Simulation Project 2019

Team: A

Ebendorfer Chaussee/ Barleber Strasse / Klosterwuhne / Lübecker Strasse

Team:
Anitha Bhat Talagini
Aravind Sai Seelam
Naveeth Reddy Chitti
Raj Rajeshwari Prasad
Vritika Kalra
Venkatesh Murugadas

Contacts:
anitha.talagini@st.ovgu.de
aravind.seelam@st.ovgu.de
naveeth.chitti@st.ovgu.de
raj.prasad@st.ovgu.de
vritika.kalra@st.ovgu.de
venkatesh.murugadas
@st.ovgu.de

Supervisor's:
Dr.-Ing. Claudia Krull
Pascal Krenckel

June 24 ,2019

Acknowledgements

It gives us immense pleasure to have successfully completed the Simulation Project 2019 for City Planning Office, Magdeburg. We are glad that we were given an opportunity by the Planning office to have hands-on experience in the real-time project regarding the safety and improvement of the traffic node.

We would like to especially thank our supervisors Dr.Ing.Claudia Krull and Pascal Krenkel for their precious time and guidance throughout the course of the project.

We would also like to humbly thank Prof. Dr.-Ing. habil. Graham Horton for his outstanding lectures regarding the course Introduction to Simulation in the winter semester 2018. The course not only created a spark within us to be part of the project but also allowed us to solve greater challenges during the project. The course paved the path for the successful completion of the project.

We are also thankful to the Faculty of Informatics, Otto-von-Guericke University for allowing us to be part of this prestigious institution.

Finally, we would like to thank our friends and seniors for providing us with support throughout the project.

Abstract

Implementing a real-time system is challenging, time taking and expensive. Simulation is a powerful tool for the analysis of best approach to model a new system designs,and to test before implementation. Our goal is to increase the safety on the node of 'Ebendorfer Chaussee/ Klosterwuhne/ Barleber Straße/ Lübecker Straße' and to reduce the traffic load with less collision issues at the node.Our report presents a step-wise process of how we identified the major point of the problem at the node, and how to improvise it keeping safety in mind. It includes deep insight of the conceptual design of the Node under consideration and acquisition of data and data analysis. A validated simulation program to simulate the real world traffic node into a computer running model is prepared. In addition,we planned and conducted the experiments to reach the objective. Being safety is the major point of concern .Significant optimization of traffic can be achieved using our experiments and safety can be better ensured.

Contents

1 Introduction

1.1 Project Description

We have been assigned the node 'Ebendorfer Chaussee/Klosterwuhne/Barleber Straße/ Lübecker Straße' to analyze and suggest possible changes to enhance the safety of the node. With initial observations, we witnessed that the node is very complex. The node has four streets converging and tram lanes.The tram lane is diverging from Klosterwuhne tram stop to 2 different directions - tram 1 for IKEA and tram 9 for Neustadter See. There is a bicycle lane in the middle of Lübecker Straße, which is hardly seen in any other node and is rarely used by localities.

Traffic inflow is very high to the node and traffic is impacted by tram arrival and departure. Traffic Signal duration for the lanes are not in sync and phases are not in sequence. Queue length is high in each node except Klosterwuhne.There are Ped Paths present in all the streets. All these above mentioned things when combined provide the traffic node which we have considered for modelling using the simulation software 'Anylogic'. We have then created a conceptual model of the real time system. We have taken records of the traffic and analyzed the data. We have created a program to simulate the real time system using any logic. We then conducted the experiments on the simulated model to check if we can make any further improvements on the system. On the validated simulated model, we have conducted five experiments which have proven to show good results. There were also certain limitations to the model because of constraints like time and resources.

Figure 1: Node

1.2 Team Organization

A team has been created with the random team assignment process under the administration of Dr. Ing. Claudia Krull before the commencement of the semester. Roles has been awarded with the voting system by team members, which are as follows:

Vritika Kalra	: Team Leader
Aravind Sai Seelam	: Conceptual Model
Anitha Bhat Talagini Ashoka	: Data Acquisition
Venkatesh Murugadas	: Software Architect
Naveeth Reddy Chitti	: Validation and Quality
Raj Rajeshwari Prasad	: Experimental Design

We kept the originality by naming it Team A. The roles were divided according to the major responsibilities to every team member, to be clear about the presentation task. But every member was efficient in functioning as a team by extending their support wherever necessary.

1.3 Software and Communication Platform

Data Storage and Sharing Platform	: Dropbox and Google Docs
Communication Platform	: Slack and Whatsapp
Team Email id	: simsoseteam.a@gmail.com
Presentation and Management Tools	: Xmind, Overleaf,Team Gantt Paint and MS Office
Simulation	: Anylogic
Software Development Tool	: Eclipse

1.4 Special Features Of The Node

- Gas Station and a Local Store.

- It's a busy junction with tram lines intersecting the road.
- Bicycle lane on the middle of Lübecker Straße.
- Increased traffic due to residential area.
- Ebendorfer Chaussee is one of the entry/exit point to the city.

1.5 Project Quality Criteria

- Implicate five project constraints : time, scope, cost, resources, and risk.
- Accumulate and investigate results from the past experience and implement the modification. a.Vehicular Operation b.Pedestrian Safety c.Accident Occurrence
- Comparing real time traffic congestion,to the experimented simulation results.
- Optimize traffic signals time for smooth traffic flow.
- Implementation and maintenance of the optimized solution should be economical.
- Modification to enhance safety of pedestrians, cyclist and other commuters.
- Experiments conducted are in accordance with the traffic rules and are feasible.

1.6 Data Required for the Project

- Vehicle Entry/Exit timing.
- Inter-arrival timing of Vehicles and Pedestrians.
- Traffic Light Cycle.
- Node Features.
- Accident Data.

2 Conceptual Model

2.1 Conceptual Model

A conceptual model is a representation of a system or situation with all its primary parameters. These models are built based on real life scenarios or problems, giving the first hand introduction to what needs to be solved. Petri-Net model is one such conceptual model used in simulation, that defines the states and event transitions of a system. Our Petri-net model describes the functioning of the junction(node) which joins the streets Lübecker Str., Klosterwhunne Str., Barlaber Str., Ebendorfer Chaussee. Certain assumptions were made with justifications to reduce the complexity of real-world scenario. We will also look into the other details like experiments to be modelled, the parameters to be measured as inputs and outputs of the simulation model and the types of events described in the model.

2.2 Assumptions and Reasons

- Vehicles:
  In order to simplify the vehicle data we have assumed all vehicles as cars and Large commercial vehicles. These vehicles adhere to the traffic rules and strictly follow the traffic signals as they move from one street to the other. This is done in-order to reduce the complexity of given data.

- Pedestrians and bicyclists:
  Pedestrians and bicyclists are considered as a single entity as they have similar behaviour and also have the same signal for crossing. We have also considered them to cross from a single direction.

- Special conditions:
  We have considered that the Bicycle lane on Lübecker Str. to be idle as the lane is hardly used in the real scenario.

- Gas station:
  The gas station and its parking lot are not considered as they have limitations for data acquisition and also this data has no significance on the actual node.

- Traffic signals:
  We have considered the traffic signals to function as per the given data, as we have observed deviations from data given to us and the real time scenario.

As it is difficult to remodel the phases as per the current situation, we have considered the phases to function in a sequence from 1-6 and the phases 3 and 6 function only when a tram 1 or 9 arrives respectively.

2.3 Petri-Net Model

A petri-net model is a conceptual model used for simulation. It models all the states and events of a system. This makes it easier to convert the conceptual model into a simulation model. It is generally recommended to use a petri-net model for a small system as the complexity of the model increases with increase in size of the system. This model consists of the agents of the real world represented as dots and named as tokens. The places represented by circles which are the states and events are termed as transitions which are represented as rectangular boxes. There are two types of transitions namely immediate and timed transitions. Immediate transitions are filled boxes and are fired whenever a token is present in the place to which this transition is connected. Timed transitions are hollow boxes which are fired when the conditions written above them are satisfied. These tokens are created and destroyed in places and this process is triggered by transitions which have specified conditions. The connections between places and transitions are made using lines named as arcs. There are special kind of arcs named as inhibitor arcs which are represented as a line with a small circular head on the end where it is connected to a transition. These inhibitor arcs are used to stop a transition from firing. In this model these inhibitor arcs can be seen near the signals of the streets. The functioning of our model is detailed in further topics.

2.3.1 Representation of the node using petri-net

Figure:5 below denotes the real-world scenario of the node. It is modelled using PIPE2 (a free source petri-net modelling software).

2.3.2 Working of Petri-Net Model

Figure6 and Figure7 below represent one secluded part of the whole model. In figure 6 the places have tokens and when the conditions on the transitions are met these token are fired, which enables an operation that destroys a token in that particular place and creates a new one in the place that is directly connected. This is similar to

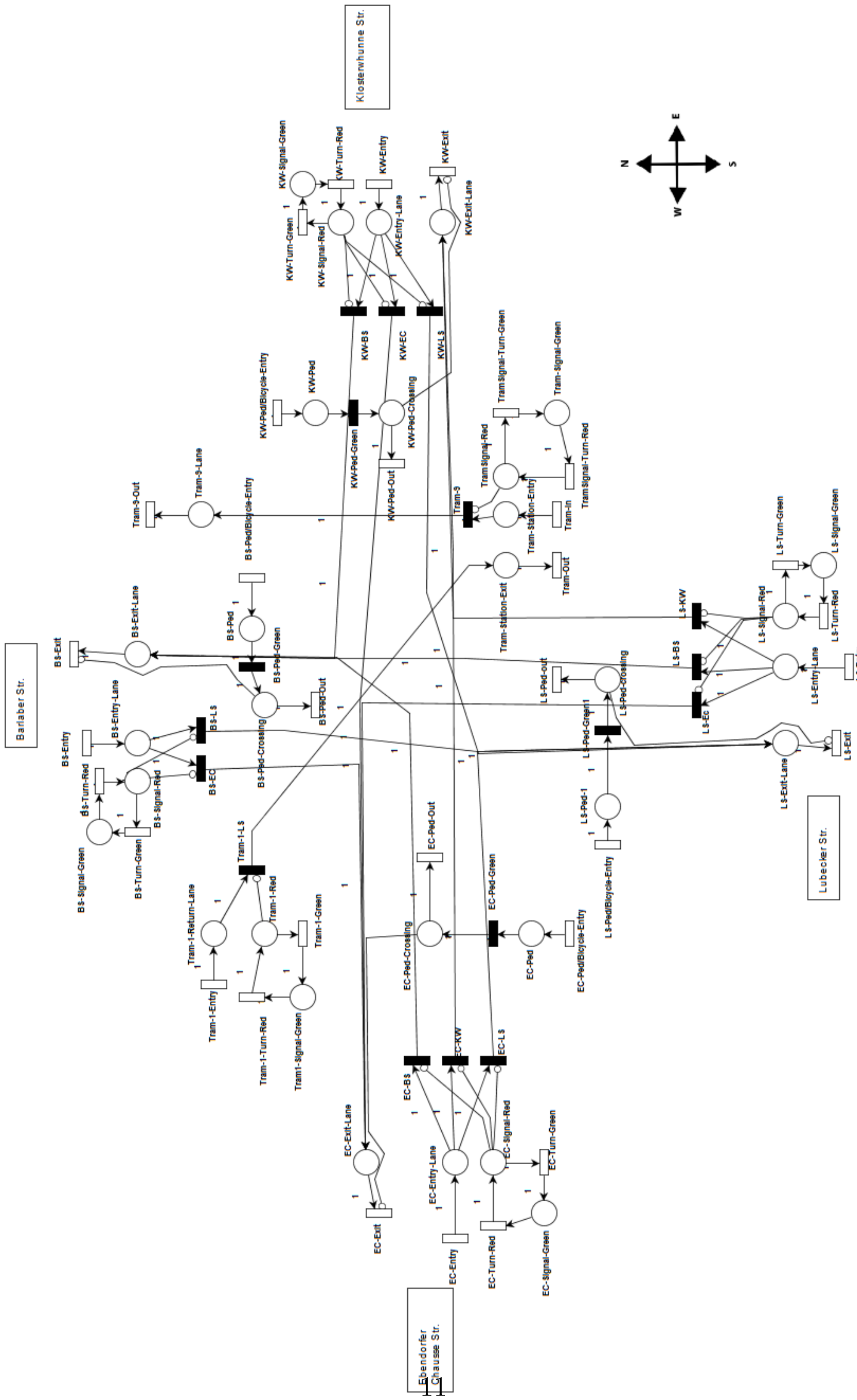

Figure 2: Petri-Net Model of the Node.

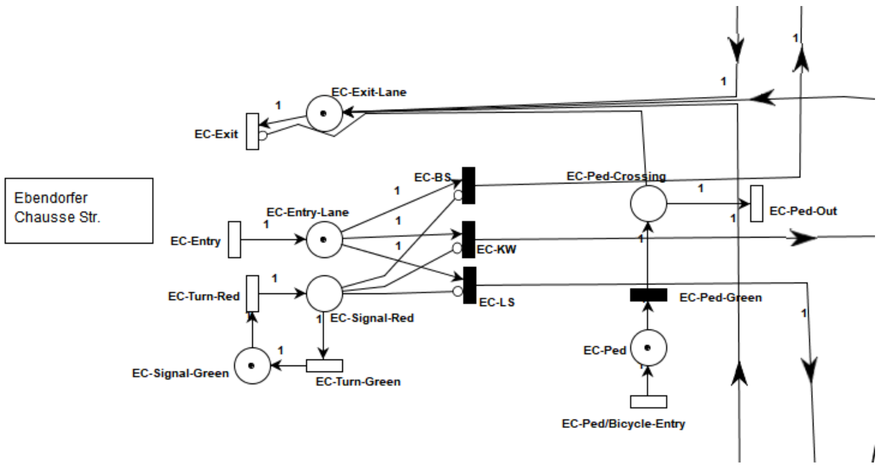

Figure 3: Secluded Ebendorfer Chausee.

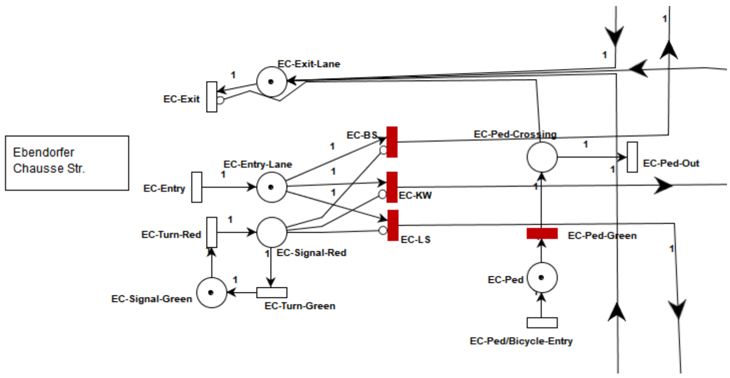

Figure 4: Working Petri-Net Model of the Ebendorfer Chausee.

the behavior of agents in the real life scenario i.e vehicles moving from one street to the other. In the figure 7 a token is present in the EC-Lane and one in the EC-Signal-Green, this shows that the transitions represented in color red can be triggered(fired) only when the conditions are met. These conditions are related to the traffic phases and are detailed in 'Simulation Model' part of this report.

2.4 Quantities to be measured

- Inter-arrival times:
  It is the consecutive time difference between agents entering the system. These provide the distribution in which the agents arrive into the system. Modelling the system using these distribution gives the real-time functioning of the systems. These also provide the probabilities of the directions the arrived agents exit the system.

- Traffic Phase cycle:
  It is the time taken for one phase of the traffic signal to change. These provide the queue lengths of different lanes for which the traffic phase is active(on).

- Delay in vehicle transition:
  It is the time taken by an agent to start when a transition is triggered. In our system the time taken for a vehicle to start crossing the lane when the signal turns green. It helps in determining time taken for a vehicle to cross the street which helps us determine the throughput when a single phase of traffic signal is completed.

- Tram Inter-arrival times:
  It is the time difference between the arrival of two trams. These are determined by the tram schedule in the data we obtained from the app named INSA (provides tram arrival information for people).

2.5 Quantities used for simulation results

- Throughput:
  It is the total number of vehicles moving through the system for a particular amount of time. This is determined by using the inter-arrival times, traffic phase cycle. It helps in tracking the amount of vehicles using the node.

- Mean time of Vehicle on the node:
  The amount of time taken by a vehicle from arrival to departure of the node.

- Queue Length:
  Number of cars accumulated on a street when the signal is Red.

2.6 Types of events in the system

Primary events:

Events which have no conditions for their transitions to occur. In our system, the primary events are

- Arrival and departure of the vehicles.
- Arrival and departure of the pedestrians and bi-cyclists.
- Arrival and departures of the trams.
- Traffic signals.

Secondary events:

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

- Vehicles leaving the node.
- Pedestrians crossing the street.
- Trams leaving the node.

3 Data analysis

Reason behind doing data analysis are to find the input for the simulated model, and to check whether the output matches the output of the real time system. The inter arrival times are calculated for the input and the queue lengths, average time spent by the vehicle in the node are calculated to validate the output.

3.1 Data Collection

For the purpose of data analysis, we took the data from all the streets of the node. i.e Lübecker Straße, Ebendorfer Chausse,Klosterwuhne and Barleber Straße.

To get maximum approximation, the data was collected in the evening(16:00 to 17:00)which is the high traffic hour of the node, . We used cameras to record the videos of the traffic for 1 hours form all the streets to find out inter arrival times. We have also taken a note of the traffic signals of all the streets and tram timings so that we can approximate the wave inflow of traffic into the simulation.

3.2 Input and Output Variables

The variables we have considered for input are:

1. inter-arrival times

The variables we have considered for output are:

1. queue length
2. Throughput
3. Average time in the node

3.3 Probability Distribution Functions Estimation

In order to make a right guess of the distribution of cars, we have drawn histograms for the inter arrival times. frequency of cars for particular value of inter-arrival time. This can be observed in the histograms - figure 6 9,12 and 15.

According to the histogram obtained, we have compared with the existing probability distribution functions and assumed that the distribution is log-normal distribution.Repeated the process for all the 4 streets and found that all the distribution as log-normal distribution.

In order to check the correctness of our assumption which is log-normal distribution, we have drawn quantile-quantile plot(figure 7,10,13 and 16) Since the plots obtained in the q-q plots is almost a straight line and the plot passes through origin, the probability distribution function estimation is correct.

We tested our assumed distribution with chi square test and got accepted with 95 percent confidence level(figure 8,11,14 and 17).

3.3.1 Given Data

1. Traffic Phase cycle
2. Accident data
3. Node Dimensions

We considered the Traffic phase cycle from given data for development of simulation model.

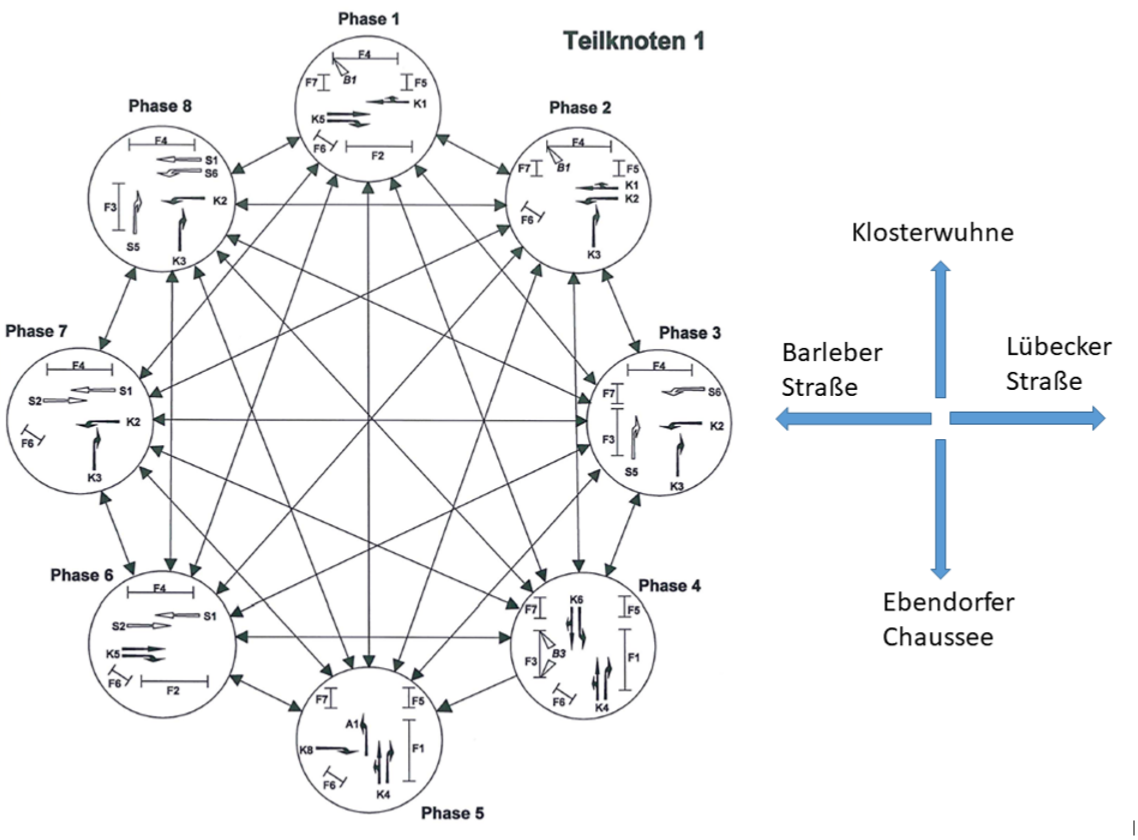

Figure 5: Traffic Phase cycle

3.4 Lübecker Straße

3.4.1 Histogram of Lübecker Straße inter-arrival time

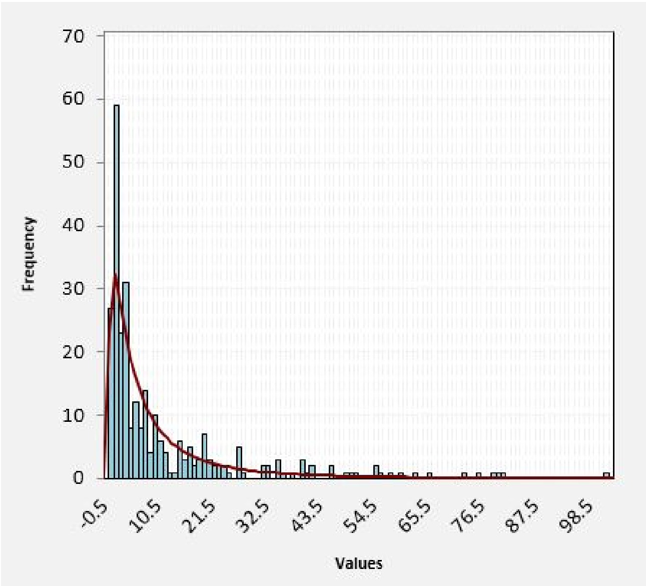

Figure 6: Histogram of Lübecker Straße inter-arrival time

Distribution	Log-normal distribution
Mean	Standard Deviation
1.50	1.26

Table 1: Distribution and parameters

From Lübecker Straße towards:

Barleber Straße	Ebendorfer chaussee	Klosterwuhne
0.5	0.4	0.1

Table 2: Probabilities of vehicle flow

3.4.2 Q-Q plots for Lübecker Straße

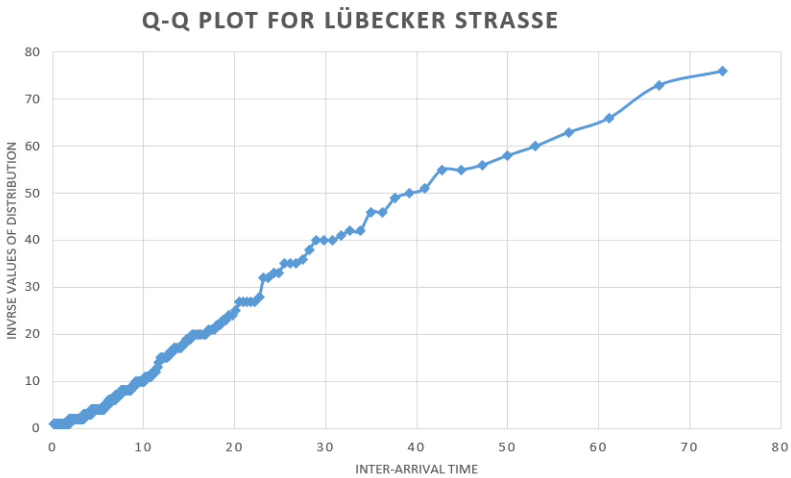

Figure 7: Q-Q plots for Lübecker Straße

3.4.3 Chi square test for Lübecker Straße

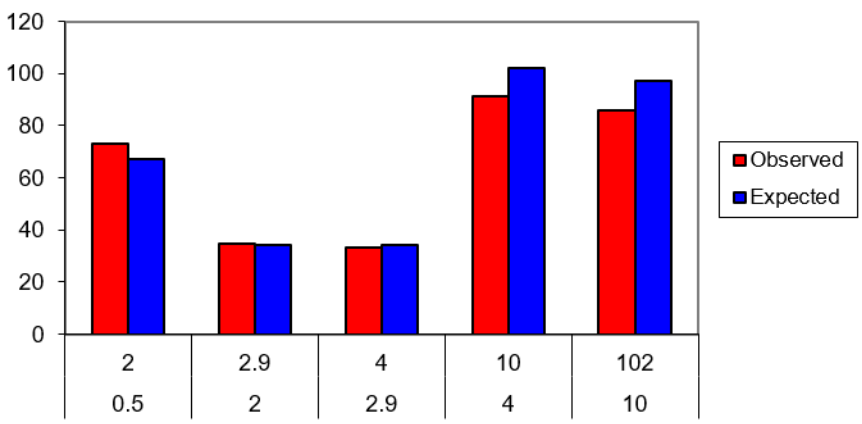

Figure 8: Chi square test for Lübecker Straße

3.5 Ebendorfer Chausse

3.5.1 Histogram of Ebendorfer Chausse inter-arrival time

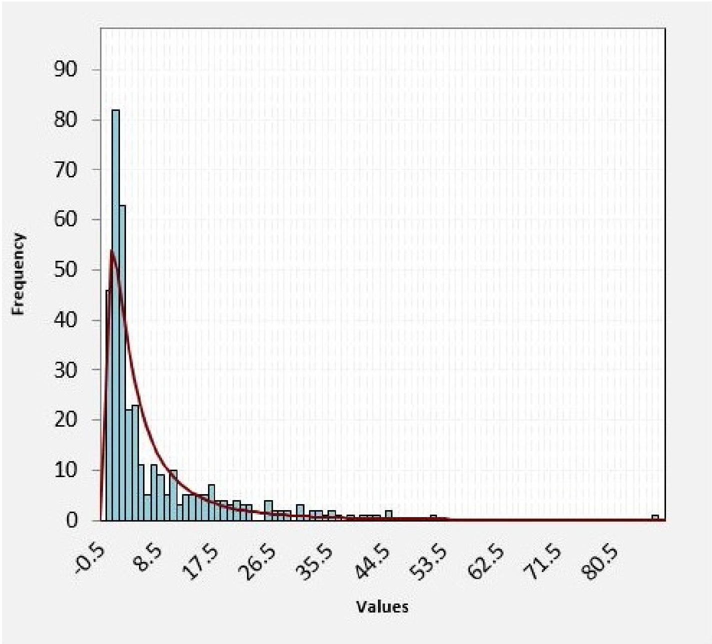

Figure 9: Histogram of Ebendorfer Chausse inter-arrival time

Distribution	Log-normal distribution
Mean	Standard Deviation
2.04	1.093

Table 3: Distribution and parameters

From Ebendorfer Straße:

Barleber Straße	Lübecker Straße	Klosterwuhne
0.37	0.36	0.37

Table 4: Probabilities of vehicle flow

3.5.2 Q-Q plots for Ebendorfer chausse

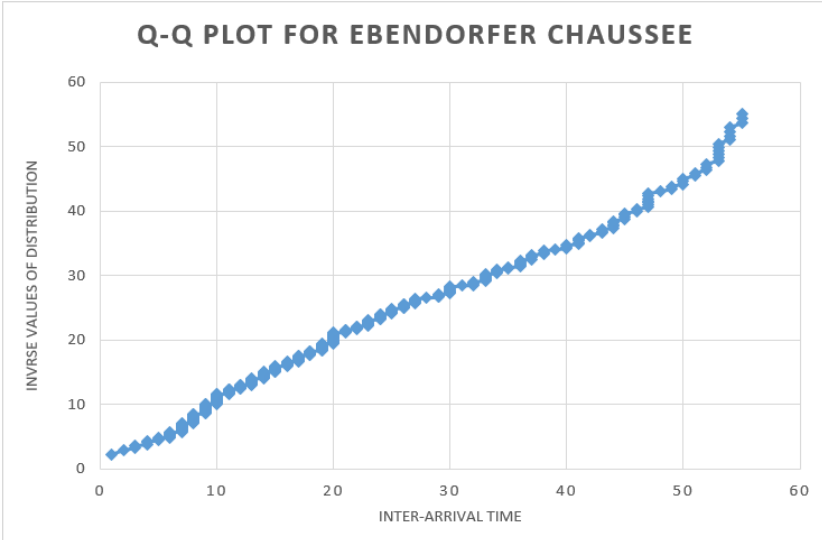

Figure 10: Q-Q plots for Ebendorfer chausse

3.5.3 Chi square test for Ebendorfer chausse

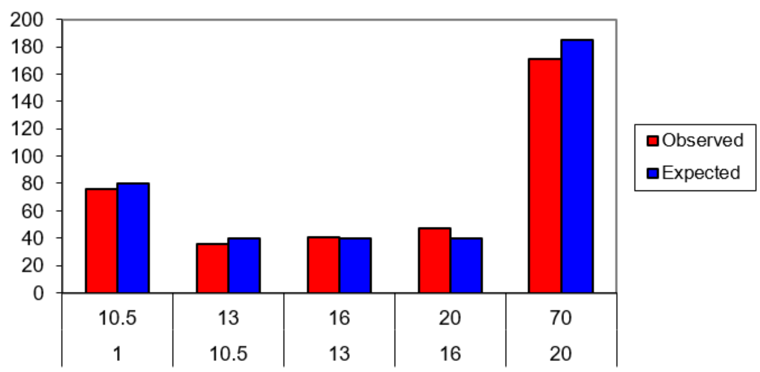

Figure 11: Chi square test for Ebendorfer chausse

3.6 Barleber Straße

3.6.1 Histogram of Barleber Straße inter-arrival time

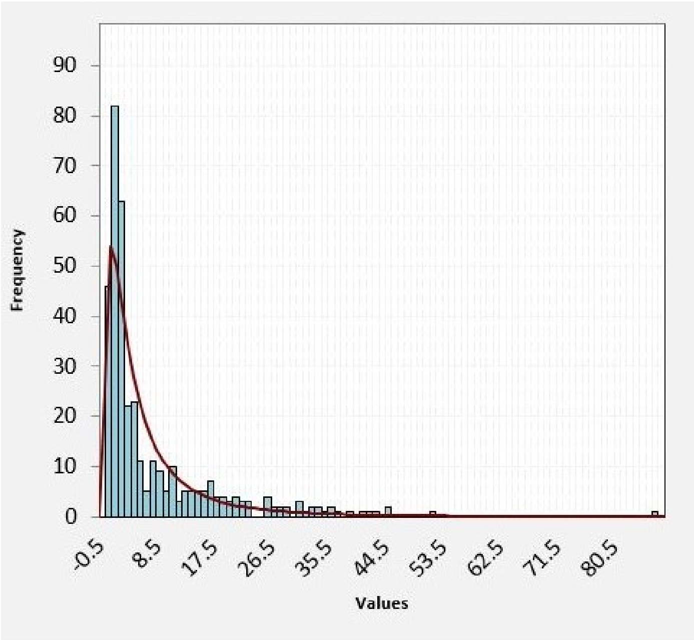

Figure 12: Histogram of Barleber Straße inter-arrival time

Distribution	Log-normal distribution
Mean	Standard Deviation
1.49	1.05

Table 5: Distribution and parameters

From Barleber Straße:

Lübecker Straße	Ebendorfer chausse	Klosterwuhne
0.43	0.57	0

Table 6: Probabilities of vehicle flow

3.6.2 Q-Q plots for Barleber Straße

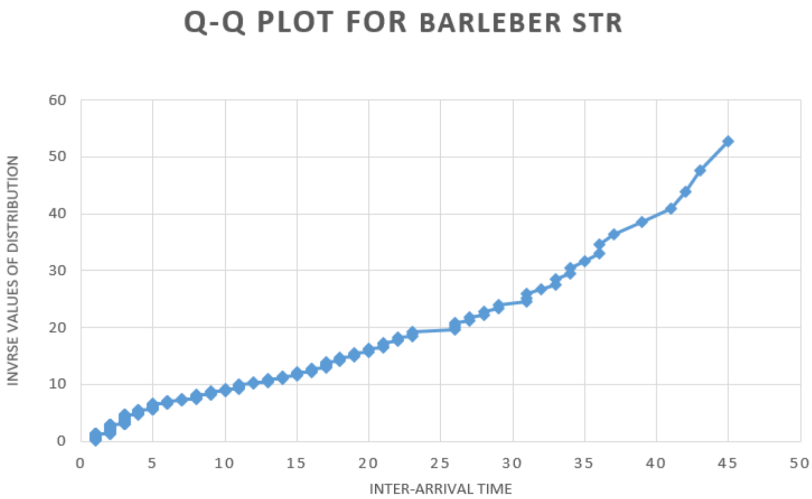

Figure 13: Q-Q plots for Barleber Straße

3.6.3 Chi square test for Barleber Straße

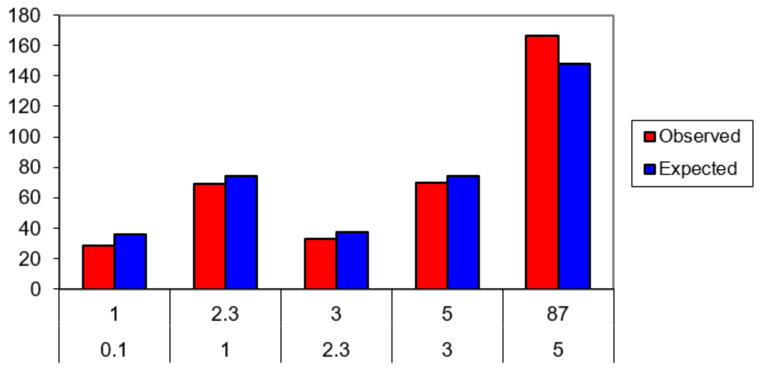

Figure 14: Chi square test for Barleber Straße

3.7 Klosterwuhne

3.7.1 Histogram of Klosterwuhne inter-arrival time

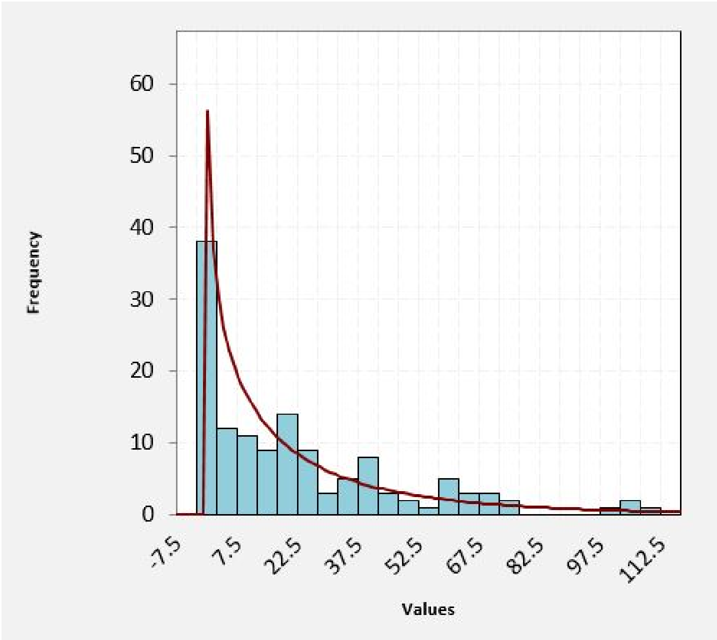

Figure 15: Histogram of Klosterwuhne inter-arrival time

Distribution	Lognormal distribution
Mean	Standard Deviation
1.034	1.082

Table 7: Distribution and parameters

From Klosterwuhne:

Barleber Straße	Ebendorfer chaussee	Lübecker Straße
0.03	0.80	0.17

Table 8: Probabilities of vehicle flow

3.7.2 Q-Q plots for Klosterwuhne

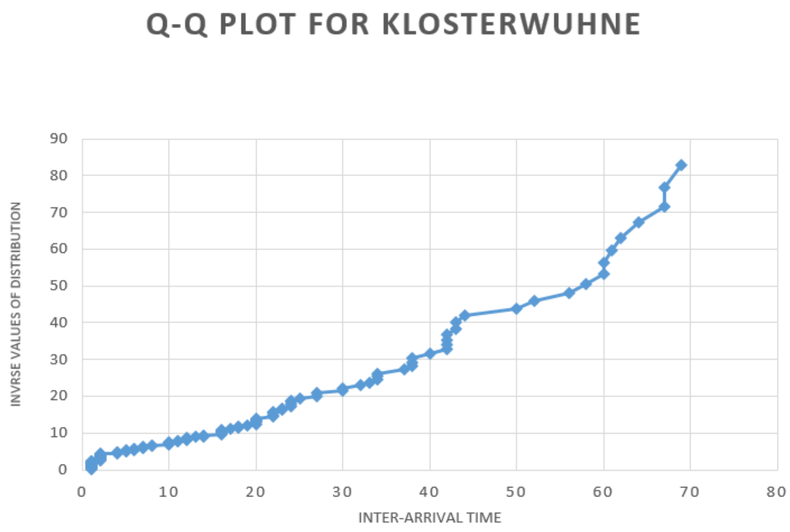

Figure 16: Q-Q plots for Klosterwuhne

3.7.3 Chi square test for Klosterwuhne

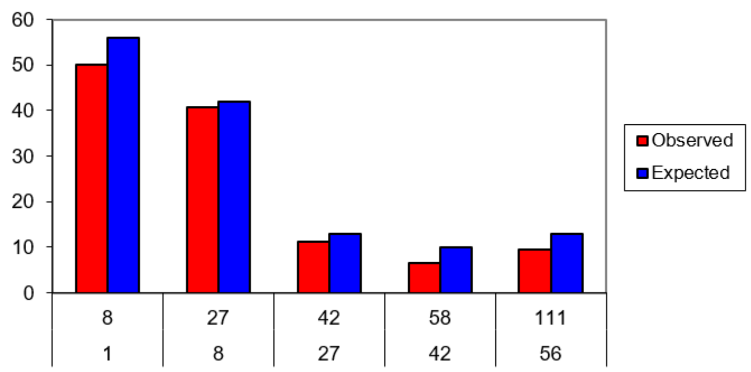

Figure 17: Chi square test for Klosterwuhne

3.7.4 Output Data

- Queue length
- Average time spent

The real-time values for the output variables are mentioned in validation chapter(table 9 and 10)

3.7.5 Difficulties encountered while obtaining the data

- Understanding the process of collecting data and deciding the critical parameters.
- Data collection got postponed due to bad weather and public holidays.
- It was difficult to fix a common time slot to collect the data among team members.

4 Simulation Program

4.1 Introduction

The traffic simulation model of the given intersection was built using the simulation software "Anylogic".

4.2 Program Structure

The software used for the modelling of the traffic simulation is Anylogic. In Anylogic, when a new model is created they provide us with three main segments. They are Agent, Experiment and Databases.

- In this model, the top level agent is “Main”. This agent is where the intersection is designed and the other agents such as Cars, Pedestrians, Truck and Experiment interact with each other.
- The Experiment segment is used to perform various experiments related to the improvement of safety and improvisation of the node along with the validation of the model.
- The Database is used in this model for providing the arrival of the tram schedule.

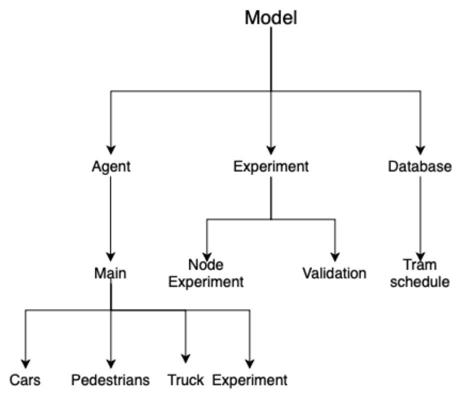

Figure 18: Program structure of Anylogic Model

4.3 Program Concept

The concept of the simulation program involves the modelling of the roads, intersection and behaviour of the agents.

4.3.1 Model Design

The roads in the model are implemented using the "Road" space markup element present in the Road Traffic Library. They are provided with the proper number of lanes according to the real world which can be done in the properties tab of the Road space mark up element.

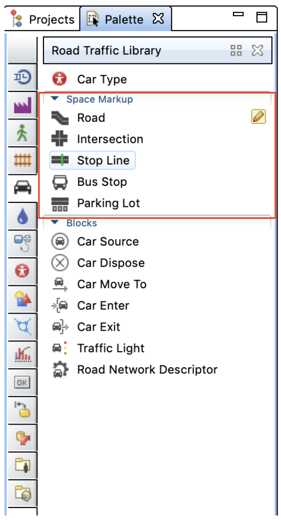

Figure 19: Road Traffic Library - Space Markup elements

Once the roads are all created, the node which is the intersection of all the roads is created using the "Intersection" space markup element in the Road Traffic Library. It inter connects all the roads creating a cross road element in the model similar to the real world. These intersection will provide the connections between the roads indication the path for the agents present on the particular lanes.

The tram lines in the real world model was reproduced by creating roads with one forward and one backward lane, which was then connected to the intersection. This was done based on the assumption of considering a Tram as a long car with different properties. Thus, the tram lines were modelled as per the real world model.

The traffic lights for the intersection was created by the “Traffic Light” block in the Road Traffic Library. They use stop lines for interaction with the agents.

The pedestrian path was built using the “Rectangular wall” space markup element and the “Polygonal Area” in the Pedestrian Library. The source for generation of the pedestrian was created using the “Target Line” from the Pedestrian Library. In the model the pedestrians were assumed to move in one direction.

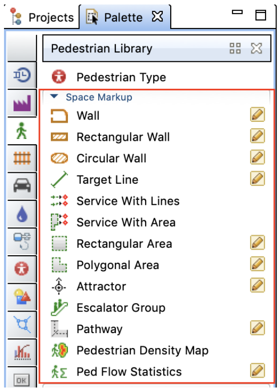

Figure 20: Pedestrian Library - Space Markup elements

4.4 Behaviour of the Agents

4.4.1 Vehicles

The vehicles on the roads were classified as Light vehicles (cars) and Heavy vehicles (Trucks). To implement these a Car agent was created and this was used in the Main agent.

The simulation program for Car was built using these four following blocks present in the Road Traffic Library.

- Car Source
- Select Output 5
- Car Move To
- Car Dispose

With the above mentioned blocks the car agents were programmed to behave in a similar way as in the real world.

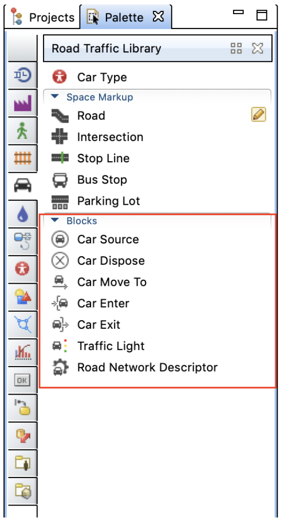

Figure 21: Road Traffic Library - Blocks

Car source is used to generate cars with an inter arrival time distribution specified from the data analysis. Once the car is generated , the select output block is used to select the road to which the car is supposed to move. This was done using the Probability provided in the select output block which determines the input to the car Move to block. When the car agent decides to move on a particular road, they are given as input the Car Move To block which will take the agent to the desired location. Finally the car agent is disposed once it reaches the end of the road.

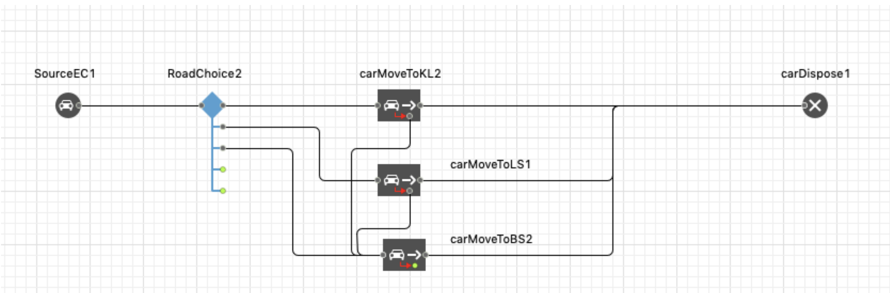

Figure 22: Simulation Program - Car Logic

The same programming logic was used for the Heavy vehicles (Truck).

4.4.2 Pedestrians

The pedestrians were modelled using the Pedestrian Library. The behaviour of the pedestrians were modelled using the following blocks.

- Ped Source
- Ped Wait Lights
- Ped Move To
- Ped Sink
- Ped Area Descriptor

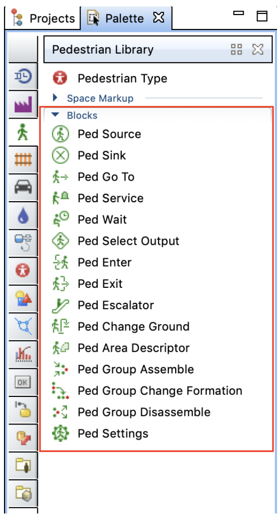

Figure 23: Pedestrian Library - Blocks

The Pedestrians were generated using the Ped Source block with respect to the Target Lines. The number of pedestrian generation is provided by the rate at which they will be generated per hour. Once the Pedestrians are generated they should not cross the road at any given time. They should cross the road only during certain phases of Traffic Light. To make this happen the pedestrians have to wait during the other phases. Ped Wait Light block is used to do the exactly same which indicates the pedestrian has to wait in certain area/target line during other phases. When the traffic condition is preferable for the pedestrians, they will move using the Ped Move

To block. This will make the pedestrian move to their destination which is their respective target line. Once the pedestrians reached their target line , they will be destroyed using the Ped Dispose block. The Ped Area descriptor is used to control the pedestrians inside the area described in their respective pedestrian area descriptor.

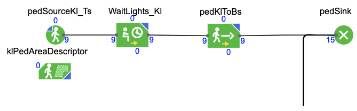

Figure 24: Simulation program - Pedestrian Logic

4.4.3 Trams

The trams are designed exactly the same way as the cars. But the only difference is in the source. The arrival timings of the tram was given in the Tram Schedule Database. This was indicated in the car source block of the trams.

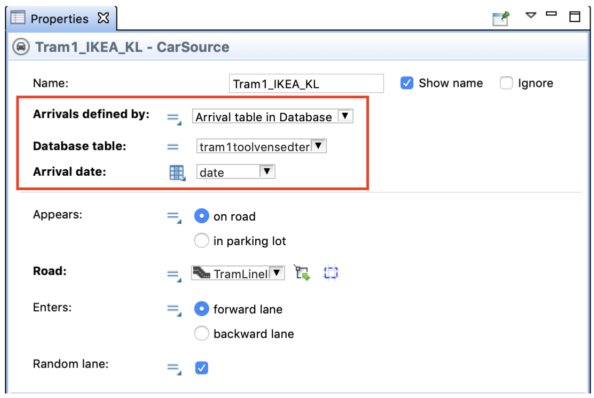

Figure 25: Car Source block modified for Tram Arrival

The following image represents the programming logic used for the Trams.

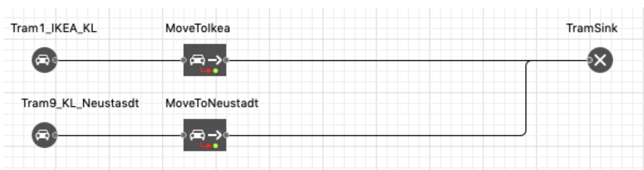

Figure 26: Simulation Program - Tram Logic

4.4.4 Traffic Signal Design

The traffic signal that resembles the real world was designed by considering various phases and the duration of each phase was calculated during the data collection. The traffic phases controlled the respective stop lines in that particular phase.

Figure 27: Traffic light design in Anylogic with respect to stop lines

4.4.5 Statistics

The statistics for the model was provided using the presentation and analysis tools in the Anylogic. The output variable such as the average mean time a car spent on the node, queue lengths of each street.

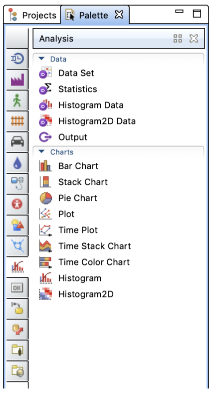

Figure 28: Analysis Library in Anylogic

So using the Bar charts and Histogram charts from the Analysis palette , the following output variables were presented as statistics.

- Current Queue Length
- Mean Queue Length
- Mean time spent by Cars on node
- Mean time spent by Trucks on node
- Throughput of the node
- Number of cars in the system at a given time

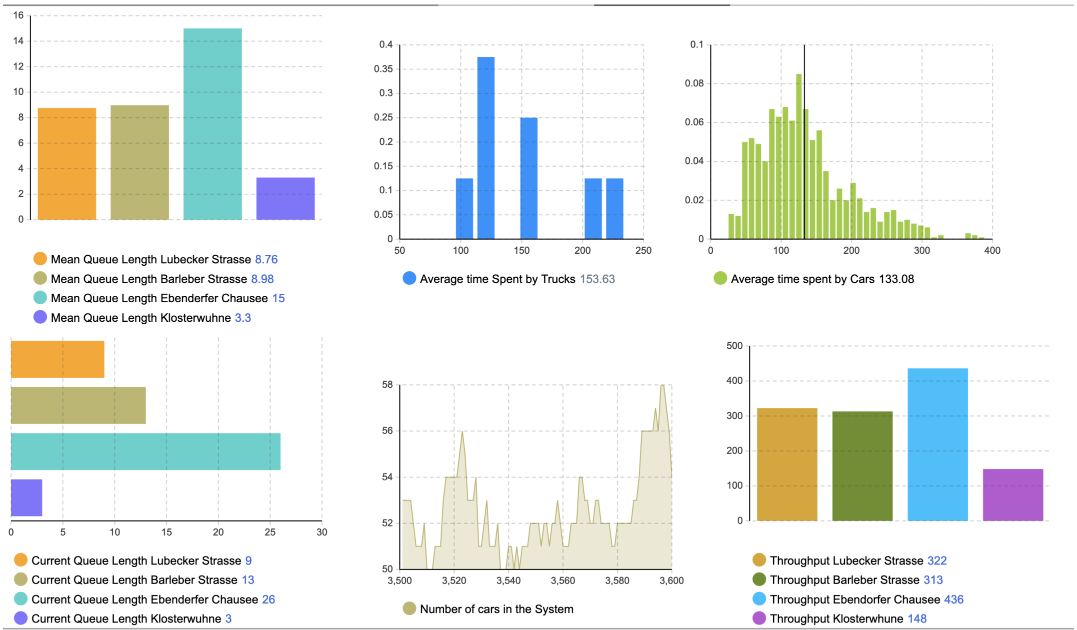

Figure 29: Display of various output variables

4.5 Special Issues

In Lübecker strasse there is a cycle lane in the middle of the lane. So while modelling to resemble this scenario the vehicles should not enter this middle lane. To make this happen, there was new road with two roads was added as in the real world and the traffic was directed in the proper lanes.

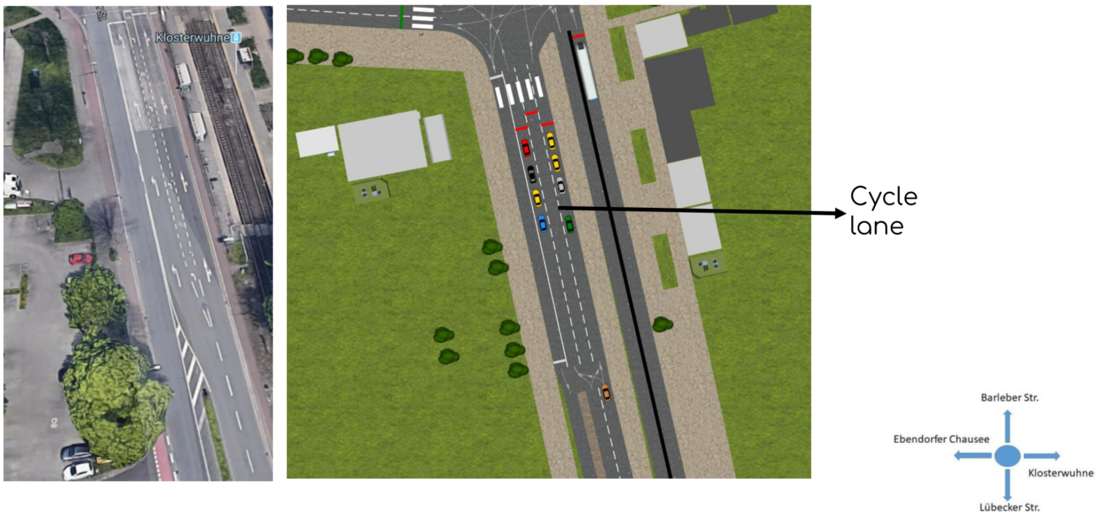

Figure 30: Picture 1 : Displays the cycle lane in real world. Picture 2 : The middle lane built in the simulated model

4.6 Verification

The model built was verified with the various scenarios such as the congestion in the middle of the intersections, traffic phase cycle, cars waiting for the pedestrians when they are crossing the road, arrival of the trams in the provided timings. These where the major parameters considered for the verification of the model. The verification makes sure that the system is built correctly.

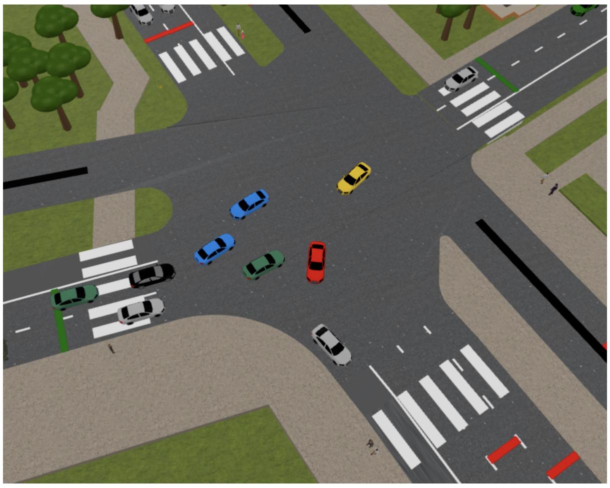

Figure 31: Congestion in the inner node which is similar to the real world

4.7 Difficulties encountered

- Synchronising the tram timings with the traffic phase cycle.
- Designing the phase cycle and calculating the phase.
- Modelling the pedestrians to walk.

The above mentioned issues were solved with a lot of effort. And these are considered to be the difficulties encountered during the modelling of the node.

4.8 Experiments Planned

- Removal of the bicycle lane on the Lübecker strasse
- Addition of a lane in Ebendorfer Chaussee
- Experimentation with the Traffic phase cycle.

All these above mentioned experiments can be implemented with the present real world model that has been developed with the Anylogic software.

5 Validation

Validation is the process of checking correctness of the model. To determine whether the simulation model is working as intended, Validation is required. Validation statistically proves whether the Simulation model is giving the results within the intended range of accuracy.

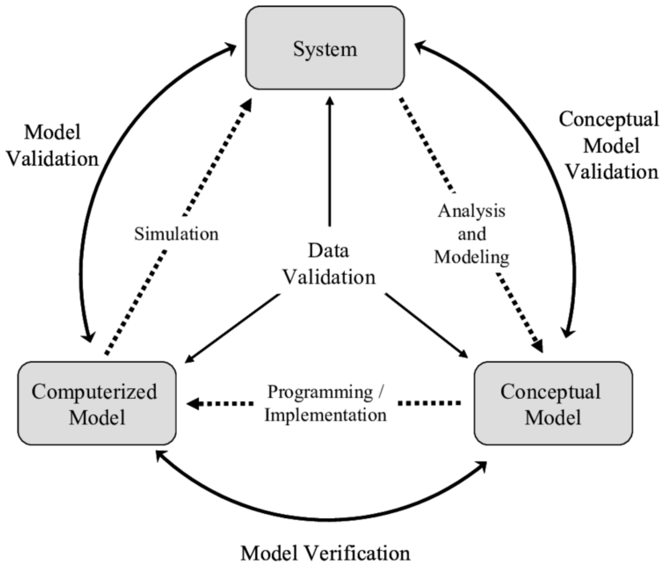

Figure 32: Validation Description

Ref:https://www.researchgate.net/publication/27523685

5.1 Verification

Simulation model is verified with the Conceptual model, then the behaviour of the Agents in the Simulation model is verified with the behaviour of the Vehicles in the real world. Verification is also done to check whether the simulation program works as intended and it is debugged.

5.2 Validation of Simulation Model

The main purpose of Validation is to check whether the simulation model is representing the real world model at least with respect to the variables of interest. This is done by comparing the results of the model with the data collected from the real world. Figure below describes the Verification and Validation process.

5.3 Quantities of interest

For validation, the Output variables considered are

- Queue Length- Number of cars accumulated in a street when the signal is 'Red'. For this we have considered the Number of Vehicles standing in a street just before the signal turns green.
- Time in Node- Time between arrival and departure of a car. For this we have calculated the time between the vehicle generated and the vehicle destroyed.

The following tables show the real world values that we have calculated for validation. For queue lengths we have collected number of vehicles accumulated for each red signal and we have computed the mean value of these queue lengths. For average time in node, we have considered a point on each street.We computed time between the car crossing that point and car leaving the node.

Street	Real world mean value
Lübecker Straße	8.21
Barleber Straße	8.29
Klosterwuhne Straße	3.32
Ebendorfer Chaussee	7.29

Table 9: Real world value for Queue lengths

Average time in node	81.36

Table 10: Real world value for Average time in node

5.4 Confidence intervals from simulation program

The model is run for 101 Replications for an hour of simulation time at a Confidence level of 90 percent (i.e., Alpha=0.05) and the confidence intervals (Lower and Upper bounds) for both the output variables are obtained for all the streets using Student t-distribution. The following tables show the confidence intervals for Queue lengths of all the streets and also for the Average time spent by a vehicle in the node.

Street	Lower bound	Upper bound
Lübecker Straße	4.09	7.08
Barleber Straße	5.73	8.35
Klosterwuhne Straße	2.96	3.43
Ebendorfer Chausse	7.79	11.07

Table 11: Confidence Intervals for Queue Lengths

Lower bound	Upper bound
79.11	89.22

Table 12: Confidence interval for Average time in node

The following Plots show the confidence intervals(Upper bounds, Lower bounds, Mean values)

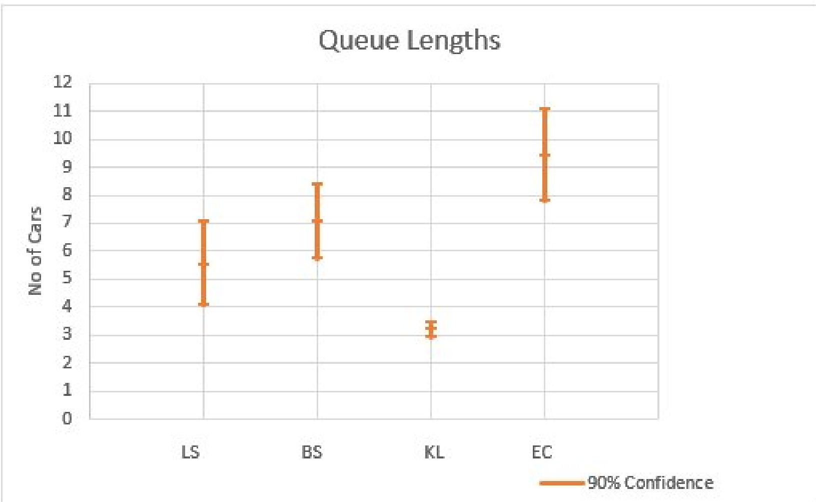

Figure 33: Confidence intervals for Queue lengths

5.5 Comparison between Real world data and Simulation program data

The results of the simulation model are then compared with the real world model. The real world value of the queue lengths are well with in the Confidence interval for two streets and for the other streets they are very close. For Average time in node the results are in acceptable range. The following plots compare the results of the simulation model and real world model.

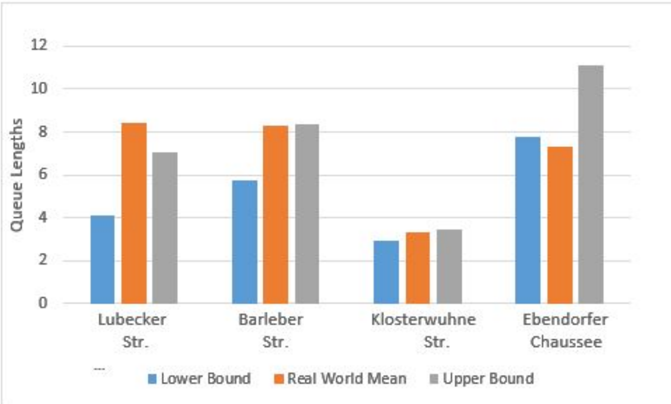

Figure 34: Comparison of real and simulation results(Queue lengths)

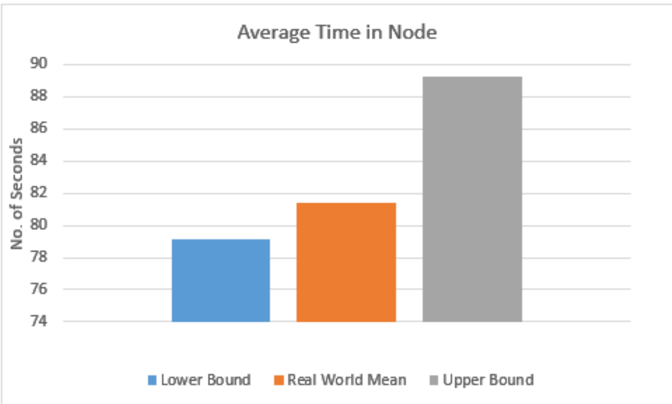

Figure 35: Comparison of real and simulation results(Avg. time in node)

5.5.1 Justification

After observing the simulation results, we came to know that for two , Lübecker Straße and Ebendorfer Chaussee, the values are not in the intended range. They are deviated from the confidence interval, but the deviations are not too much. These may be due the human errors while collecting the data or some other external factors. so, we ignored these deviations and considered our model to be validated.

5.5.2 Statement of Confidence

The results were obtained by 101 Replications in the simulation model with a confidence level of 90 Percent (Alpha = 0.1) and the results obtained are in the acceptable range. Hence, The model is said to be valid with respect to the output variables considered.

5.6 Conclusion

It is difficult to validate a model to be perfect. So, we have considered that our model is validated by ignoring small deviations. Now we can perform the Planned Experiments on this model and obtain the results.

6 Experiments

6.1 Aim of the Experiments

The main aim of the experiment was to "Improve the traffic safety of Ebendorfer Chaussee/ Klosterwuhne/ Barleber Straße Node". For the successful completion of the task, the milestone was divided into several sub-tasks. These are as follows:-

- Analysis of Accident Data.
- Finding the root causes.
- Formulating Experiments.
- Investigating the effect of the experiment on the node.
- Recommending the solutions.

6.2 Analysis of Accident Data

For initiating the experiments,Accident data for the year 2016, 2017 and the year 2018 was provided by "The city council of Magdeburg".

Our primary job was to find out the types of accidents that happened in the past 3 years and also investigate the possible causes.

Additionally, to understand the working of the node, several visits to the node was made.

6.3 Number of Accidents and their Types

In the past 3 years, 34 accidents have been recorded in the node. Below is the image depicting the total number of accidents and their location in the node.

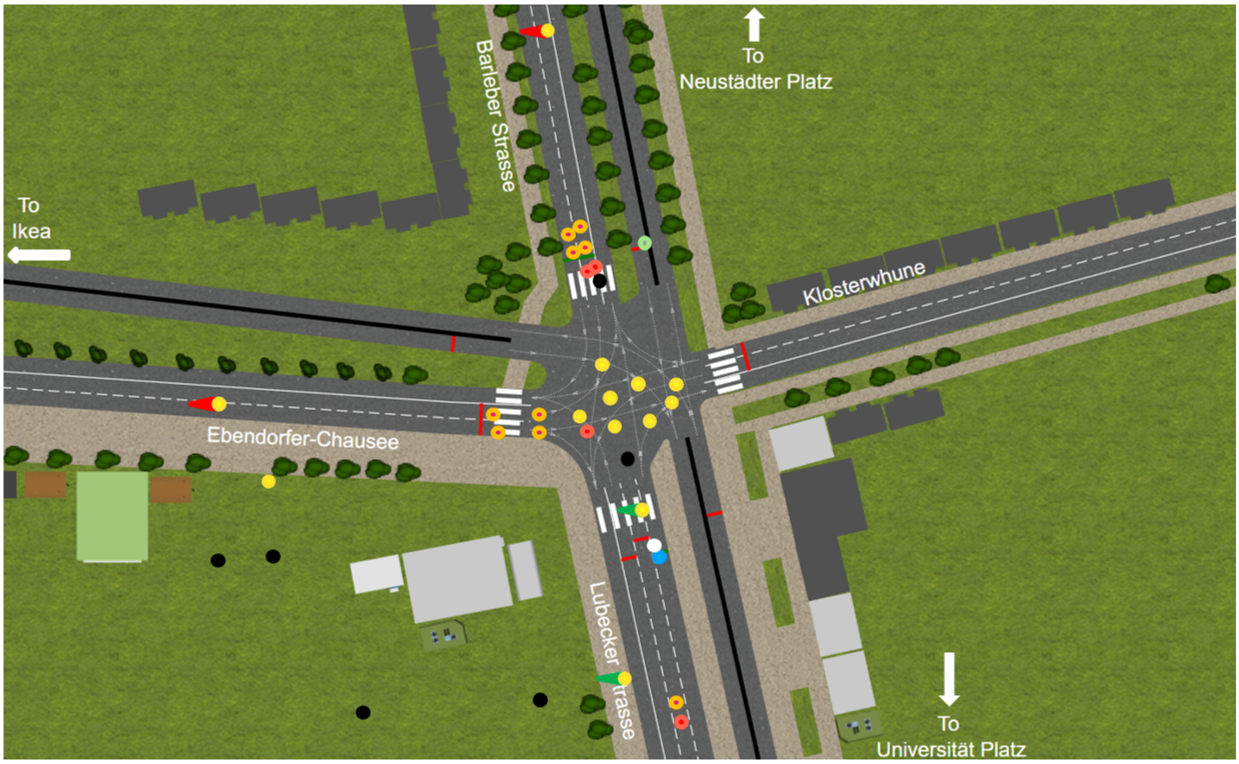

Figure 36: Accidents in the year 2016 to 2018

Figure 37: Accident Legends

According to the given data, the number of accidents and their types are mentioned below:-

S.NO	Types of Accidents	Accidents counts	Possible Causes			
			Cause 1	Cause 2	Cause 3	Cause 4
1	Turning Accidents	13	Insufficient safety Distance	Over Speeding	Turning Left	
2	Cross/ Bend in Accidents	4	Faulty Lane Change	Over speeding		
3	Longitudinal Accidents	10	Insufficient Safety Distance	Over speeding	Faulty Phase	Ped crossing
4	Driver Error	1	Alcohol Influence			
5	Other Accidents	6	Unknown			

Figure 38: Possible Causes

6.4 Scope of Experiment

Based on the given data, we found that some accidents have happened either in the nearby parking lot or gas station. Also, the reasons for some accidents have not been mentioned.

There has been an accident in which alcohol influence was found.

These sorts of accidents are uncertain and thus cannot come under the scope of our accident data. Thus out of 34 accidents, we are only able to consider 25 accidents.

6.5 Root Cause of the Accidents

Studying the accidental data, and with the observations made in the node, we found that two factors were the main contributors of the accidents. The factors are as follows:-

- Over Speeding
- Congestion in the Node

6.5.1 Over Speeding

As per our investigation, out of 25 accidents, over speeding can be held accountable for more than 10 accidents.

There have been accidents recorded between vehicles, pedestrians and bicyclists on Lübecker Straße, Barleber Straße and Ebendorfer Chaussee which could have been avoided if the vehicle could have stopped at the correct time.

Also, there have been accidents while changing the lane on Lübecker Straße. These kinds of accidents suggest that vehicle coming from behind did not have the time to stop in case of emergency. This leads to the assumption that vehicles were moving at elevated speed.

As per our observations from the node, we found that some vehicles tried to rush at yellow light at the end of the green phase compromising the safety of the node. In past there are many accidents recorded in the affinity of the centre of the node. These accidents may have been the result of over speeding.

6.5.2 Congestion in the Node

The Accident pattern suggests that most of the accidents in the node have happened due to a specific situation in which the vehicles have come closer than prescribed safety distance.

With our observation and the traffic phase provided, we found that vehicles from opposite lanes are allowed to move in the same phase. For example- Vehicles from Ebendorfer Chaussee and Klosterwuhne move in the same phase as shown in the given figure in phase 4.

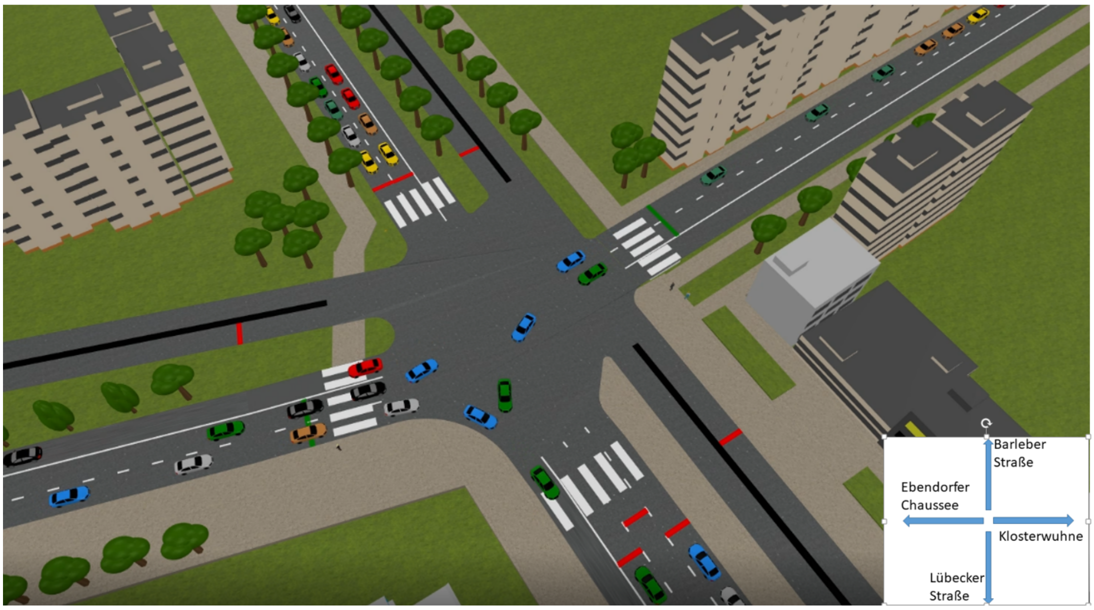

Figure 39: Congestion in the Node

This results in a chaotic situation in the node as shown in the above figure. In these sorts of condition, generally, the drivers depend upon the actions of the other driver. This may be confusing at times and thus may lead to an accident.

Similarly, there are many phases in which vehicles moving to the backward lane has to wait for the pedestrians who are crossing the street thus causing further congestion in the node. At the same time the vehicles from other streets are allowed to move due to starting of another phase and if they want to use the same backward lane as the former vehicles, this worsens the situation near the backward lane and hence affect the whole node.

We also observed that during phase 6 as shown chapter Data Analysis figure 5 , the vehicles on the innermost lane on the Lübecker Straße should not move as Tram 9 is moving from Neustadter Platz to Klosterwuhne and vice versa. Due to this vehicles cannot turn toward Klosterwuhne. But in actual the green light for the inner lane turns on and vehicles try to move towards Klosterwuhne in a rush before the tram starts moving. This is a disastrous situation and should be tackled as soon as possible.

6.6 Formulation of Experiments

The successful analysis of accident data leads us to the formulation of the experiments. But before framing of experiments, few points were kept into consideration. These are as follows:-

- The experiments performed should be feasible, logical and economical.
- The experiments should be designed such that they do not violate any traffic rules.
- The experiments should be able to eliminate the major causes of accidents. i.e., over speeding and congestion in the node.
- The experiment should also pave a way to reduce the average time in the node.

6.6.1 Experiment 1 - Speed Limit

Our atmost priority was to reduce the accident which was caused due to over speeding. To resolve the issue, we decided to apply the speed limit of 30Kmph on all the streets. This will allow the drivers to stop safely in case of an emergency. This will also prevent accidents that may be caused due to reduced traction between tires and road during winters or rainy condition.

For the implementation of the "Speed limit experiment" in the Anylogic, a stop line from the road traffic library was assigned to each street and in the property window, the speed limit was assigned as 30kmph.

Further, in the property option-Road sign of the main stop line of each street, it was made sure that the end of speed limit was checked.

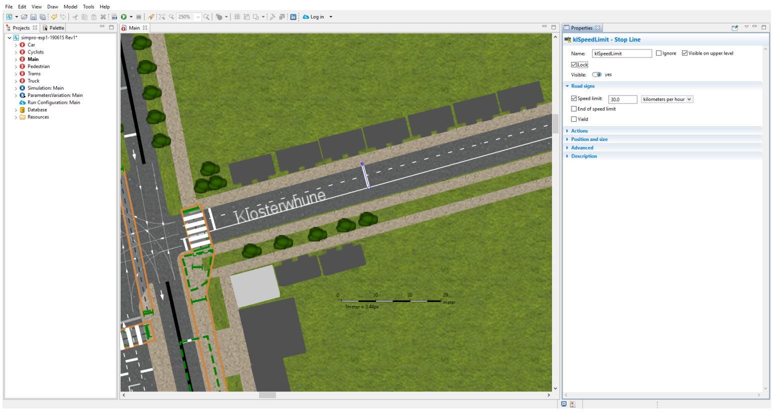

Figure 40: Applying Speed Limit

6.6.2 Experiment 2- Allowing the traffic flow from Klosterwuhne and Ebendorfer Chaussee at different phases

As earlier stated, allowing the vehicles to move from Klosterwuhne and Ebendorfer Chaussee creates a chaotic situation in the node. To solve this issue, we came up with a very simple idea that is to separate the phases for both the streets.

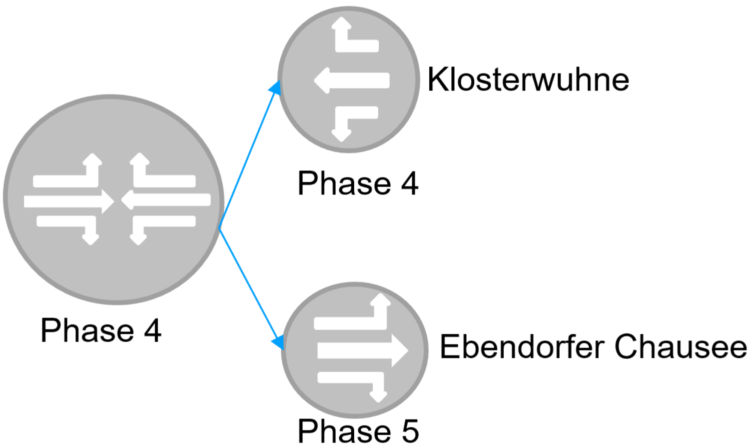

Figure 41: Separation of Phase

6.6.3 Experiment 3- Redesigning the whole traffic node

To eliminate the congestion in the node and increase the overall safety, we decided to rephrase the whole node. The main concept was to allow vehicles from only one street at a time. This will allow the smooth traffic flow in the node.

Further, if the backward lane is not being intersected by any vehicle that is going out of the street then the adjacent street can use it. For an example- In the figure, in phase 1 the vehicles from Lübecker Straße are allowed to move to remaining streets. In doing so, the backward lane in the Lübecker Straße is not being hindered and vehicles from Ebendorfer Chaussee can use it freely.

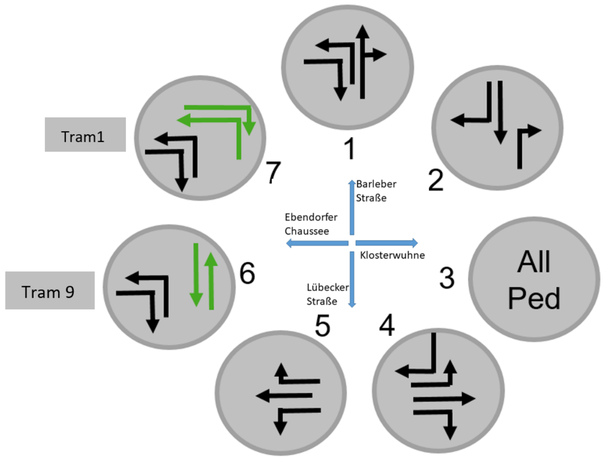

Figure 42: Redesigning New Phases

Also, to make the node safer for the pedestrians and bicyclists and to stop congestion, we assigned a phase only for the movement of pedestrians and no vehicles.

In the above figure, phase 6 is for the movement of Tram9 and phase 7 is for the movement of Tram1. The green marking signifies the movement of trams.

6.6.4 Experiment 4- Addition of Lane and implementation of new phases.

Our aim was to increase the safety of the node but at the same time, we also tried to reduce the average time in the node. We tried to do this by adding a forward lane in Ebendorfer Chaussee. For doing this, there is already a space available and is not being used by any structure. Once implemented the backward lane can be shifted more towards tram 1 line.

The new lane in Ebendorfer Chaussee will allow the drivers to select their lane more easily as inner lane will be directed to Lübecker Straße, the middle lane will be directed to Klosterwuhne and the 3rd lane will allow the vehicle to move to Barleber Straße. The backward lane will as it was working earlier.

Similarly, in the case of Lübecker Straße, a forward lane was added but the method of implementation was different than compared to the Ebendorfer Chaussee. In Lübecker Straße, a bicycle lane was present which was hardly being used by any riders. This bicycle lane measured 1.6meters of width. To create a new lane, additional 2 meters of the footpath was acquired. The addition of a new lane will help to reduce the queue length and similarly reduce the average time in the node.

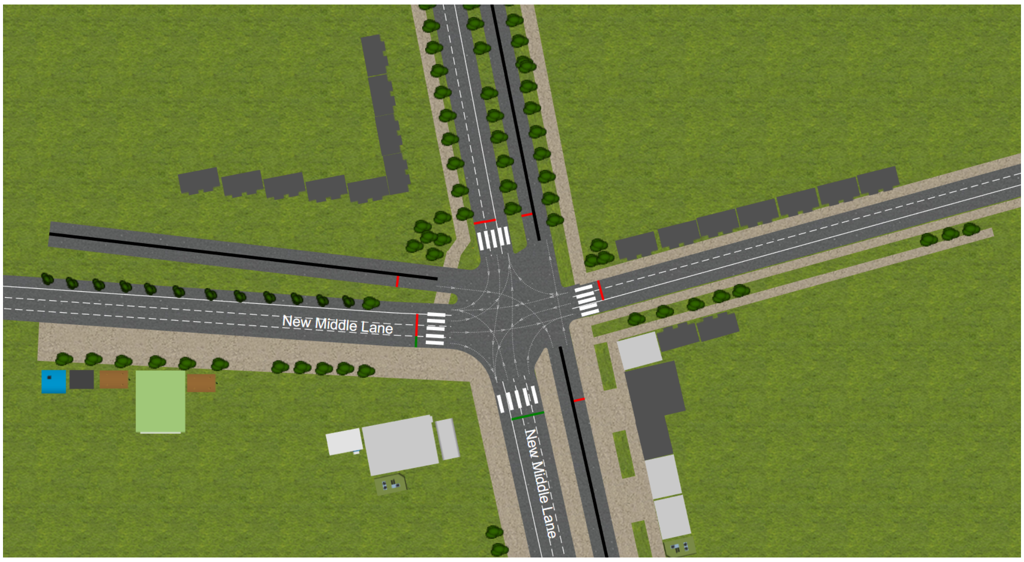

Figure 43: New Middle Lanes

6.6.5 Experiment 5- Addition of Speed limit in Experiment 4

To increase the safety of the node, we decided to eliminate the cases of over speeding and congestion form the node. For doing this we decided to mix experiment 1 with experiment 4. This will allow us to cover all the 25 accidents that were under the scope of the accident.

6.7 Results of Experiment

For the evaluation of results, we decided to consider "Average time spent by vehicles in the Node" as an output parameter. The experiments were also performed by considering a situation in which traffic load might increase due to some unavoidable conditions. To know how the node will behave, Traffic load was increased up to 30 percent of the current load in steps of 5 percent. To attain the increased 30 percent traffic load in the node, each street was subjected to increase its traffic condition by 5 percent in every step. The experiments were then compared with the data gathered from the Base validated model.

Moreover, in the case of experiment 2, 3, 4 and 5, phase timing was an important parameter as a random time can lead to misleading data. To avoid this condition, optimizing the phase timing became a crucial task. For doing this, all the respective experiments were first allowed to run for 101 replications with assumed phase timings. Then afterwards average time in the node was recorded for reference. Later each experiment was made to run for 500 iterations in the optimization experiment option and the average time in the node was recorded.

The parameters that needed to be optimized in the optimization experiment were the individual phase timings. Also, in addition to this, a constraint was applied which says that the sum of all the phase time in the node should be equal to 102 seconds. i.e.

$Ph1 + Ph2 + Ph3 + Ph4 + Ph5 + Ph6 + Ph7 = 102 seconds.$

For respective phase please refer to the image.

Once the optimized timings were attained for each experiment, the value of parameters like Ph1, Ph2, etc. was applied and then experiments were allowed to run for 101 replications.

6.7.1 Results of Experiment 1- Speed Limit

By introducing the speed limit in our node, the “Average time spent by cars in the node” increased. Talking about a particular condition of current traffic load, the difference in time is found to be 6.29 seconds. The increased time in the node can be called as a trade-off between safety and time.

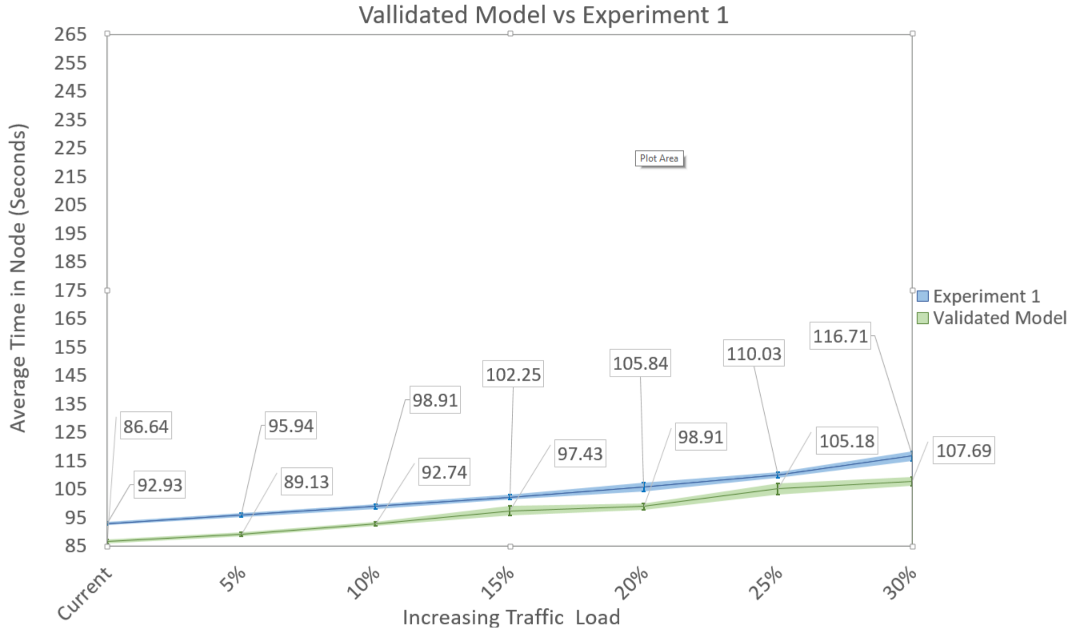

Figure 44: Experiment 1

6.7.2 Results of Experiment 2- Allowing the traffic flow from Klosterwuhne and Ebendorfer Chaussee in different phases

Separating the phase for Ebendorfer Chaussee and Klosterwuhne reduced the congestion in the node but increased the average time spent by vehicles by 5.25 seconds in case of normal traffic load. Although when compared with experiment 1, the difference appears to be small, but as the traffic loads increases, the average time in the node starts increasing more than that in the case of experiment 1.

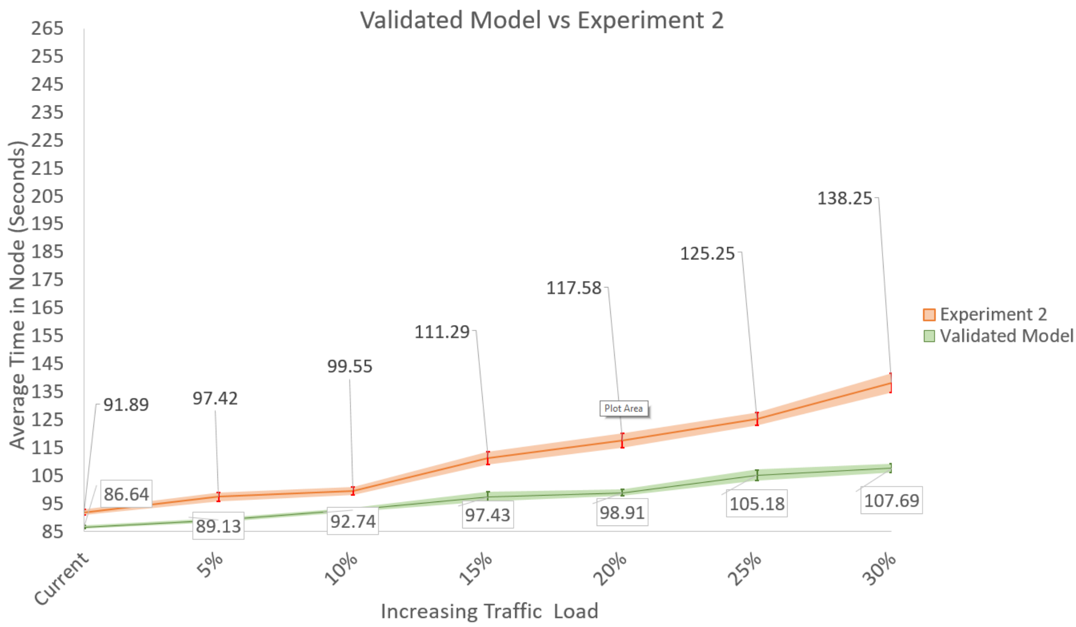

Figure 45: Experiment 2

6.7.3 Experiment 3- Redesigning the whole traffic node

Implementation of the redesigned phase led to a huge increase in "Average time spent in the node".

This suggests that, although it being safe, the experiment should not be implemented in the real world.

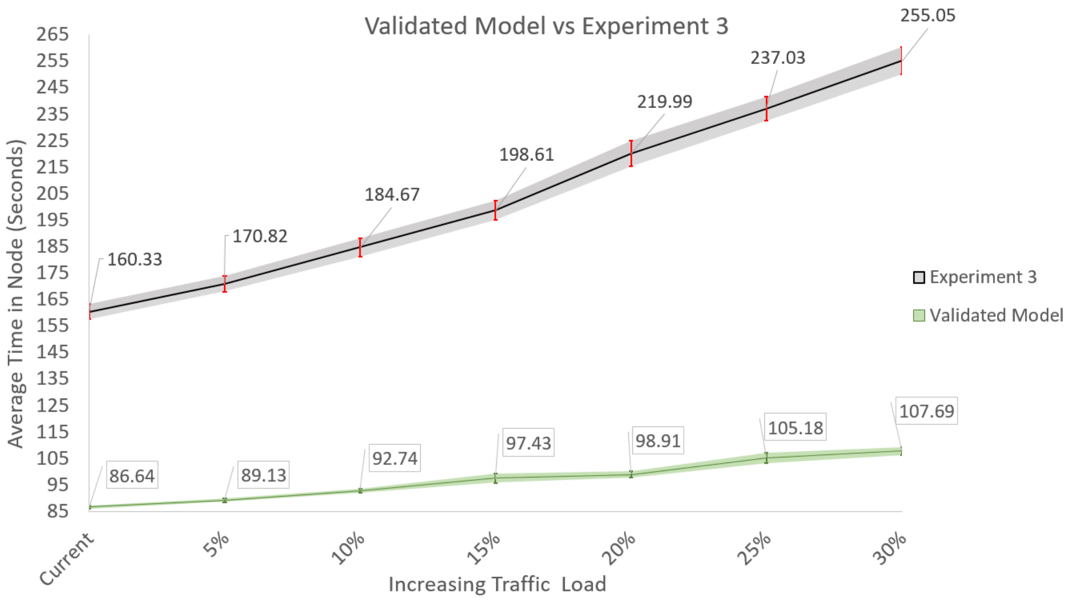

Figure 46: Experiment 3

6.7.4 Experiment 4- Addition of Lane and implementation of new phases.

The problem of increased "Average time in the node" can be handled by the implementation of new lanes on Lübecker Straße and Ebendorfer Chaussee. This experiments made sure that there is no congestion in the node and the vehicles move smoothly.

Moreover, the experiment also helped to make the node run much smoother and without any congestion. This gives us the confidence that the safety in the node will definitely increase if this experiment is implemented.

Figure 47: Experiment 4

6.7.5 Experiment 5- Addition of Speed limit in Experiment 4

Experiment 5 provides the maximum safety in the node but on the other hand, it also increases the average time spent on the node.

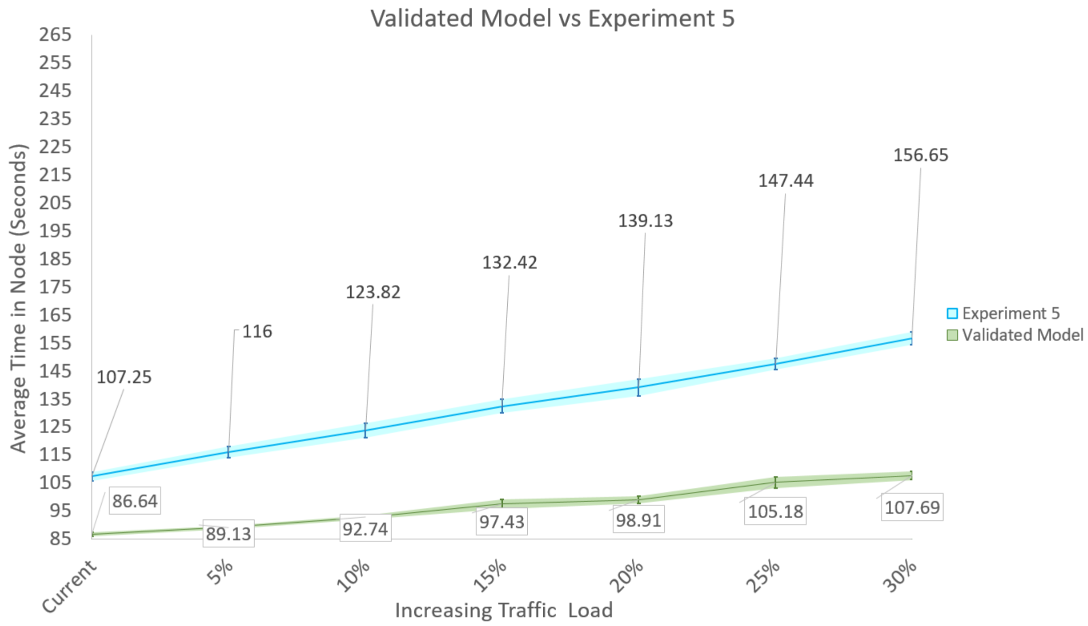

Figure 48: Experiment 5

6.8 Recommendations

The experiments were further compared to the base model to plot the confidence interval in terms of "Average time spent in the node".

For experiment 1 and 2, it cannot be clearly stated that either the experimental model was better or the Base Validated Model. In the case of experiment 3, 4 and 5, it was clear that the base model had better statistics in terms of average time. The aim of the project was to increase the safety of the node, hence better statistics only does not imply that the experiment was successful or unsuccessful. When we say that the Base model was better in terms of "Average time spent in the node", it has to be noted that the base model is although being much efficient, it is still prone to the accidents.

Moreover, the confidence interval that we are plotting will only help us to rank our experiments and not state the level of safety an experiment is providing. For the purpose of ranking the experiments, it was checked that which experiment is much closer to the positive Y-axis.

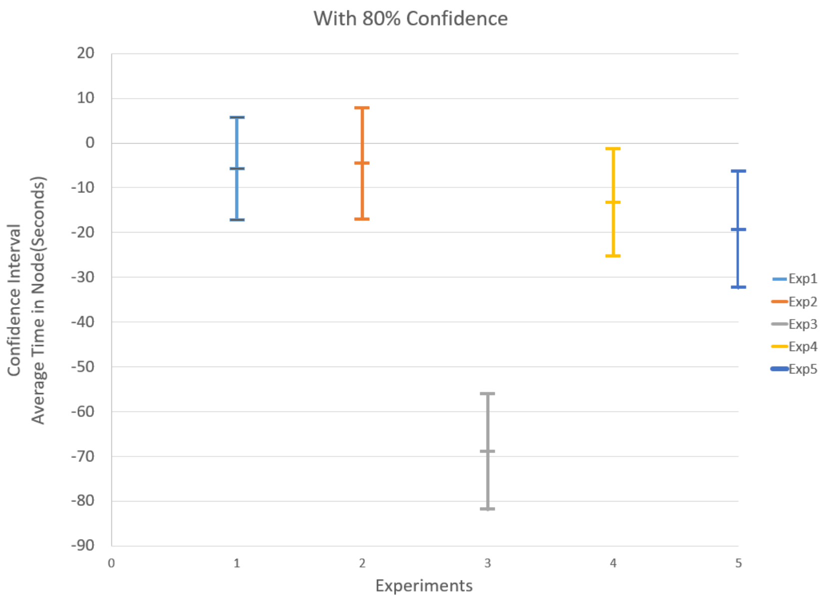

Figure 49: Comparing Experiments

Thus on the basis of the results, the recommended experiments are mentioned below in chronological order.

Experiment	Title	Feasibility	Economical	Safety
Experiment 1	Speed Limit	Very Easy	Very Economic	Safe
Experiment 2	Separation of Phase for EC and KL	Very Easy	Very Economic	Safe
Experiment 4	Implementation of new Lane with new Phases	Easy	Expensive	Safe
Experiment 5	Implementation of the speed limit in Experiment 4	Easy	Expensive	Safest

Figure 50: Recommendation

All the experiments performed will significantly increase the level of safety in the node but will result in increased time spent in the node. This increased time can be considered as a trade-off for safety. In case of experiment 5, although being the last on the recommendation list, it provides the maximum safety for the public as it is able to take care of both the root causes that are “Over speeding” and “Congestion in the node”.

6.9 Limitations of the Experiment

- As stated earlier, safety is a subjective issue and cannot be measured. Moreover, we are unable to model accidents hence we don’t know the uncertainties that can occur in the node.
- The node is tested for increased traffic load by up to 30 percent. In case the traffic increases more than 30 percent then the functioning of the node is unknown.
- As stated earlier , we were not able to cover 9 accidents due to unavailability of reasons or maybe the accident happened due to alcohol influence. These accidents may occur even if the recommendations are implemented.
- The experiments done are only to tackle the situation of Over Speeding and Congestion in the node. Influence of other factors like weather and darkness is not considered.

List of Figures

List of Tables

7 References

1. Matti Pursula "Simulation of Traffic Systems - An Overview" Journal of Geographic Information and Decision Analysis, vol.3, no.1, pp. 1-8, 1999

2. MarthaA.Centeno "ANINTRODUCTIONTOSIMULATIONMODELING" Toceedingsofthe1996WinteT/,imulationConfeTenceed.J.M.Cbarnes,D.J.Morrice,D.T.Brunner,and. J.Swain

3. AnyLogic Road Traffic Simulation Software https://www.anylogic.com/road-traffic/

4. Maps.google.com

5. Robert G. Sargent "VERIFICATION AND VALIDATION OF SIMULATION MODELS" Proceedings of the 2011 Winter Simulation Conference S. Jain, R.R. Creasey, J. Himmelspach, K.P. White, and M. Fu, eds.