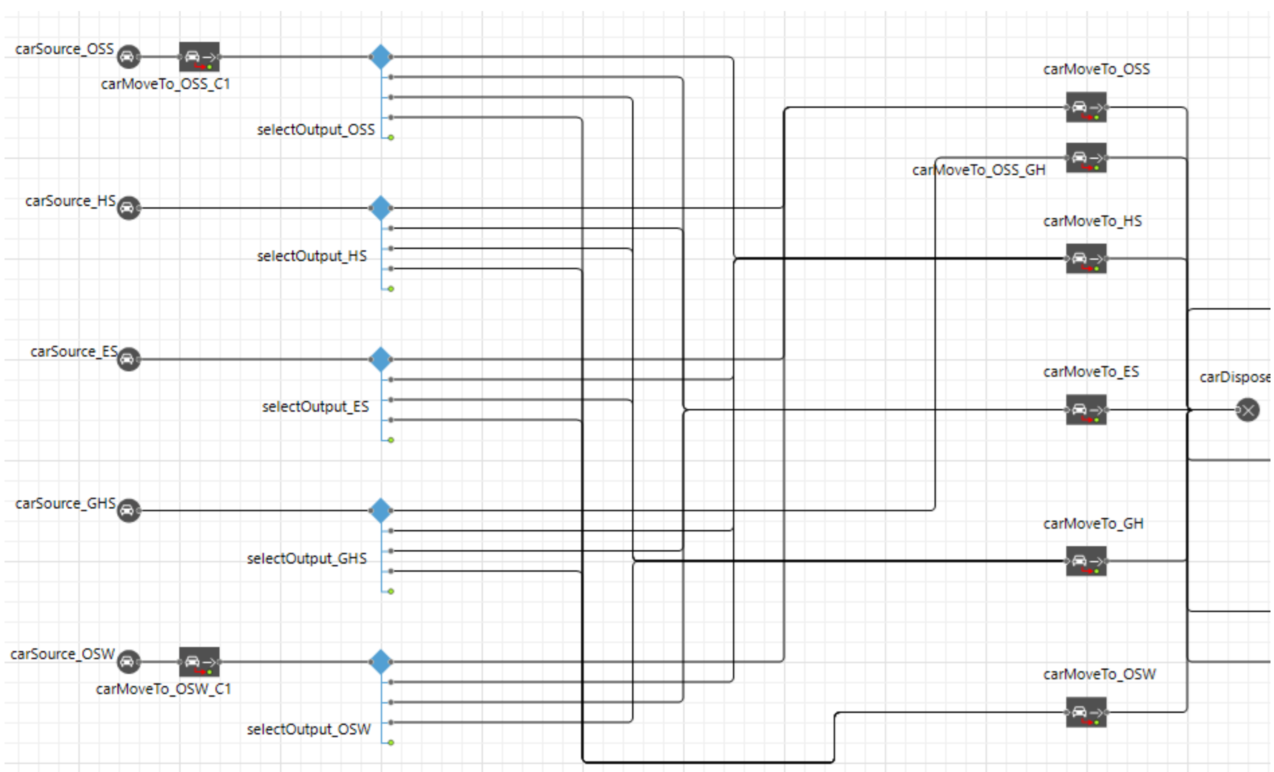

Figure 32: Car agent life cycle and behavior

Bus/Trams: These agents behave similar to Cars but they have one extra step in their life cycle. To imitate stops made by the real world public transports, an instruction was added to stop near their destination stopLine (acting stations), wait for a set amount of time (delay blocks) and then move towards dispose.

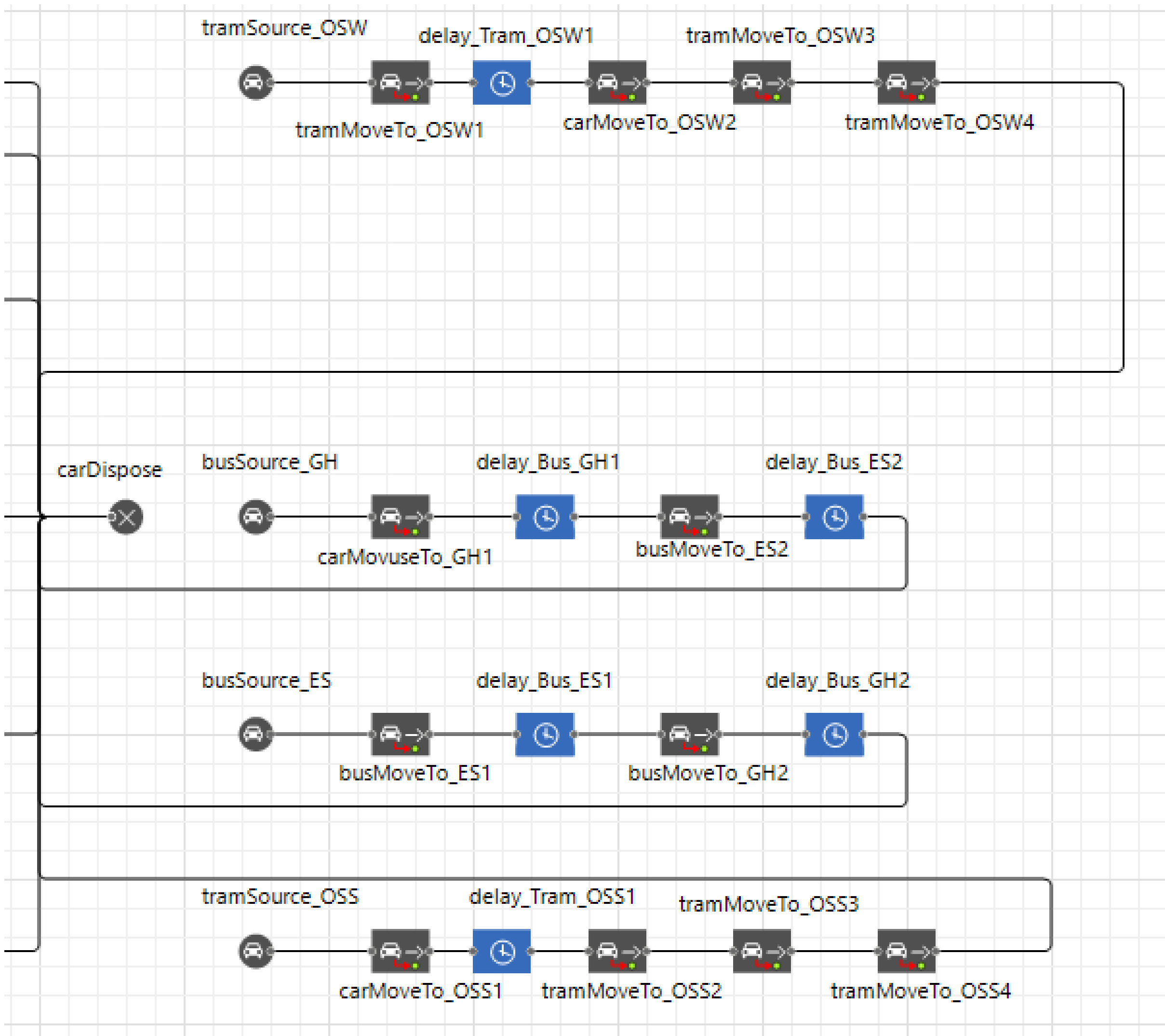

Figure 33: Public Transport - Bus/Tram agent life cycle and behavior

Pedestrians: These agents were modelled to get created at one end of a Pedestrian crossing, wait for the signal to allow the cross and then 'sink' (or get destroyed) when they reach the other side of the road/crossing.

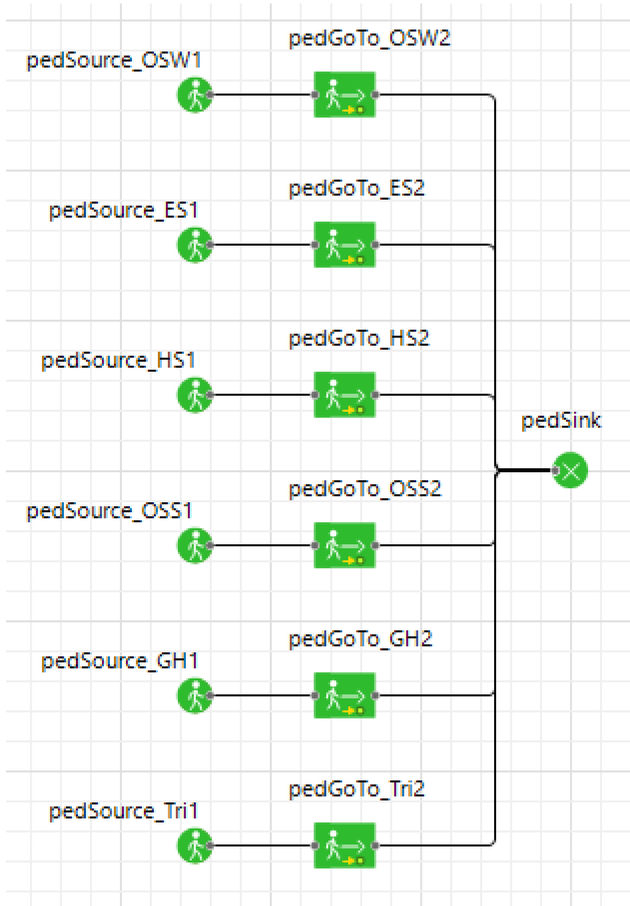

Figure 34: Pedestrian agent life cycle and behavior

Calculation of variables:

There are two main variables being calculated: Average queue length and average time in node.

Average Queue Length is calculated after every signal phase change. Whenever the signal of a particular road turns Green, all the vehicles standing in that road (previously waiting in Red signal) would be recorded. This would then be converted into an average after all the signal phase changes during the complete simulation.

Average time in node is calculated for each car. A custom parameter startTime of type time() is attached to this agent. Whenever a car gets created, the parameter records the startTime. While the car goes through its journey and moves into 'dispose',i.e., its destination finish line, the current time is recorded and startTime is subtracted from it. This gives the time the car spent inside the node or our model. Then the mean is calculated towards the end by reading the time spent by each car.

5.6 Testing:

The testing of the program was done in two different aspects: To check whether the system ran without errors and to check if the system behaved like the real world when data recorded from the real world were given as input.

Simulation Test:

This part consisted testing of the system against errors such as:

- Individual blocks such as Vehicles, Pedestrians, Buses, Trams and their life cycles.
- Regression test with varying parameters
- Collision between vehicles and pedestrians

Comparison with real world:

This part consisted of confirming if the system acted as expected when fed with real world data.

- Vehicle counts in each of the roads
- Vehicle routes based on probabilities
- Signal phases (Approximation)

6. Validation

6.1 Approach

To validate our model and simulation program we have followed the two-step approach

Face Validity – Results appeared to be reasonable for our team members. The real-world data we have collected manually from the node.

Quality of the simulation output - Compared the results of real and simulated system data using input-output transformations

6.2 Variables of interest

We have considered two variables to validate the model and the simulation program. They are

Time in the node – Time between arrival and departure of vehicles. This is the duration of time when a vehicle enters any intersection of the node and enters the destination road.

Queue length – Number of vehicles waiting in each signal when the signal just turns green from red.

6.3 Data

6.3.1 Data from the real-world system

Average time spent in the node by vehicles: 58 seconds

Here, the Mean queue length is the mean number of vehicles waiting in each signal when the signal just turns green from red.

Street	Mean Queue Length
Herder Straße	1.57
Ebendorfer Straße	3.55
Olvenstedter Straße (West)	2.0
Gerhart-Hauptmann Straße	3.13
Olvenstedter Straße (South)	1.59

Table 17: Real World data

6.3.2 Data from the simulation model

Confidence intervals for all the streets using student t-distribution is mentioned in the below table. The first table contains the intervals for the queue length of each street while the second one contains the average time spent by vehicles inside the node - from reaching the intersection to entering their destination street after crossing through the intersection. Confidence level is 99%:

Street	**Lower Bound**	**Upper Bound**
Herder Straße	1.556	1593
Ebendorfer Straße	3.509	3.589
Olvenstedter Straße (West)	2.01	2.152
Gerhart-Hauptmann Straße	2.974	3.156
Olvenstedter Straße (South)	1.468	1.632

Table 18: Confidence interval for average queue lengths for each street.

Upper Bound	Lower Bound
53.23	58.651

Table 19: Confidence interval for average time spent by vehicles in the node

6.3.3 Comparison of the real and simulated data

The below depicted graphs show the comparison between the real world system and the validated system. The compared variables are average queue length for each road and average time spent by vehicles in the node

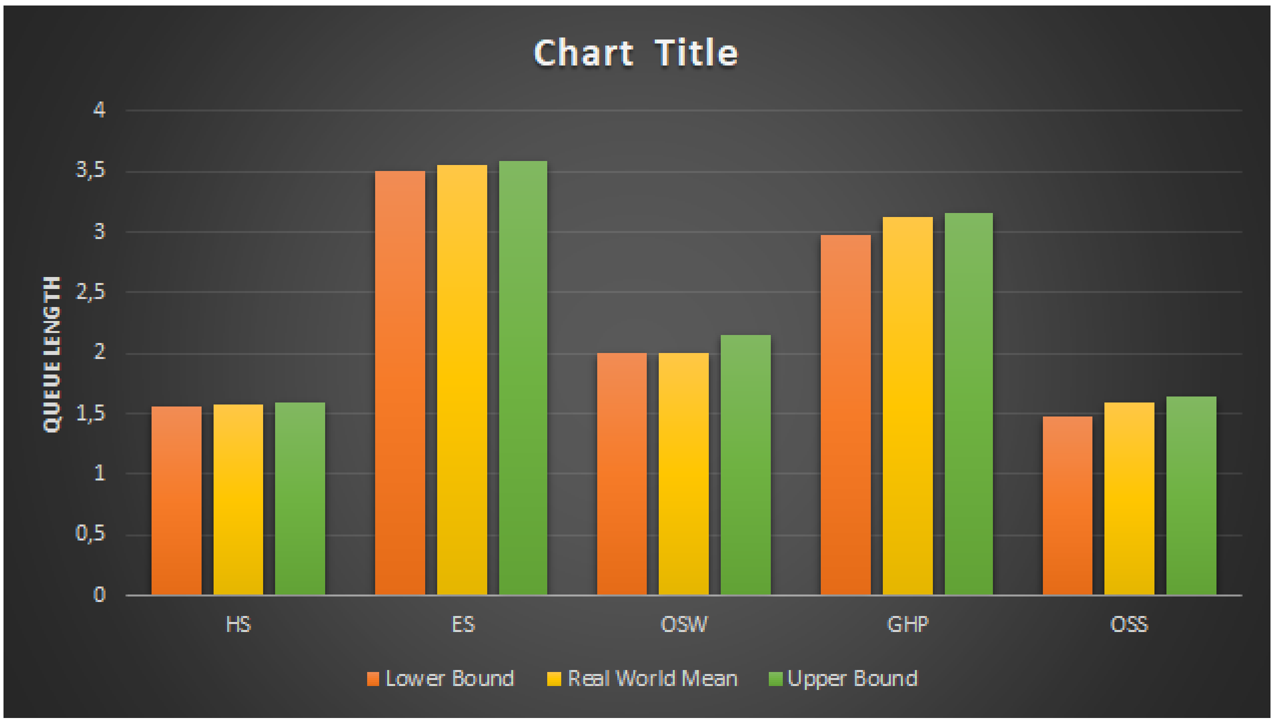

Figure 35: Average queue length for each of the roads. The upper bound, lower bound and mean value.

In comparison of queue length between Real world data and simulated data, it can be seen that the real-world data is well in the limit of upper bound and lower bound of confidence intervals.

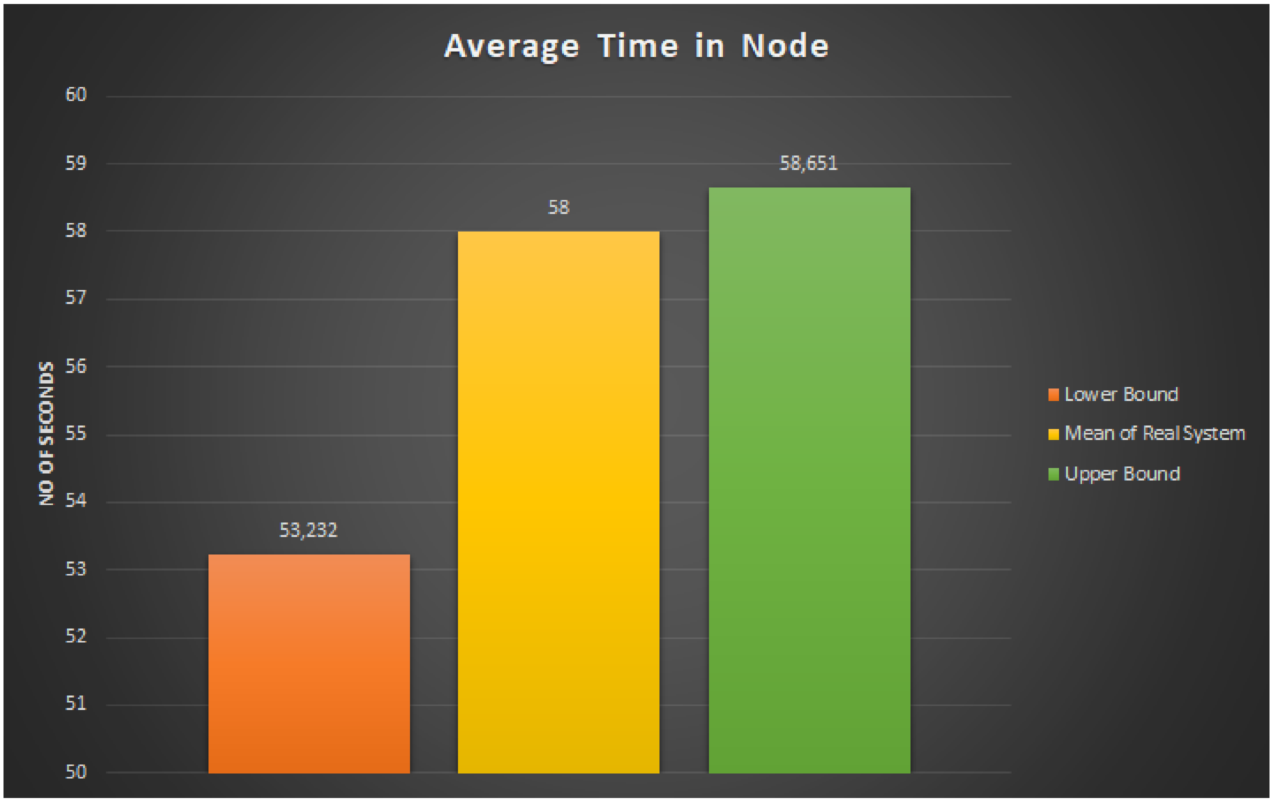

Figure 36: Average time spent by vehicles inside the node. The upper bound, lower bound and mean value.

The real-world average is 58 which is well inside the limit of lower bound and upper bound of 53.232 and 58.651 respectively.

6.4 Statement of Confidence

The statement of confidence was obtained after running the simulation for a number of replications for a predefined amount of time for each replication.

Total number of replications: 100

Total time per simulation run: 3599 (maximum allowed in Learning version of Anylogic)

Confidence level: 99%

Model validation status: OK

7. Experiment

7.1 Aim of the Experiments

The aim of the experiments is to improve the performance of the node. The experiments are conducted to see if the Average waiting time in the node and the average number of vehicles waiting in each signal can be reduced.

The whole Experiments Milestone task is divided into the following sub-tasks

- Analysis of initial simulation
- Performing Experiments
- Results summary
- Recommendations

7.2 Analysis of initial Simulation

After observing the initial simulation Program, we have discovered some important factors to initiate the experiment. These factors can play a major role in improving the performance of the entire node. The observed factors are:

Traffic loads in each of the roads

In Ebendorferstraße & Gerhart-Hauptmann straße, the traffic loads are much higher compared to other remaining roads. Some methods are required to balance the load of traffic on these roads.

Signal Patterns

At occasions, signals turned back to red from green even before all the waiting cars exited the road. That causes an additional delay for vehicles waiting at the signal.

Pedestrians crossing the streets

Multiple times, cars had to wait for some crossing pedestrian before entering the destination road because the signal turned green for vehicles before the pedestrians completely crossed over the road.

Vehicle Routes

Vehicles moving to Gerhart-Hauptmann straße had to go into Olvenstedter Straße and enter from the half arm and that led to an additional delay.

7.3 Performing Experiments

For the Experiments, we have considered two quality measures,

- Average queue length
- Average time in Node

The experiments were done in two sections to check for results:

- Existing traffic metrics with 10 repetitions
- Increased traffic flow upto 5 times the current recorded traffic load

The traffic variance graphs show the parameter in focus (queue length or average time in node) in the y axis and the traffic load in the x axis. Traffic load starts with 1 which denotes the existing traffic scenario. The experiment will increase the load upto 5 times the current flow and test the system against it.

We ran the traffic variance for the existing setup to analyse how it would react and found the below points:

- Ebendorfer Str. and Gerhart-Hauptmann Str. see steep increase in queue length with increased traffic flow. But gradually slow down as the load increases.
- Olvenstedter Str. West and Herder Str. see a gradual increase in the queue lengths.
- Olvenstedter Str. South does not get impacted until the traffic load is 3 times the current value but after that shows a sharp incline in its queue length.

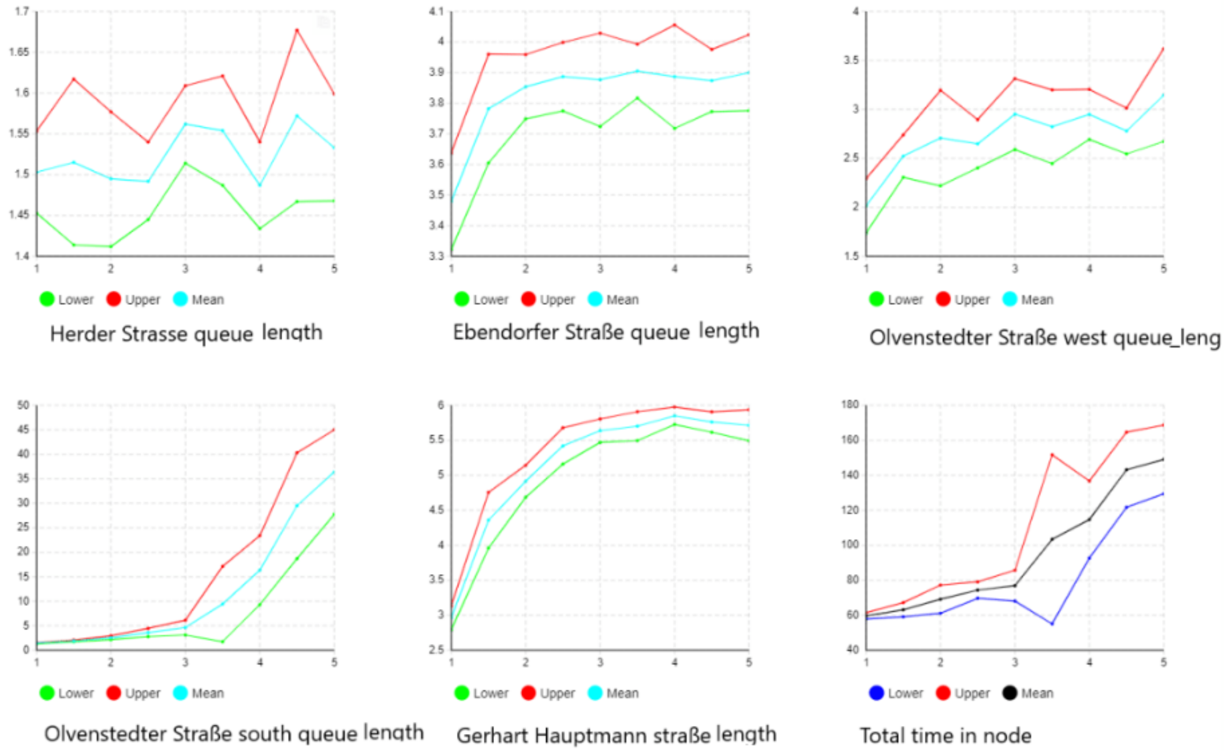

Figure 37: Traffic Variance Graphs for the average queue length of each road and average time spent in the node

7.4 Experiment 1: Increase the number of lanes in Ebendorferstraße

Ebendorferstraße saw most numbers of inter-arrivals and currently has one lane on each side of the road, the experiment is to Increase the number of lanes in Ebendorferstraße leading into the intersection, from one to two.

Variable	Real World Value	Validated CI (99%)	Experiment CI (99%)
Average Queue Length	3.55	3.509 - 3.589	4.967 - 5.137
Avg. time in node (Secs)	58	53.23 - 58.651	54.833 - 57.377

Table 20: Differences made by Experiment 1.

Other streets are unaffected by this change along with a similar time spent in the node. Hence only the queue length of Ebendorferstraße is considered as an impacted parameter. This experiment increases the queue length in Ebendorferstraße from around 3.5 to approximately 5 after adding one additional late to it. That means, now there are more vehicles waiting at the signals.

Traffic variation:

This experiment withstands increased traffic to an extent. While the initial load of traffic produces a mean of around 7.6 queue length at Ebendorferstraße. Increasing it to 5 times the existing traffic load ends up producing queue length of about 8.2. Thus this experiment will withstand higher load of traffic without creating any significant concern.

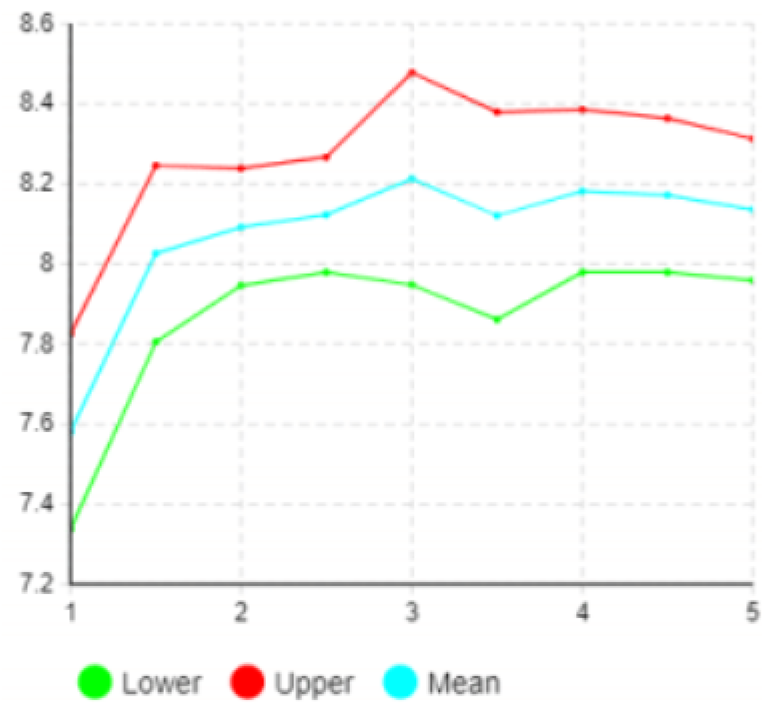

Figure 38: Traffic variation effect on Ebendorfer Str. after implementation of Experiment 1.

7.5 Experiment 2: Signal optimization

Changing of signal phases is not in the most optimal order. Changing the signal from red to green at the same time for Gerhart-Hauptmann Str. and Olvenstedter Str. (S) also created a relatively high queue sometimes.

The current Signal denoting stopline for each of the streets is:

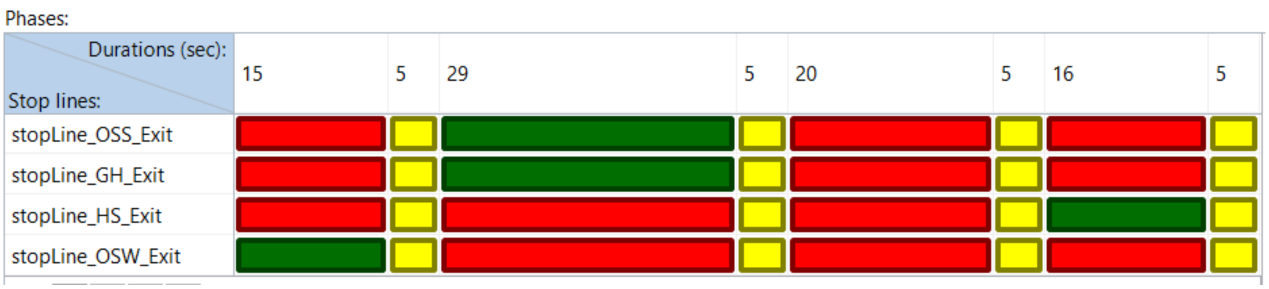

Figure 40: Signal phases (approximate)

Splitting the phase GH/OSS so that GH and OSS have their own phase. In the following order of phases obtain minimal 'average time in node' value.

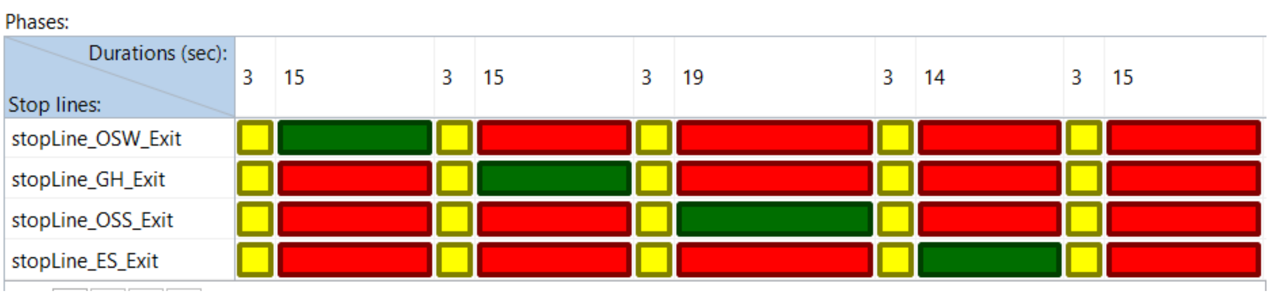

Figure 41: Signal phases after implementing Experiment 2.

Variable	Real World Value	Validated CI (99%)	Experiment CI (99%)
Herder Str. (Av-Que-Len)	1.57	1.556 - 1.593	1.554 - 1.595
Ebendorfer Str. (Av-Que-Len)	3.55	3.509 - 3.589	3.131 - 3.199
Olvenstedter Str.-W (Av-Que-Len)	2.0	2.01 - 2.152	1.679 - 1.822
Gerhart-Haupt. Str. (Av-Que-Len)	3.13	2.974 - 3.156	2.91 - 3.093
Olvenstedter Str.-S (Av-Que-Len)	1.59	1.468 - 1.632	1.125 - 1.289
Avg. time in node (Secs)	58	53.23 - 58.651	46.584 - 52.001

Table 21: Differences made by Experiment 2

After changing the signal pattern, there is only a slight reduction in average queue length for all the roads in the node. However, there is a significant decrease in average time in the node changing from 58 in the real world to 46.584 - 52.001 in the experiment. That means a vehicle requires at least 6-12 seconds less to travel through the node.

Traffic variance:

The traffic variance part of the experiment showed that this change will majorly reduce the average time spent by vehicles in the node even with a higher traffic load. There are a few spikes in that value but even those are still less or the same as the current value. Thus no concerns are observed.

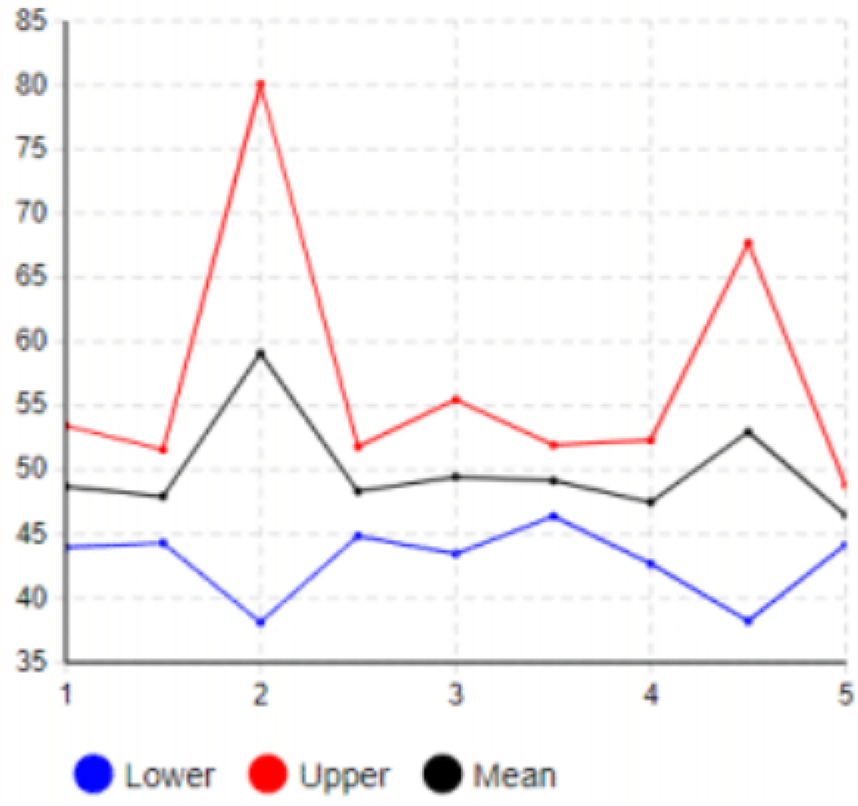

Figure 42: Traffic variation effect on Average time in node after implementation of Experiment 2.

7.6 Experiment 3: Pedestrian over-bridge/Subway

While the Pedestrians are crossing the road, the signal changes to green for the vehicles, making the vehicles wait for an additional time. Hence, increases time spent in the node. An over-bridge can totally remove the pedestrians from the road and allow uninterrupted vehicle movement.

Variable	Real World Value	Validated CI (99%)	Experiment CI (99%)
Avg. time in node (Secs)	58	53.23 - 58.651	43.771 - 44.446

Table 22: Differences made by Experiment 3.

The average queue length does not get affected by removing the pedestrian. The only variable to consider is the Average time in node. The average time in node has decreased to 43.771 - 44.446 from the real-world value of 58.

Traffic Variance:

The average time spent inside the node by vehicles increases constantly with an increase in traffic load. There is a steep increase beyond traffic load of 3 times more than the current system but that is related more to the overall setup of the node than to the experiment in particular.

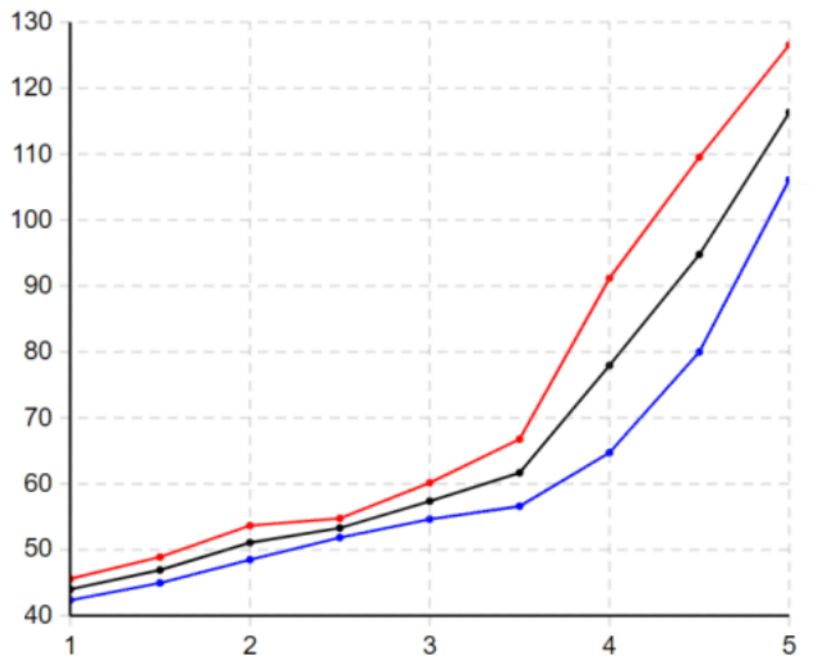

Figure 43: Traffic variation effect on Average time in node after implementation of Experiment 3.

7.7 Experiment 4: Combining the half arm in Gerhart-Hauptmann straße

Vehicles are taking a longer routing coming from anywhere except Olvenstedter strasse (south) into Gerhart-Hauptmann straße. This increases time spent in the node. In the experiment, we are removing the two-way arm into Olvenstedter strasse (south) and converting the one way exit to the intersection into a two-way connection in Gerhart-Hauptmann straße

Variable	Real World Value	Validated CI (99%)	Experiment CI (99%)
Gerhart-Haupt. Str. (Av-Que-Len)	3.13	2.974 - 3.156	1.628 - 1.648
Avg. time in node (Secs)	58	53.23 - 58.651	46.391 - 50.053

Table 23: Differences made by Experiment 4.

After the experiment, there is a significant decrease in both Average queue length and Average time in node. The average queue length and average time in node both have decreased from 3.13 to 1.628 - 1.648 and 58 to 46.391 - 50.053 respectively.

Traffic variance:

The increase in traffic does not seem to bother the result of this experiment in particular. Though the queue length at Gerhart-Hauptmann straße increases in proportion to the traffic load, it still maintains an acceptable level of queues. The queue length of around 4.2 after this experiment is implemented, at 5 times the traffic is almost comparable to the current system’s mean of 3.13.

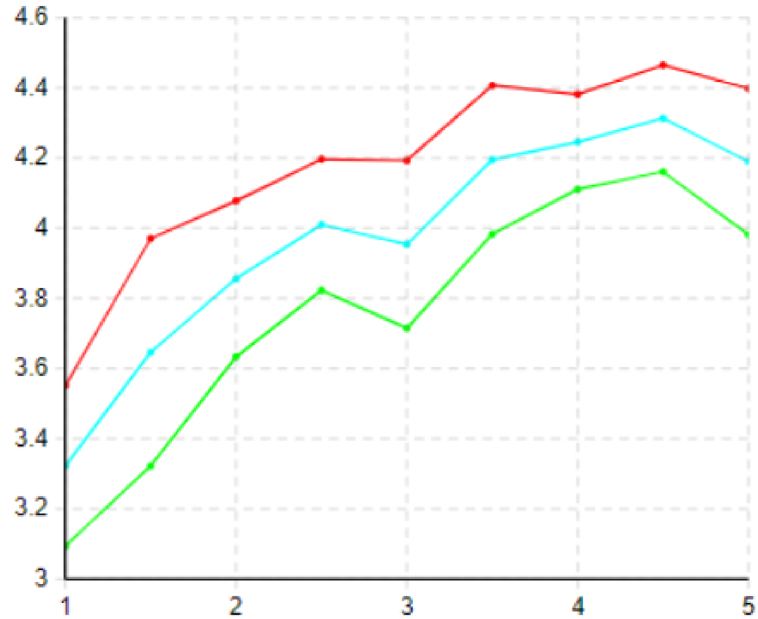

Figure 44: Traffic variation effect on Queue length at Gerhart-Hauptmann Str. after implementation of Experiment 4.

The average time spent in node by the vehicles also sees a gradual increase with the load but still ends up having value of around 60 seconds at 5 times the traffic load of current situation which already sees the value reach upto 58 seconds with the existing setup.

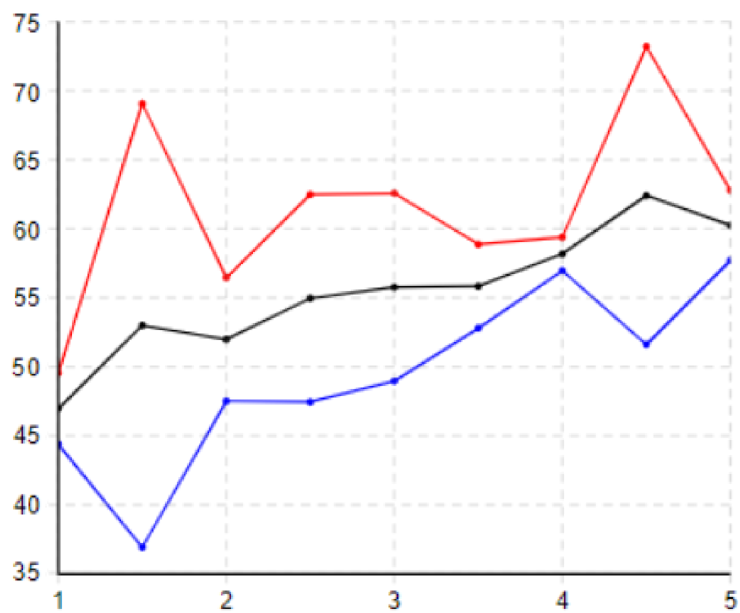

Figure 45: Traffic variation effect on average time spent in node after implementation of Experiment 4.

7.8 Results summary

Experiment 1 (Increasing lanes): Increase in Average queue length at EbendorferStr. No clear indication of improvement.

Experiment 2 (Signal optimization): All the roads show a slight decrease in average queue length. The average time spent in node was reduced by 12%. Indication of improvement.

Experiment 3 (Pedestrian over-bridge/subway): Average time spent in node reduced by around 20%. Indication of improvement.

Experiment 4 (Combining half arms): Gerhart-Hauptmann str. queue length reduced by approximately half. The average time was reduced by around 13%. Indication of improvement

7.9 Recommendations (order)

Experiment	**Complexity**	**Cost**	**Improvement**
Experiment 2 (Signal Optimization)	Easy	Low	High
Experiment 3 (Pedestrian bridge/subway)	Medium	Medium	High
Experiment 4 (Combining Half Arms)	High	High	Medium
Experiment 1 (Extending lane at Ebendorfer Str.)	High	High	Bad

Table 24: Recommendation order

Overall, the signal optimization has proved to be our recommended change considering the low complexity and cost involved in implementing it combined with a high rate of improvement.

8. Limitations & Validity

All the aspects of this project, from data collection to experiment recommendations are subject to the specific situation we are currently in. The pandemic has reduced a lot of traffic on the roads and nearby constructions have added further dent into the numbers collected. Any result obtained out of this project might not work the same way when the traffic situation gets back to 'normal' - like before the COVID-19 era.

9. Project Cost & Progress

We finished the project well within the budget. We used 425 hours (€42,500) out of the initially allocated 500 hours (€50,000). As per project planning,time for each milestone was dedicated and utilized effectively. 40 hours (€4,000) were given bonus to the project cost for being voted the best presentation of the milestone for 4 out of 7 milestones.

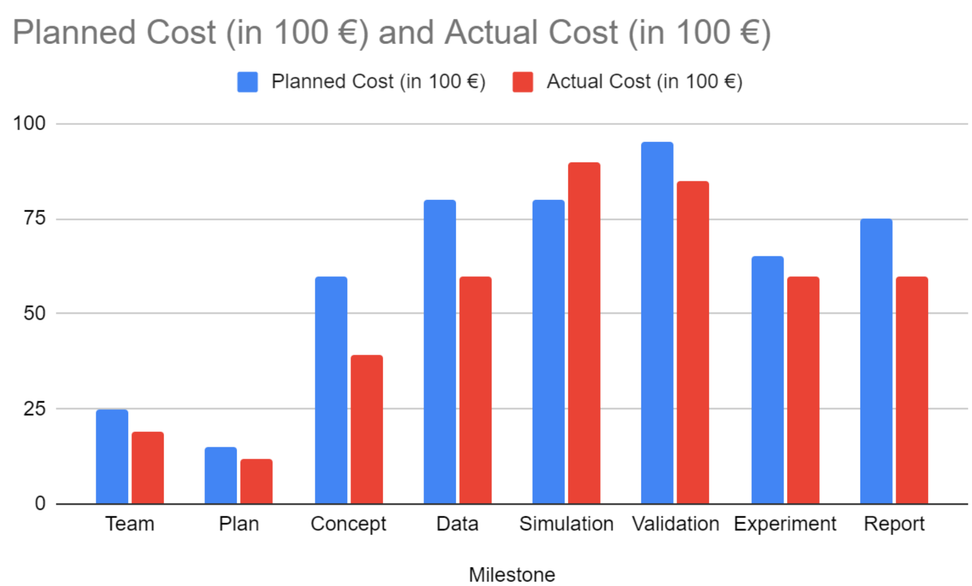

Figure 46: Project Cost for each milestone.

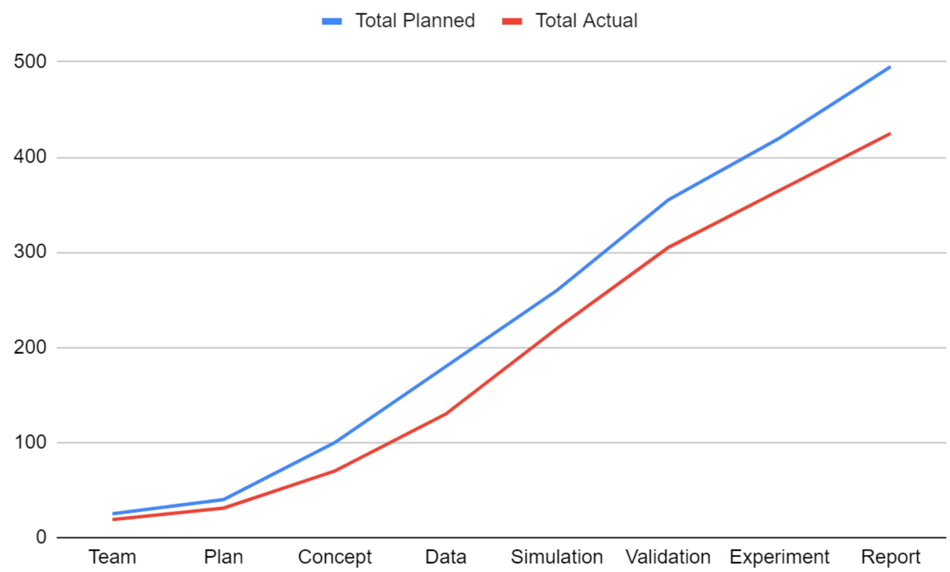

Figure 47: Overall Project Costing

In order to keep track of the project progress, we visualized and graphed the progress per milestone. We were ahead of the planned progress until milestone 3. The subsequent milestones until the 6th one derailed our progress and we lagged behind until we almost caught up in milestone 7. We have now completed the project as expected by the end of milestone 8.

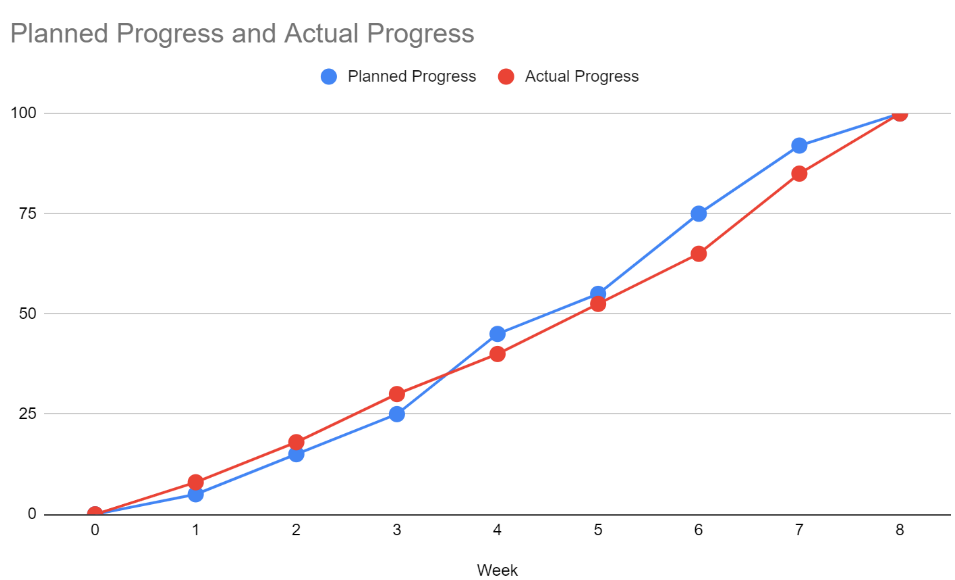

Figure 48: Overall Project Progress Tracking

10. Problems & Experiences:

Problems faced:

- Clarifying fundamental doubts during the start of the project.
- Planning of team members’ availability.
- Communication and knowledge transfer in case of unavailability during critical times.
- Dealing with delays in data collection due to weather.
- Planning buffer times for tasks and setting deadlines accordingly.
- Leaking delays and cascading efforts from previous milestones into current ones.

Experiences gained:

- Teamwork produces a high level of efficiency.
- Good communication is very important for the team to reach conclusions quickly.
- Open mindedness allowed the team to quickly adapt to Kanban board and project framework.
- Gained technical knowledge on multiple aspects of a Simulation Project.
- Documents like Cost Tracker, Issue Tracker and Task Board enable a smooth team meeting.
- Importance of a high quality data analysis.
- Different approaches towards Verification and Validation.

11. References

1. Matti Pursula "Simulation of Trac Systems - An Overview" Journal of Geographic Information and Decision Analysis, vol.3, no.1, pp. 1-8, 1999
2. AnyLogic Road Trac Simulation Software: https://www.anylogic.com/road-traffic/
3. Road Traffic Library Webinar: https://www.anylogic.com/resources/educational-videos/road-traffic-library-webinar/
4. Google Maps: maps.google.com
5. ItS - Winter course at OVGU, Magdeburg