OTTO-VON-GUERICKE UNIVERSITY MAGDEBURG
SIMULATION PROJECT 2022

Simulation Model for Improved Traffic Safety
Node: JERICHOWER PLATZ

Team: THE SIMULATORS

Authors:
Paul Gescher
Evelina Ignatova
Gracy Joseph
Nagar Rajat Bharatbhushan
Sricharan Koneru
Shaikh Rezwan
Harikrischnan Changaramkulath
Jayalaxmi Botsa
Maruf Hossain

Coach:
Pascal Krenckel
Department of Computer Science

Advisor:
Dr-ing. Claudia Krull
Department of Simulation and Graphics

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We thank our advisor Dr-ing. Claudia Krull and coach Pascal Krenckel for their guidance, constant supervision, and support as well as for providing necessary information and assistance in completion of this project. Their constant guidance, availability and willingness to share their vast knowledge made us understand this project and its manifestations in great depths and helped us to complete the assigned tasks on time.

We take this opportunity to thank the Faculty of Computer Science, Otto-von-Guericke University for providing opportunities like these for the students to attain experience from a real-life project.

Finally, an honourable mention goes to each of our team members for putting up with the calls, doubts at ungodly hours, and sticking together till the end with their brazened honesty, ideas and their unfaltering support on our project to improve in many ways.

Abstract

Simulation is an attempt to model and make changes to a real-life project on a computer involving large amount of resources. Evaluation and the behaviour of the system can be predicted by changing the variables. By developing a simulation model, the performance of the system over the course of time can be studied. Once the model is validated, any number of experiments can be investigated which is similar to a real-life scenario, in order to predict the performance and their impact.

In this project, we have simulated the traffic junction of Jerichower Platz. Our main goal was to increase the traffic safety of the junction. We have simulated 6 experiments to increase safety. The experiments were conducted after we validated the model and based on the results, recommendations to the City of Magdeburg have been made.

This report also contains some key features of the project in a time-sequence manner including Conceptual Model, Data Analysis, Simulation Model, Validation and Experiments. We have also included the lessons learned during each of our milestones.

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1 Introduction

For this project we were assigned to study and work on the node/intersection of Jerichower Straße/Herrenkrug Straße. The node connects the four roads - Jerichower Straße West, Jerichower Straße East, Herrenkrug Straße North and Herrenkrug Straße South. For reference, an image is attached.

Figure 1: *Jerichower Straße/Herrenkrug Straße*

This is a four way traffic junction consisting of, Jerichower Straße (West and East) with 3 entry lanes and 2 exit lanes, Herrenkrug Straße (North and South) with 2 entry and 2 exit lanes. There are also pedestrian crossings in all the four directions. There are tram lines on all the three directions other than on Jerichower Straße (East). Since Jerichower Straße is the main road to and from the city, high traffic is to be observed there, especially in the peak hours. We also observed some irregularities at certain traffic nodes like, possibilities of cars' collision when they are taking turns from Herrenkrug Straße (North). Our main goal is to propose changes which would improve the safety of the junction for all participants - vehicles, which includes cars, public transportation and big vehicles such as trucks, pedestrians and cyclists.

2 Milestone Journey

2.1 Milestone 1 - Team Formation

Our team 'The Simulators' is a 9 member group, consisting of members from different faculties, but working on the same goal. We assigned milestone roles for each group members, according to their skills and expertise. Each milestone comprises detailed explanations of how every member has worked upon it, by completing tasks and problems and documenting it with visual representations.

It is crucial to the team's success to set the right roles. For that, we determined each member's strengths and weaknesses, interests and abilities. Based on this, the role and the corresponding milestone was assigned to each member, as shown below. The person responsible for each milestone has to ensure that the task was achieved by the entire team.

Team Member	Responsibility	Corresponding milestone
Paul Gescher	Project Leader	All
Evelina Ignatova	Project Co-Leader	All
Maruf Hossain	Conceptual Model	Milestone 3 - Conceptual Model
Jayalaxmi Botsa	Conceptual Model	Milestone 3 - Conceptual Model
Gracy Joseph	Data Acquisition	Milestone 4 - Data Analysis
Nagar Rajat Bharatbhushan	Data Acquisition	Milestone 4 - Data Analysis
Sricharan Koneru	Chief Software Architect	Milestone 5 - Simulation Program
Shaikh Rezwan	Validation and Quality Control	Milestone 6 - Validation
Harikrishnan Changaramkulath	Experimental Design	Milestone 7 - Experiments

Figure 2: *Team formation*

2.1.1 Assessment criteria for team's performance

One critical aspect of effective teamwork is that all team members agree on what they expect from one another. Failure to reach an agreement on this before the project begins may result in problems later. We agreed on the following set of performance criteria in general for the team and in particular for the team leader in our case, valid also for the team co-leader.

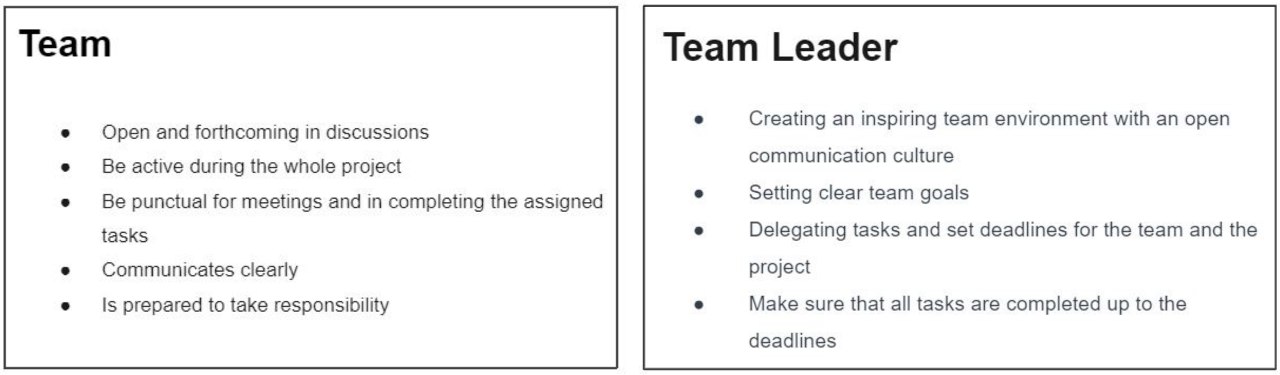

Figure 3: *Assessment criteria for team's performance*

2.1.2 Quality criteria for the project

Along with the assessment criteria for the team's performance, we have agreed on quality criteria for the project. Following them, it helped us till the end of the project to deliver success.

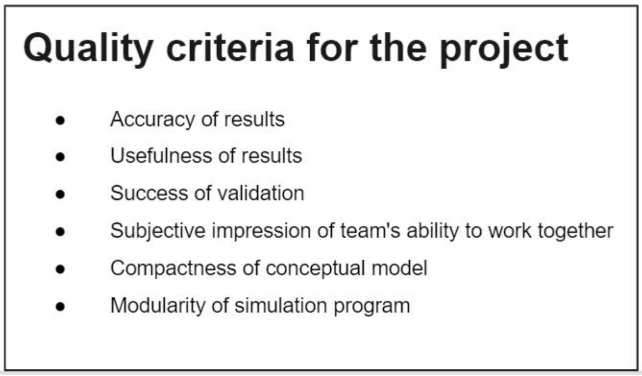

Figure 4: *Quality criteria for our project*

2.1.3 Team goal

Team goal prepare the team for a clear direction and plan-of-action for the project. It fosters opportunities for trust and collaboration. Team goals also contribute to professional development and the acquisition of new skills among team members. Setting team goals keeps communication open and ensures that everyone is on the same page. Our team committed to the following:

We are called '**The Simulators**' and our objective is to successfully complete the Simulation project by providing a better solution to the ongoing Traffic issues of Jerichower Platz. Our individual goals are to gain experience while working on a real-life project, establishing deadlines and sticking to them, tracking progress and supporting each and every team member from start to finish.

Our project goal is to understand the available data, suggest enhancements for the problems, suggest tools to stay productive, define milestones for each goals, schedule regular team reviews to keep everyone on track.

Each and every team member is focussed and committed to his/her role within the context of the shared goal, each of us have planned to formulate their own strategies for bettering themselves in a way that contributes to the overall success of the main goal leading to a final result which is efficient and accurate. Our team goal also includes providing structure and guidance to each member, attend to individuals' objectives along with attending scheduled meetings.

Date: 12 April, 2022

Signed by all Team Members

Evelina I. Maruf H. Gracy J. Sricharan K. Harikrishnan C. Paul G. Nagar Rajat B. Jayalaxmi B. Shaikh R.

Figure 5: *Signed team goal*

2.1.4 Lessons learned during the milestone preparation

From the preparing for milestone 1 and first time working together as a team for this project, we have learned the following:

- Communication is the key for the success of any project
- Planning the appropriate time for meeting to fit the deadline
- Understanding between the team members is helpful
- Making compromises

2.2 Milestone 2 - Project Planning

The second step was to plan our project, because project planning plays an essential role. It is needed to identify desired goals, reduce risks, avoid missed deadlines, and ultimately deliver the agreed product, service or result.

2.2.1 Project plan

Project plan always comes with project scheduling. On the image below is shown an example of our project plan on the basis of work packets. As we understood with the time, having and following a project plan is helpful on not missing deadlines, knowing what are our key tasks and keeping all members on the same page. Unfortunately even having the plan we had difficulties always to follow it, because of different circumstances we had to repeat some processes all over again, till we reach efficiency and that pushed back the entire process. After all ups and downs, we believe we reached our goal and completed our task on time.

Forming Team

Item	Assignee	Timeline	Estimated Cost
Assigning Roles	P GJ JB MH SR +2	Apr 5 - 6	900€
Assessment and project quality cri...	EI GJ P JB MH +2	Apr 5 - 6	900€
Photographs of current traffic situ...	EI P SR MH JB +2	Apr 7 - 8	900€
Decide and sign team goal	EI GJ JB MH SR +2	Apr 5 - 8	900€
Milestone presentation	P EI	Mar 8 - 10	600€
Meetings	EI P SR MH JB +2	Apr 5 - 11	2,700€
+ Add Item			
		Mar 8 - Apr 11	6,900€ sum

Project Plan

Item	Assignee	Timeline	Estimated Cost
Work Packets and their assignment	P SR JB GJ	Apr 12 - 13	1,800€
Estimation of the costs	P EI	Apr 14 - 15	600€
Creation of Diagrams	P EI	Apr 16 - 17	800€
Presentation Preparation	EI MH	Apr 17 - 19	900€
Meetings	EI GJ JB MH SR +2	Apr 12 - 19	3,600€
+ Add Item			
		Apr 12 - 19	7,700€ sum

Figure 6: *Example of project schedule*

In addition to the project schedule, we had another milestone schedule assigned by our supervisors before the start of the project. It helped us in combination with the project plan to be ready for presenting results of each milestone and seeing how far have we come.

Introduction and Project Assignment	KW14	0
Milestone 1: Team	KW15 05.04 - 11.04	6
Milestone 2: Project Plan	KW16 12.04 - 18.04	8
Milestone 3: Conceptual Model	KW17 19.04 - 25.04	22
Milestone 4: Data Analysis	KW18 26.04 - 02.05	29
Milestone 4: Data Analysis	KW19 03.05 - 09.05	37
Milestone 5: Simulation Program	KW20 10.05 - 16.05	47
Milestone 5: Simulation Program	KW21 17.05 - 23.05	58
Milestone 6: Validation	KW22 24.05 - 30.05	65
Milestone 6: Validation	KW23 31.05 - 06.06	70
Milestone 7: Experiments	KW24 07.06 - 13.06	75
Milestone 7: Experiments	KW25 14.06 - 20.06	87
Milestone 8: Final Report	KW26 21.06 - 27.06	100

Figure 7: *Project progress plan by milestone*

2.2.2 Budget estimation

Next part is the budget planning. One of the reasons for having a budget plan is that it serves as the foundation for project cost control. By comparing the actual cost of the project to the approved budget, we can determine whether the project is progressing as planned or if corrective action is required. This is accomplished by creating a cost baseline, which in our case is based on the milestones.

Milestone #	Milestone	Planned Costs
1	Team Formation	6.900 €
2	Project Plan	7.700 €
3	Conceptual Model	10.600 €
4	Data Analysis	20.000 €
5	Simulation Program	18.000 €
6	Validation	13.000 €
7	Experiments	14.000 €
8	Final Report	8.400 €

Figure 8: *Budget estimation on a milestone-by-milestone basis*

2.2.3 Lessons learned during the milestone preparation

- Planning for the meeting and taking responsibilities.
- Using the meeting time efficiently.
- Planning and not exceeding the budget if not necessary.
- Helping other members if necessary.

2.3 Milestone 3 - Conceptual Model

A conceptual model is the representation of a system with some assumptions and abstractions, made of a composition of concepts used to know, understand and simulate the real system, and it's behaviour. In this milestone, we created a conceptual model for the node **Jerichower Platz**. Although the real-world system has not been completely modelled, but a level of abstraction is maintained. This section elaborates on the assumptions made during the modelling process and the final quantities that were identified to be used as input & output parameters. The Stochastic Petri Net(SPN) modelling technique was used as it enabled us to build the model by idealization and simplification and also gave a clear representation of the system.

2.3.1 Assumptions

Following were the assumptions made while modelling the SPN:

- **Type of vehicles** : We presumed that every vehicle would be a car having the same length. The model does not contain emergency vehicles like ambulances and fire trucks.
- **Pedestrians** : The lane phases for bikes were assumed to be identical to those for pedestrians for the sake of simplicity.
- **U-turns** : While it is feasible for vehicles to do U-turns from any of the node's arms in the real-world, these cases are reported to be extremely rare, leading logically to the conclusion that they have little or no impact on the system. As a result, when modelling, these situations were not taken into account.
- **Modelled for the peak time of a regular day** : The system we modelled for the node Jerichower Platz is designed to mimic the peak time of a regular day, based on the fact that the performance of the node throughout the day is always better than or equal to that during its peak hours and also most of the assignments were noted to be around that period due to high congestion at the node.
- **Trams lines were ignored** : When observed in the real-time scenario, the tram lines have separate signals and does not hamper the vehicular traffic directly as the signals are taken care of when there is a tram arriving, hence to reduce the complexity of model we ignored the tram lines.
- **Same speed** : Chances of overtaking of vehicles are seen very negligible in the real-time scenario when we visited the node, hence all the vehicles maintain same speed

(no vehicle is faster than other), hence reducing the chances of overtaking and also with this the throughput measured would be uniform for all the vehicles.

2.3.2 Annotations

For the purpose of simplicity, we used some keywords to denote each node in the conceptual model:

- University : Jerichower Straße (West)
- Outside City : Jerichower Straße (East)
- Herrenkrug : Herrenkrug Straße (North)
- Cracau : Herrenkrug Straße (South)

2.3.3 Petri net

A separate chunk of the whole conceptual model i.e., the pedestrian model in the Petri net is shown below, where bidirectional behaviour (crossing from both sides) is adapted in the model.

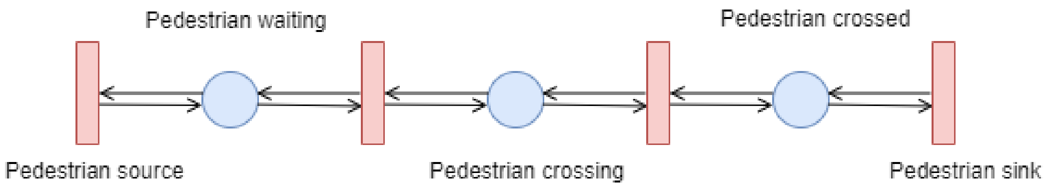

Figure 9: *Pedestrian Model*

The final conceptual model after adapting all the changes as per the later phases and making it consistent with the model built by the simulation program is shown below.

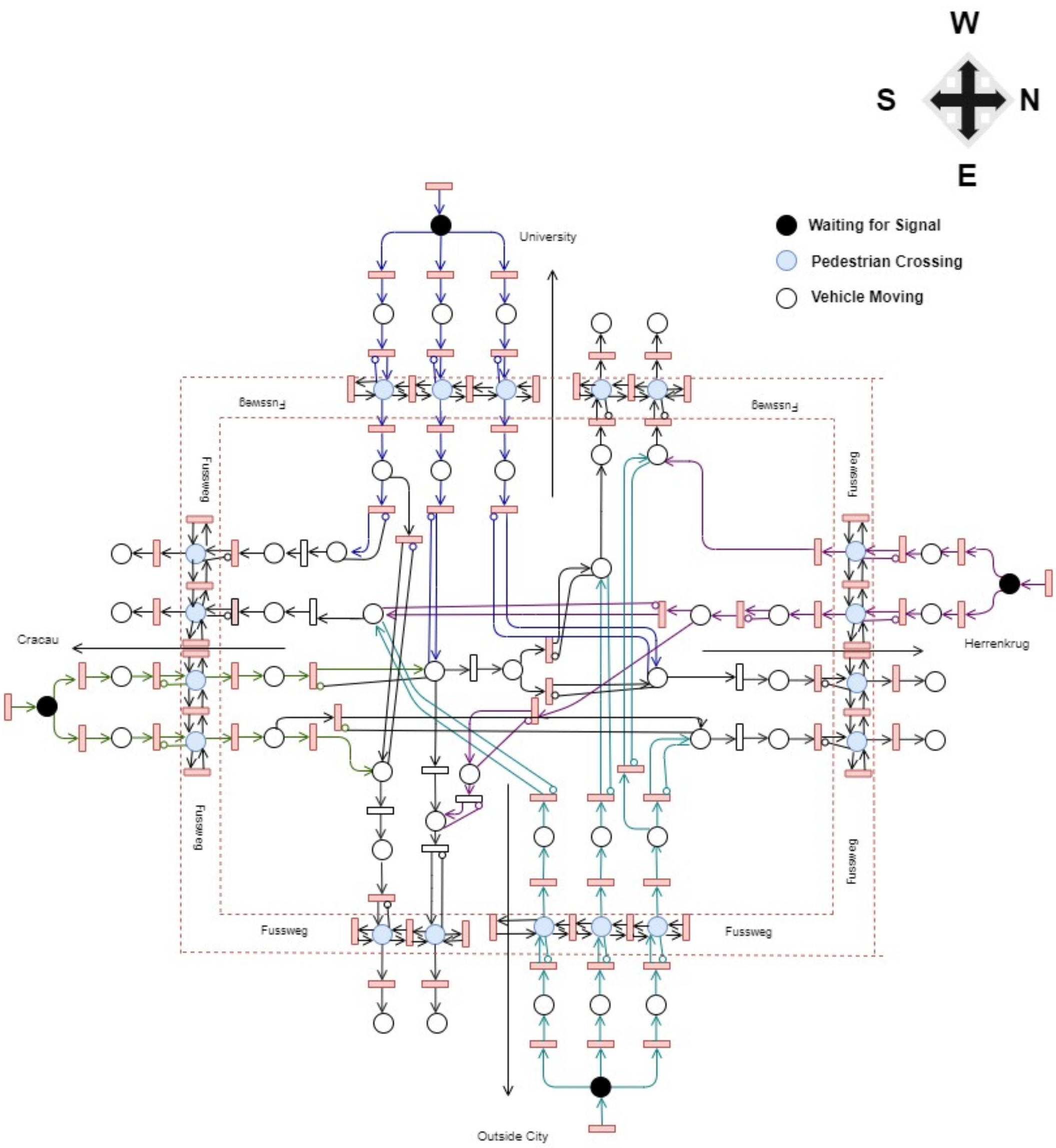

Figure 10: *Complete Conceptual Model*

2.3.4 Quantities to be measured

With the goal of improving the safety at the node, we identified quantities that would be required as input to the model and the ones that we intended to use as simulation results:

1. Input variables

- Inter-arrival times of vehicles
- Turn probability
- No. of vehicles entering & exiting each lane

- Traffic light phases, transition & duration
- Pedestrian count

Though we have collected the above mentioned quantities, all weren't utilized in the later phases due to some complexities and hurdles (e.g.: Adapting the observed traffic patterns in the simulation model made the model behave differently and causing some issues in the model behaviour.) in building the model and validating it.

2. Output variables

- Throughput
- Average queue length
- Total time taken by the vehicles in the system

2.3.5 Quantities to be used as simulation results

As results of our simulation, we decided to we use the variables **'Average queue length'**, **'Throughput'** and **'Total time for vehicles in the system'** as the values for these could be easily recorded in our simulation model and also collected from the real-world, thus enabling us to validate the model.

2.3.6 Experiments planned

As a part of this milestone, we also defined experiments we planned to implement in the later stages of the project. We realized that only on analysing the data would have a better understanding of the problems that may be affecting the node. Thus, at this stage, ideas for possible experiments that we could conduct were brainstormed. We decided that we would finalize the experiments to be implemented during the concerned stage of the project. The experiments agreed upon at this stage are listed below.

- **Separate Flyover for Cyclists/Pedestrians** - Observing the data about accidents, cyclists and pedestrians were most vulnerable with high probability for accidents, using a separate flyover for them could reduce the accidents to a considerably low level.
- **Basic Roundabout with a Tunnel** - Vehicle tunnels/underpass built in the University and East roads and Roundabout built in the intersection, thus relieving the intersection from traffic volume since most cars are going straight from University and East, and the Roundabout is better for lower traffic volumes.

- **Flyover for Vehicles in West-East direction** - Flyover for the main traffic direction of West to East as heavy traffic going straight over intersection, hence, to relieve the intersection of high traffic volume.
- **Road Widening in West direction towards University** - West direction(Outside city towards University road) widened into three lanes road as the density of traffic is observed to be very high here.
- **Roundabout at the intersection** - Roundabout is better for lower traffic volumes. Traffic lights can be avoided here. Right turning lanes reduce traffic congestion in the roundabouts in case of heavy traffic and accident reduction and pedestrian safety can be improved.
- **Improvising the signals** - As the traffic signals were very dynamic and complex, we thought of improving the signal patterns, hence, reducing the congestion and traffic at the node.

2.3.7 Events, types(events), distributions

- **Arrival of vehicles** at the intersection is considered as a primary event and since it behaves randomly, it is of Stochastic distribution type.
- **Signal state** is considered to be the primary event and since we have adapted the city office signal pattern, it is of Deterministic distribution type.
- **Bicycle (Pedestrians) crossing** is considered to be a Conditional event as they start crossing after the signal turns green for them, and it is of Stochastic distribution type because the pedestrians or cyclists arrival can be random.
- **Vehicles waiting** at the signal is a Conditional event as it is effected by the signals and is of stochastic distribution type as their arrival is random.

2.3.8 Changes adapted later....

- **Changed the Experiments** - Later on we changed some of the planned experiments.

2.3.9 Modified Experiments:

- Road Widening
- Left turning lane extension
- Tunnel or Underpass for Vehicles
- Vehicle Tunnel and Roundabout
- Pedestrian Tunnel and Roundabout
- Pedestrian Tunnel

2.3.10 Lessons learned during the milestone preparation

- Understanding that Conceptual model is the basis for further milestones.
- We must have a clear understanding of what we are going to do and how we are going to proceed forward.
- Changes to the conceptual model can be anytime in the project timeline and should be adapted accordingly with other milestones.
- Should be consistent with other parts of the project.
- Pool knowledge and skills with better teamwork would lead us to move further in the project successfully.

2.4 Milestone 4 - Data Analysis

The Magdeburg city officials provided us with the historical data that consisted of: vehicle density at each lane, power load plan, map with location of recent accidents, and vehicular traffic at different hours of the day for the year 2020 at Jerichower Platz.

We analysed this data and found that the maximum number of vehicles flow between 07:00 and 10:00 and between 16:00 and 18:00 which we then considered as peak hours in the Traffic count numeric document (in Quotes German Name, followed by a brief explanation). These two peak times were used by us for our Data Collection.

2.4.1 Collected Data

We performed data collection of the following variables for 2 hours on the same day, once from 07:00 to 08:00 and once from 16:00 to 17:00, which as previously explained, we considered as peak hours.

- inter-arrival time of the vehicles (cars/trucks/buses/motorcycles),
- pedestrian counts,
- accident-prone areas as focal points,
- queue length,
- estimated time in node, and
- throughput.

After collecting the above parameters, we realized there was data inconsistency, hence, we performed data collection again on a different day from 08:40 to 09:40. (All timings mentioned follow a 24-hour clock format). As per the privacy laws of the state, we respectfully took into consideration that none of the personal data of any person or vehicles will be collected accidentally or on purpose.

2.4.2 Input data measured

1. **Inter-arrival time of the vehicles** : The time between the arrivals of cars on each road, collected using a stopwatch app from our phones. We choose specific locations from where the inter-arrival times were measured.

2. **Pedestrians count** : The number of pedestrians crossing each arm of the intersection during an hour. Collected by one member and recorded on a sheet of paper. Below is the count of them according to each junction.

Pedestrian Count on each Junctions	
Junctions	Count in one hour
University (West)	28
Cracau (South)	17
Herrenkrug (North)	34
Outside City (East)	22

Table 1: *Pedestrian data collected between 07:00 and 08:00*

3. **Cars going at a Certain direction** : The number of cars that would take a certain turn coming from a certain direction. This was collected through simple counting and was used to calculate a turning probability for the cars on each road.

2.4.3 Output data measured

1. **Time taken through the node**

   The time it takes for a car to travel through the Intersection, measured using a stop-watch app. ,As the Intersection was very busy and large we decided to travel through the Intersection in a car ourselves and track the time it takes from entering to exiting at specific and previously defined locations.

2. **Throughput**

   We measured the total number of vehicles in the intersection. Throughput is indirectly calculated from the total number of inter-arrival time of the vehicle.

3. **Queue lengths**

   The length of the queue at a Red light. It was measured along each arm of the junction to a fixed point, through basic counting. The specific point considered was noted so that it could be used while measuring the queue lengths in our model. An average of the queue length is calculated on each arm, and the values are shown below in tables 2 and 3.

Cars at queue length distance		
Junctions	Left lane	Straight+Right
University (West)	6.902	6.75
Outside City (East)	1.6	14.58

Table 2: *Mean Queue length for University and Outside city lanes*

Cars at queue length distance	
Junctions	Lanes
Cracau (South)	2.10
Herrenkrug (North)	3.32

Table 3: *Mean Queue length for each lanes on Cracau and Herrenkrug*

4. **Accident prone areas as focal points**

   Areas that were observed to be problematic and more likely to cause accidents. Noted down on a map seen below, counted and graded according to severity.

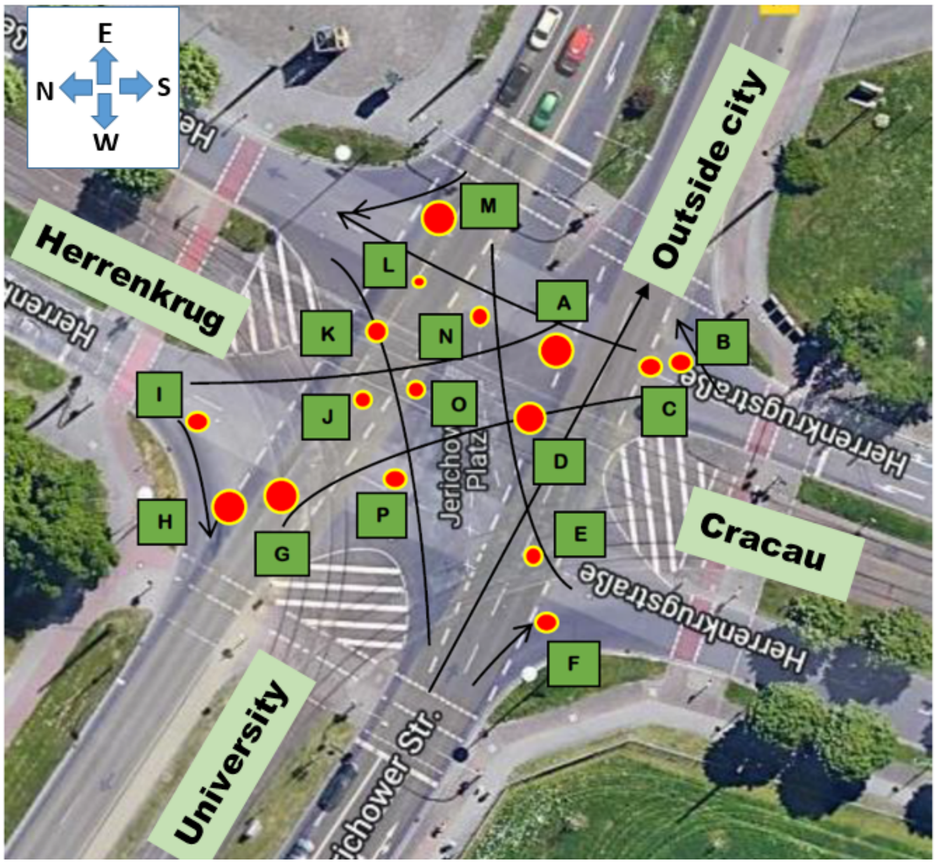

Figure 11: *Accident prone areas marked as focal points in red*

Severity of possible collisions according to the number of times the incidents are occurring shown in figure 12:

- Herrenkrug to University - H
- Cracau to University - D, G
- Herrenkrug to Outside city - A
- Outside city to Herrenkrug - M

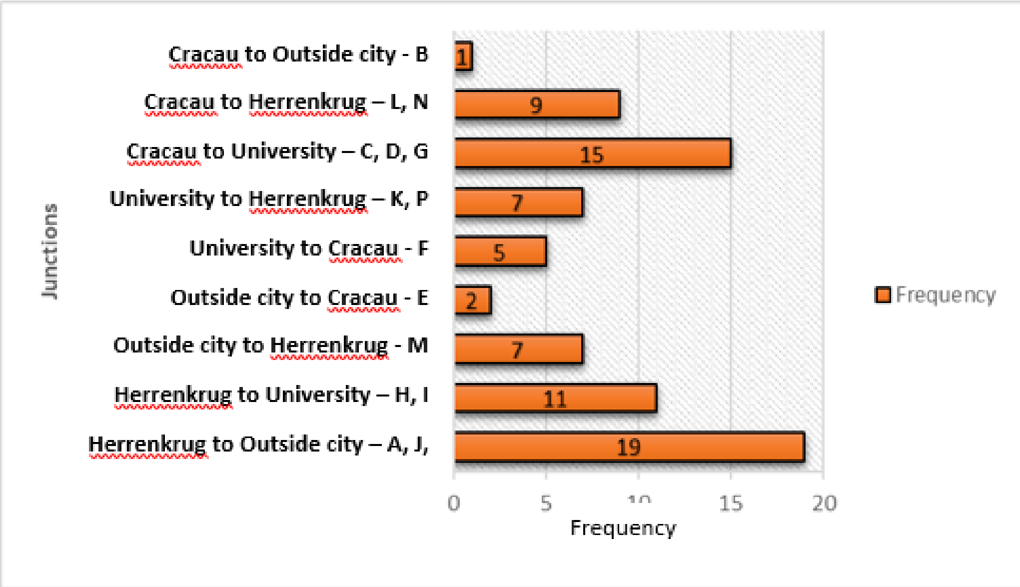

Figure 12: *Frequency data of collisions according to the directions*

The figure 12 shows the vehicles travelling from one arm to other with the red points shown in figure 11. These red points are called the focal points of that area. According to the statistics in figure 12, of vehicles travelling, from Herrenkrug to Outside city ranks among the most frequent side for a collision.

There were instances where, multiple signals of the junction turned green, increasing the probability of collision like Herrenkrug to Outside city, Herrenkrug to University and Cracau to University. There were times, when the vehicles coming from Cracau to University and vehicles coming from Herrenkrug to University were simultaneous.

2.4.4 Analysis of data collected

Part of the Data Analysis was to find distributions for the inter-arrival time of the vehicles. In our first attempt at Data Analysis, we manually created histograms to first guess a distribution, followed by QQ plots and a goodness of fit, Chi-Squared test.

Large volumes of data made the manual analysis a tedious process, so we switched to a data analysis tool called OriginPro. Although the approach followed by the tool was different, it was more efficient and accurate. After analysing the data using OriginPro we could find a distribution for only Cracau arm of the intersection yet, we failed to do so for the other arm of the intersection. This led us to look at the data more closely, and we were able to find that the vehicles approach the junction in a pattern, this pattern we labelled “Wave”.

The Waves:

1. **Wave pattern in the inter-arrival times:**

   While observing and trying to find the distributions of the data, we realized that the inter-arrival times of cars are affected by the signals which are outside the purview of the model. That is, the signals directly outside the intersection are influencing the flow of vehicles. A period in which a number of cars have a shorter inter-arrival time followed and led by a period of larger inter-arrival time is defined as a Wave. We took an average of the duration of each wave and assumed that each wave occurs for a specific duration. It is then followed by a longer inter-arrival time and this pattern repeats.

   Just as it's highs and lows in the patterns of flowing water, waves are the cycles of data analysis that extend in time and in our case its inter-arrival time for vehicles. We have decided to segregate the data into two different parts, considering the inter-arrival times less than a threshold as part one and higher range than the threshold as the other.

2. **How does waves affected our analysis:**

   Going forward with this approach, we could find a distribution type for each Road. We have estimated the distributions for 3 Roads except for Cracau, here we found distribution for the entire data without having to consider the Wave pattern.

Data Analysis using OriginPro: After feeding the data into OriginPro, the analysis is carried out as explained below,

1. **Generating a Histogram**
   Through OriginPro we could generate a Histogram and also curves for possible distributions which would help us better guess what distribution it could be. Figure 14, depicts the parameter values of the guessed distributions of the University Straße (For the group of shorter inter-arrival times).

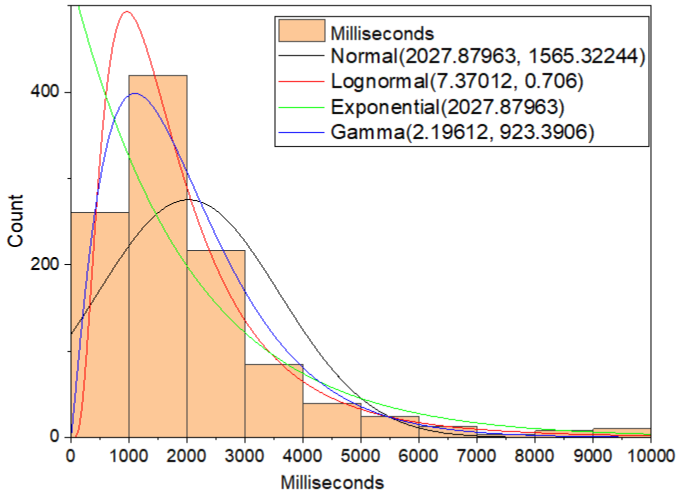

Figure 13: *University Straße (West) Histogram*

The parameter values are calculated for each guessed distribution. These values are used for comparison in PP-plots and Goodness of fit test. Below is an example of our findings on University arm (For the group of shorter inter-arrival times). Such estimation were produced for the rest of the roads.

Parameter Estimates

	Distribution	Parameter	Estimate	Lower 95%	Upper 95%
A	Normal	Location mu	2027.87963	1934.52411	2121.23515
		Scale sigma	1565.32244	1500.63868	1632.79433
	Lognormal	Location mu	7.37012	7.32802	7.41223
		Scale sigma	0.706	0.67683	0.73643
	Exponential	Mean theta	2027.87963	1910.47313	2152.50124
	Gamma	Shape alpha	2.19612	2.02975	2.37613
		Scale theta	923.3906	845.2126	1008.79967

Figure 14: *University Straße (West) Parameter estimation*

2. **Generating PP-Plots**

   A PP-plot (Probability-Probability or Percent-Percent or P value plot) is a probability plot used for assessing how closely two data sets agree. It plots cumulative distribution functions against each other, given two probability distributions. If the data sets belong to a same distribution, then the plotted points lie on a 45-degree line.

   The more popular QQ-plot, plots quantiles of two distributions against each other. PP-plots and QQ-plots are used to visually analyse the data sets, OriginPro employs PP-plot. Figure 15, is an image of PP-plot for the University-West road (For the group of shorter inter-arrival times).

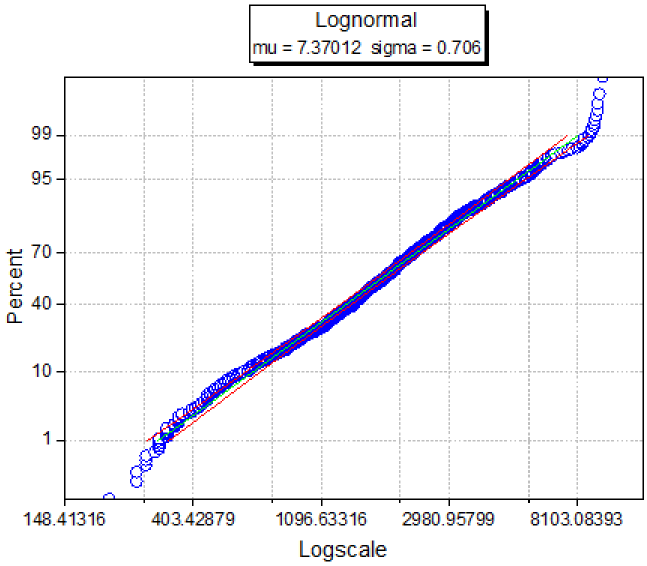

Figure 15: *University Straße (West) P-P Plot*

3. **Goodness of fit test using Kolmogorov–Smirnov test:**
   The Kolmogorov-Smirnov test (KS test) is a statistical test for the agreement of two probability distributions. With its help, random samples are used to check whether,

   - two random variables have an identical distribution or
   - a random variable follows a previously assumed probability distribution.

   An attractive feature of this test is that the distribution of the K-S test statistic itself does not depend on the underlying cumulative distribution function being tested. Figure 16, is an example for Goodness of fit test results, the results belong to the University Straße (West) (For the group of shorter inter-arrival times).

Goodness-of-Fit Tests

	Distribution	Goodness of Fit tests	Statistics	P-value	Decision at level(5%)
A	Normal	K-S test	0.14714	8.99122E-21	Reject Normal
		A-D test	51.94117	3.26169E-107	Reject Normal
	Lognormal	K-S test	0.03606	0.11988	Can't reject Lognormal
		A-D test	1.68747	2.50073E-4	Reject Lognormal
	Exponential	K-S test	0.16459	6.96838E-26	Reject Exponential
		A-D test	59.82835	0	Reject Exponential
	Gamma	K-S test	0.06024	7.77117E-4	Reject Gamma
		A-D test	5.49205	<0.005	Reject Gamma

Figure 16: *University Straße (West) Goodness-of-Fit Test*

Figure 17, depicts the end results of our data analysis. The table shown in the figure is read from left to right and the first distribution type encountered is for the group of shorter inter-arrival times on each arm of the intersection. It is then followed by the values of duration of the wave (Average Wavelength), the final distribution type is for the longer inter-arrival times.

Junctions	No. Of cars	Distribution	Parameters (mean, standard deviation, minimum value)	Average wavelength	Distribution	Parameters (mean, standard deviation, minimum value)
University	1070	Lognormal	7.37, 0.70, 210	51,792(ms)= 52 sec	Lognormal	9.95, 0.42, 10330
Outside city	947	Lognormal	7.35, 0.62, 260	25,000(ms)= 25 sec	Lognormal	8.79, 1.02, 660
Herrenkrug	350	Lognormal	7.84, 0.37, 160	33,776(ms)= 34 sec	Lognormal	9.93, 0.53, 7930

Figure 17: *Results of Data analysis for each Junctions*

Figure 18, depicts the results of data analysis of the Cracau arm. As there were very few cars and no signal nearby, the inter-arrival times follow a single distribution

Junctions	No. Of cars	Distribution	Parameters (mean, standard deviation, minimum value)
Cracau	96	Lognormal	9.97, 1.111, 2110

Figure 18: *Results of Data analysis for Cracau*

2.4.5 Limitation on validity and accuracy of data

- Limited accuracy for the vehicles due to limited data collection.
- Limited accuracy for the pedestrians due to small sample size.
- Different vehicles were considered same, i.e. bicycles, motorcycles, car, truck, other motor vehicles travelling through the intersection
- Manual data collection is prone to human errors, for instance line of sight, mis-click, miscount etc.

2.4.6 Challenges in data collection

- A best fit distribution type for the inter-arrival times is not found initially. We had to analyse the data further to find the issues.
- Peak hour traffic load created inconsistencies in data collection. During peak hours there were too many vehicles at the intersection, making the vehicles waiting in the queue stretch beyond the data collection location. This affected the collection of inter-arrival times.

- Presence of signals on certain arms of the road before the junction made the data collection process much restricted.
- Insufficient expertise in data collection, analysis and usage of data collection tools lead us to collect data multiple times.
- Data cleaning/preparing data for analysis was difficult due to huge traffic volumes on certain arms of the intersection.

2.4.7 Lessons learned during the milestone preparation

- The complexity of the data and the data collection should be considered earlier. Focusing on the goal from the beginning would help on strategized collecting information.
- Along with that the importance of retrieving and organizing data should be kept in mind.
- While doing the data analysis we realized that the occurred pressure resulted in more teamwork.
- Being able to look at various pieces of data, ability to think analytically, approach problems and draw a conclusion is probably the most valuable skill which we all learnt throughout this milestone.

2.5 Milestone 5 - Simulation Program

The objective of this milestone, is to create a simulation model that mimics Jerichower platz intersection as close as possible. To create the model Anylogic Simulation Software (Personal Learning Edition Version : 8.7.11) is used. The following libraries of Anylogic were employed in building the model,

- Pedestrian Library
- Road Traffic Library
- Process Modelling Library
- Agent Library
- Analysis Library

2.5.1 Concept & Structure

The model is structured based on the following abstractions,

- **Simplification:**
  All the vehicles travelling through the intersection are considered as cars with uniform dimensions and they travel with identical speeds, braking capacity. Bicyclists do not ride on the roads, they use pedestrian footpaths and hence they are modelled as pedestrians. All vehicles in the model obey the road traffic rules.
- **Idealisation:**
  Vehicles on the arms of University, Herrenkrug, Outside City come in waves as explained in the input data analysis chapter. So custom functions are built to draw the inter-arrival times of vehicles on these arms.

The model design was modularized into two parts,

- Modelling Vehicles
- Modelling Pedestrians

2.5.2 Model designing

1. **Modelling Vehicles**

   The design began from the construction of road network over a scaled image of map taken from Google Earth. Space markup elements of the Road Traffic Library were used to sketch the roads and form the intersection. The number of lanes on each arm of the intersection is same as that of real-world. Lane Connectors are used to control the permissible directions the vehicles can take at the end of each arm in the intersection.

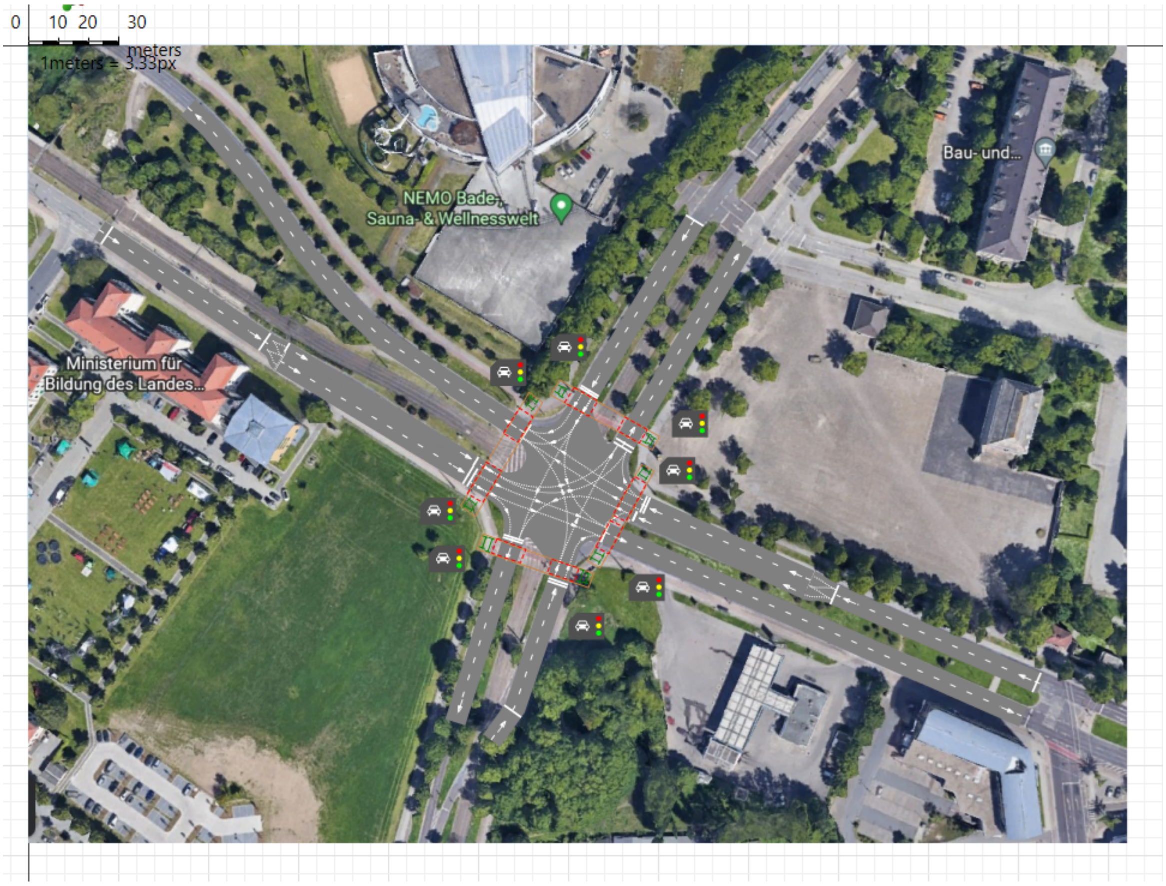

Figure 19: *Graphical representation of Jerichower platz*

The second step involved creation of vehicular traffic. A custom agent of ”Car Type” was created to represent all the vehicles in the intersection. The control flow of the vehicles is designed using the elements of ’Blocks’ in the Road Traffic Library. ”Car-Source” element is used to create vehicles of custom agent type and place them at the beginning of each forward lane. ”CarMoveTo” elements are used to move the cars from one arm of the intersection to the other. Vehicles (Agents) are destroyed using ”CarSink” once they travel to the end of road network. ”SelectOutput5” block is used to route the incoming Vehicles (Agents) to take a specific direction depending on the probabilities calculated in the Input data analysis.

The final step involved creation of traffic signals and custom functions for inter-arrival times of the vehicles. Signal Pattern 4 (VA-Einwärts_Früh) provided by the city office is used to model the traffic signals. To induce wave-effect of the incoming traffic on each arm of the road except for Cracau arm, individual ”Functions” are defined.

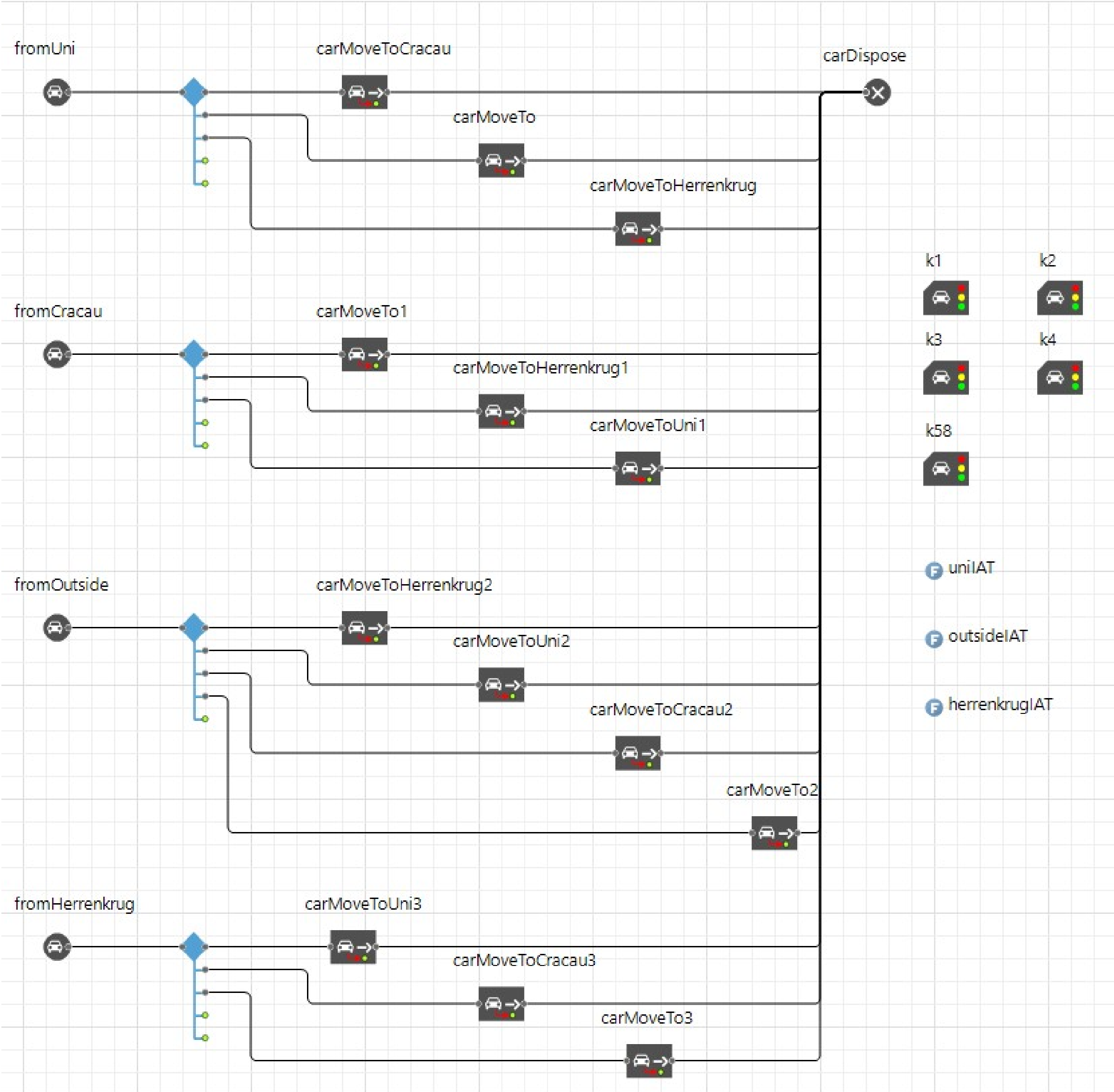

Figure 20: *Control Flow logic of Vehicles*

2. **Modelling Pedestrians**

Space Markup elements of the Pedestrians library are used to define the areas of movement for pedestrians in the road network. A custom agent was created for pedestrians and ”PedSource” is used to generate pedestrians. ”PedGoTo” is used to move the pedestrians to specific locations(Target lines). Once pedestrians reach their destination points, they are destroyed using ”PedSink”. Pedestrian crossing is a two-way crossing. Pedestrians (Agents) are created at a predefined rate as shown in the input data analysis chapter. Separate signals are used to control the pedestrian crossing. The pattern for these signals is adapted from Signal Pattern 4 (VA-Einwärts_Früh) provided by the city office.

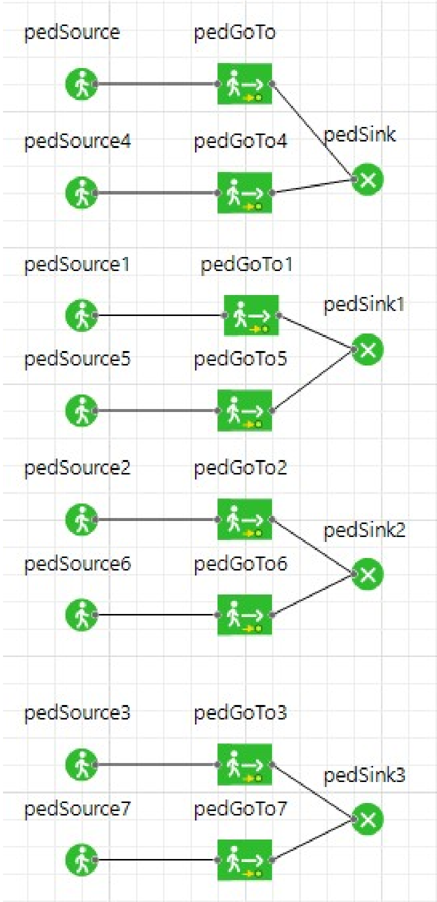

Figure 21: *Control Flow logic of Pedestrians*

2.5.3 Model peculiarities

The simulation model has the following differences to the real-world road layout,

1. **Intersection on University and Outside City Roads**
   Both the University and Outside City arms of Jerichower platz split into three lane roads from two lane roads. The functionality to fork the roads is not available in AnyLogic, hence the arms were constructed as two different roads which led to creation of an intersection.

2. **Construction of three lane roads**
   The University and Outside City arms of the intersection have two different sets of traffic signals each. This behaviour could not be modelled with single traffic signal

node in AnyLogic, so the three lane road is constructed as a two lane road and a one lane road with separate signals.

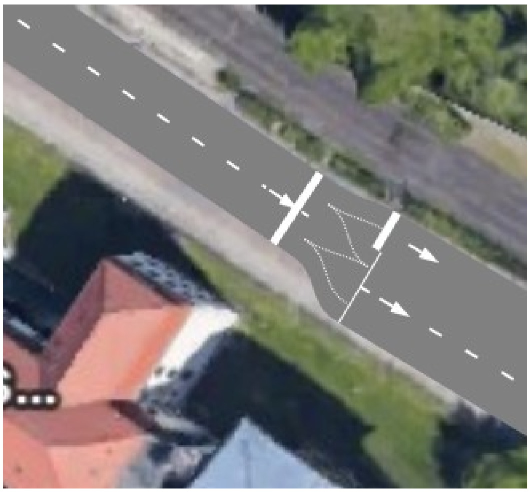

Figure 22: *Splitting of two lanes to three on University Road*

2.5.4 Differences to the conceptual model

The simulation model had the following differences to the conceptual model,

- Traffic signals for pedestrians were not included in the conceptual model. This was because pedestrians were not considered part of the system in the initial conceptual model design.
- The conceptual model had one lane for each direction the vehicles can travel. On the contrary, lanes in the simulation model are constructed to mimic the real-world road layout and Vehicles (Agents) lane change behaviour was controlled by AnyLogic implicitly.

These differences are only seen as limitations of the conceptual model and they do not adversely effect the simulation model.

2.5.5 Steps taken to verify the program

After the creation of the simulation model, below steps were taken to verify the model

1. The model was peer reviewed to find semantic errors.
2. A comparison with conceptual model was performed, to ensure that the simulation model did not deviate from the conceptual model.
3. Face validated traffic signal phases, movement of pedestrians, inter-arrival times of vehicles and pedestrians.

2.5.6 Special issues

The following issues were faced during the design of simulation model,

1. Dynamic behaviour of the traffic signals could not be modelled. As, a work around a static signal pattern provided by the city office was chosen. Out of the various patterns provided, Signal Pattern 4 ”VA-Einwärts_Früh” was selected because the input data was collected in the early hours of the day.

2. Integrating Pedestrian and Road Traffic Libraries caused run-time errors (Vehicles running over Pedestrians). An additional stop line was introduced which stopped the vehicles until pedestrians crossed the road.

2.5.7 Lessons learned during the milestone preparation

- Learnt about the industry specific libraries (Road Traffic Library, Pedestrian Library) of AnyLogic Simulation Software.
- We understood that modularized development of software models/programs is difficult without version control tools (like Git)
- Had a glimpse of how complex and dynamic traffic signal patterns at intersections can be.
- Came across different traffic rules and understood their importance.

2.6 Milestone 6 - Validation

2.6.1 Verification

The simulation model was verified to check if we built the model right. For this, we compared the behaviour of the agents in the simulation program with the behaviour of the corresponding entities in the conceptual model, along with the assumptions made, and found no inconsistencies, which shows that the model mimics the real-world as closely as possible. Hence, we concluded that our model was verified.

2.6.2 Validation

The process of validation is essential in determining whether the correct simulation model was built. This action authenticates whether the model built gives satisfactory results within a predetermined range of accuracy by making a comparison between the simulation results and the output data of the real-world system, for a stated input from the real-world. To prove that we built the right model, we performed validation experiments with our collected input data from the real-world, and then compared the model outputs with our own collected outputs from the road junction, to inspect the model's validity.

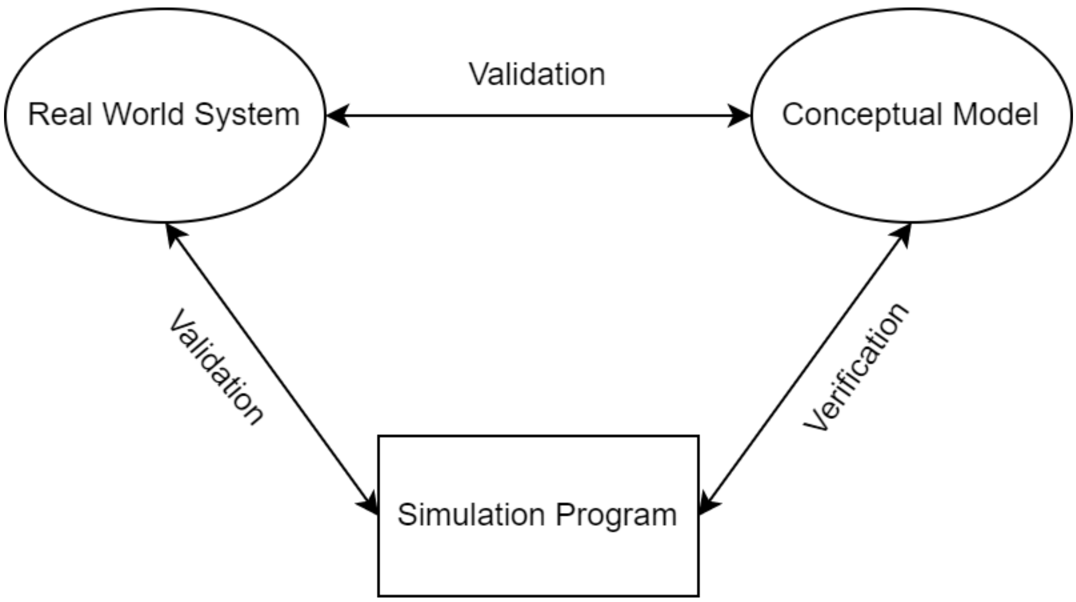

Figure 23: *Comparison Cycle of Validation and Verification*

2.6.3 Quantities of interest

The following output variables were considered to evaluate the validity of our simulation model in comparison to the real-world:

1. **Queue Length -** The number of cars accumulated in a street for the duration of the traffic signal staying "RED" for each cycle. We measured this by counting the number of cars gathering in a queue in the lane whenever the signal turns red and then noting down the total count of cars waiting in line just when it turns green.
2. **Time Taken through Node -** The total time spent by a car in the model from the source to the sink. We measured this by driving through the node a few times and recording the time it takes for each drive through the roads with respect to the source and sink points of the simulation model.
3. **Throughput -** The total number of cars that crossed through each road for a certain span of time, e.g. 1 hour. We collected this data during the data analysis phase, by counting the total number of cars for each road for an hour.

2.6.4 Confidence Interval of validation results

We ran the simulation for 25 replications for an hour of simulation time with a confidence level of 95%, that is alpha = 0.05. Hence, we found the upper and lower confidence intervals for each output variable for every street.

We then checked to see if the mean values of the real-world measured variables lie within these confidence intervals obtained from the simulated model. If the real-world's mean data would lie within, it would be a success, otherwise, we would have to figure out why they do not fit, and maybe make alterations to the model.

2.6.5 Comparison of real-world and simulated data

From the validation experiments we conducted, it is observed that the real-world mean values are somewhat comparable to the simulation confidence intervals, but most of them do not fall within these limits. The following tables and visualizations portray our findings:

Queue Length	Lower Bound	Upper Bound	Real-World Mean
Uni S & R	14,128	14,584	12,262
Uni L	5,622	6,342	13,476
Outside S & R	15,944	16,174	16,024
Outside L	0,445	0,569	1,600
Cracau	1,818	2,043	2,105
Herrenkrug	11,959	11,959	3,325

Table 4: *Upper and Lower bound of the confidence intervals and real-world mean of Queue Lengths for individual streets, measured in the number of vehicles*

Here, Uni S & R denotes University Road - Straight and Right. Uni L denotes University Road - Left.

Outside S & R denotes Road from Outside the city - Straight and Right. Outside L denotes Road from Outside the city - Left.

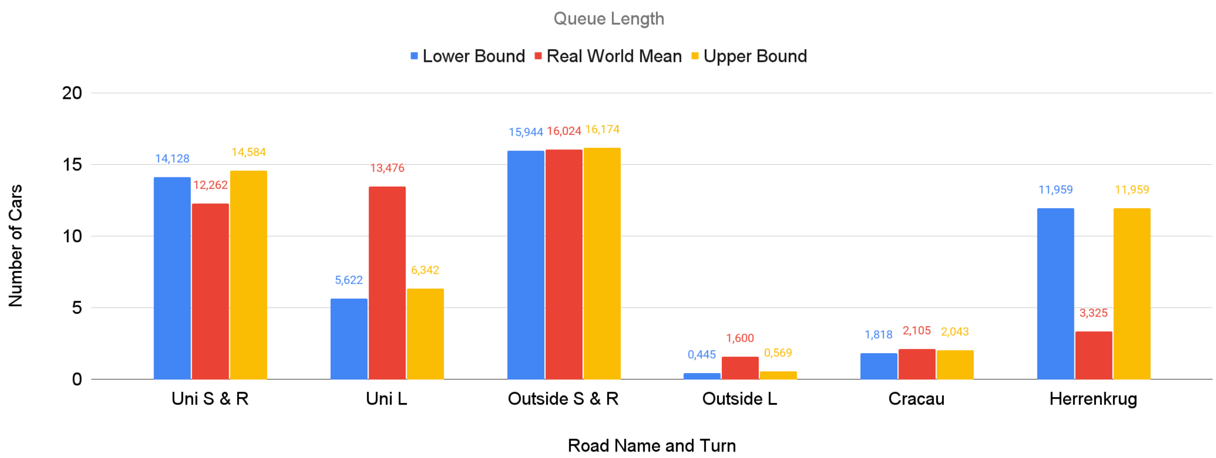

Figure 24: *Graphical Representation of Queue Length Comparisons*

It is evident from the above illustrations that only the queue length value of the real-world mean of Outside S & R (16,024) is within the confidence intervals of the simulated Lower and Upper Bounds. Otherwise, all the other mean values fall outside the range of the confidence intervals.

Time Taken	Lower Bound	Upper Bound	Real-World Mean
Herrenkrug	128,322	136,255	68,337
Outside	99,612	104,900	68,131
Cracau	59,415	65,156	79,026
University	160,246	169,438	40,144

Table 5: *Upper and Lower bound of confidence intervals and real-world mean of times in the node for all vehicles, measured in seconds*

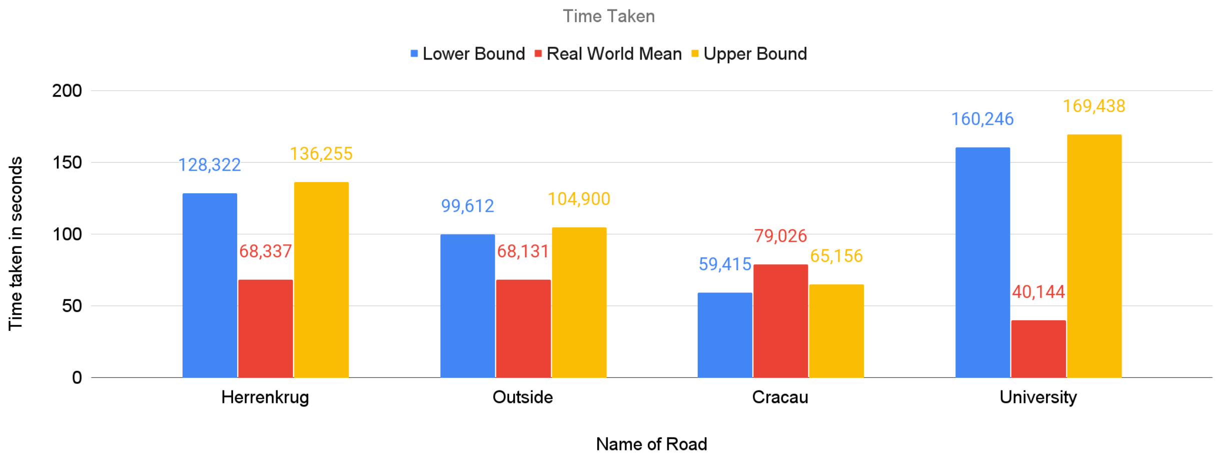

Figure 25: *Graphical Representation of Comparisons for Time Taken*

Throughput	Lower Bound	Upper Bound	Real-World Value
Base Throughput	1802,108	1821,927	2444,000

Table 6: *Upper and Lower bound of confidence intervals and real-world value of the total number of cars in the node, measured for an hour*

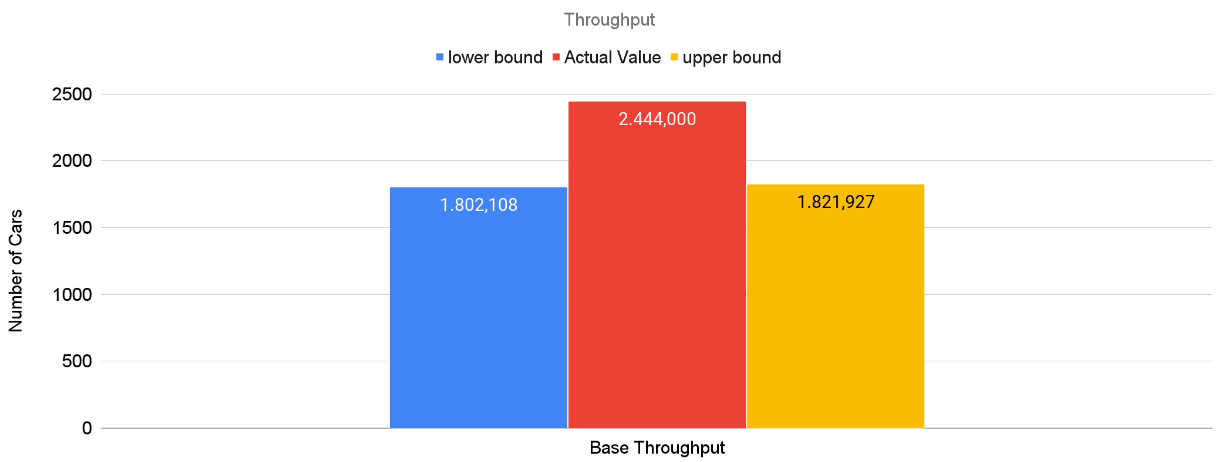

Figure 26: *Graphical Representation of Comparisons for Throughput*

2.6.6 Changes made to the model

Since the real-world mean values did not lie within the confidence intervals of the simulation results, we tried changing a few parameters to check if our model provides any improvements. The following changes were made to the model during the validation phase:

- **Increased Road Lengths:** The throughput values in the simulation were nowhere near the real-world values since AnyLogic stops generating cars when the population reaches a certain limit. For this, we increased the road lengths for each lane but did not notice any improvement in the throughput.
- **Modified Input Data:** We went back to the data analysis section to spread out the data into better distributions to get a more accurate representation of our inputs. We still did not find any further improvement in our simulation results.
- **Car Parameters:** We adjusted the length, acceleration, deceleration, maximum / target speed and initial speed to realistic averages.
- **Traffic Lights:** We tried implementing the collected traffic pattern and also manually adjusting it, but any slight desynchronization introduced Deadlocks or Traffic Jams in the system.
- **Lane Connectors:** Agent behaviour was often not realistic so we had to change, add or remove several lane switching options.

In the next steps, we explore some of the problems that we encountered during the validation phase.

2.6.7 Problems encountered

- **Traffic Lights:** It was impossible to manually adjust the traffic lights and achieve a better result than from the SP4 pattern we started with. Any changes to the traffic lights would eventually result in a Deadlock / Traffic Jam.
- **AnyLogic Agent Limit:** AnyLogic limited the number of cars that would appear in the model despite our inter-arrival times, which resulted in differences in the simulated queue lengths compared to the real-world.
- **Data Limitations:** The 'Time Taken' data we have from the real-world is too little.
- **AnyLogic Agent Behaviour:** AnyLogic car agent behaviour was sometimes not realistic, but it was impossible to narrow the options down enough.

2.6.8 Scope of validity

These are some of the assumptions we had to keep in mind while validating our results:

1. Vehicles initial speed and max/preferred speed of 50 km/h
2. Pedestrians cross whenever there is a green signal
3. Tram signals do not need to be modelled
4. Traffic lights use fixed time plans
5. Same turning probabilities for vehicles
6. All cars have the same length
7. All cars follow the traffic rules
8. Everything on the road was considered a car

2.6.9 Statement of confidence

We obtained the results by performing 25 replications for an hour of simulation time and finding the confidence intervals with a confidence level of 95 percent (i.e., alpha=0.05).

The result of our validation is that the model is not mathematically valid with regard to the measured output parameters. The agent parameters and behaviour as well as the inter-arrival pattern are as close to the observed values as possible. Any further changes would only be possible through adjustment of the traffic lights, which is not viable.

It is clear from the above illustrations and findings that most of our real-world mean data do not lie within the confidence intervals from the replications, and hence, our simulation model is not valid.

Despite not being valid, the model still does mimic the real-world as much as possible. This means that it gives a sound basis, allowing for comparisons with the experiments, thus maintaining usefulness.

2.6.10 Lessons learned during the milestone preparation

- Traffic Signals are very complicated and they have a very low margin of error for precise measurement.
- We underestimated the time required for this milestone.
- Rectification of the model takes a very long time.
- Replications have a long run time.

2.7 Milestone 7 - Simulation Experiments

After the validation of simulation model, it was subjected to six different experiments with the prime goal of improving the road safety and intersection/node performance. The output parameters which we took for evaluating the models were the average queue length of cars in each road, average total time spent by cars from each source/road and the total throughput of the model. In addition to the output parameters, on finding the overlap of green signal for pedestrians and cars taking immediate right turn from their source road or that approaching from the opposite roads, we decided to count such instances where the pedestrian-safety depends on the awareness of drivers. In short all the four parameters were measured for the experiments and compared with the validated model to analyse the performance and safety improvement of the system. All experiments were executed with 25 replications and 95% confidence level. The graphs used for comparison are:

Output parameter graphs

- Average queue length:

  The X-axis of the graph represents the road name of base/validated model and the experiment model respectively. The Y-axis represents the average number of cars or queue length.

- Total time taken:

  X-axis of the graph represents the source-road name of base/validated model and the experiment model respectively. The Y-axis represents the average time taken in seconds.

- Throughput:

  X-axis indicates the six different experiments and Y-axis, the number of cars in thousands respectively.

- Pedestrian safety parameter:

  X-axis indicates the six different experiments and Y-axis, the number of pedestrians who had a chance of hitting respectively.

All the graphs are having confidence intervals obtained for 25 replications as values. They are read from left to right having comparison with the base/validated model results.

2.7.1 Road widening

In this experiment all the four roads around the intersection were widened into three lanes. The system still was allowed to follow the optimized SP4 signal pattern from the City Office.

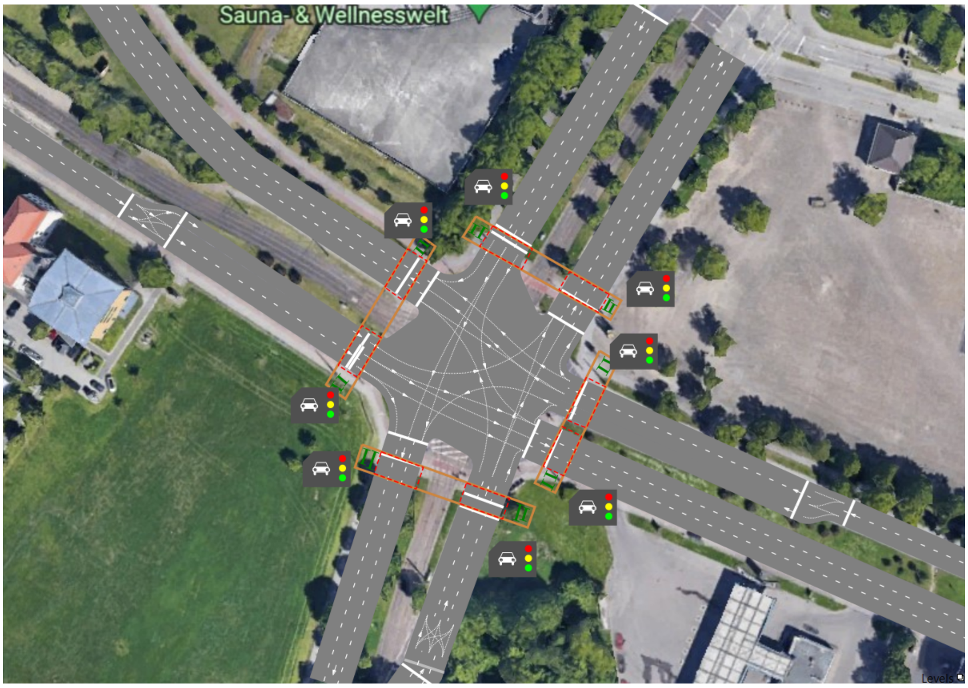

Figure 27: *Three lane roads on all four parts of the intersection*

1. **Justification**

   As per the validated base model, we observed a yielding of cars in the Herrenkrug road due to those taking a turn to the right affecting others intending to go straight and left. Inspired by the finding we expected an improvement in the traffic performance by road widening on all roads of intersection. Running through few scientific papers, we also came to know about improving the safety by widening the roads as they provide more leeway and maneuver to prevent an accident.

2. **Results and comparison with validated model**

   The following graphs show the results of the significant output parameters obtained compared with that of the base or validated model.

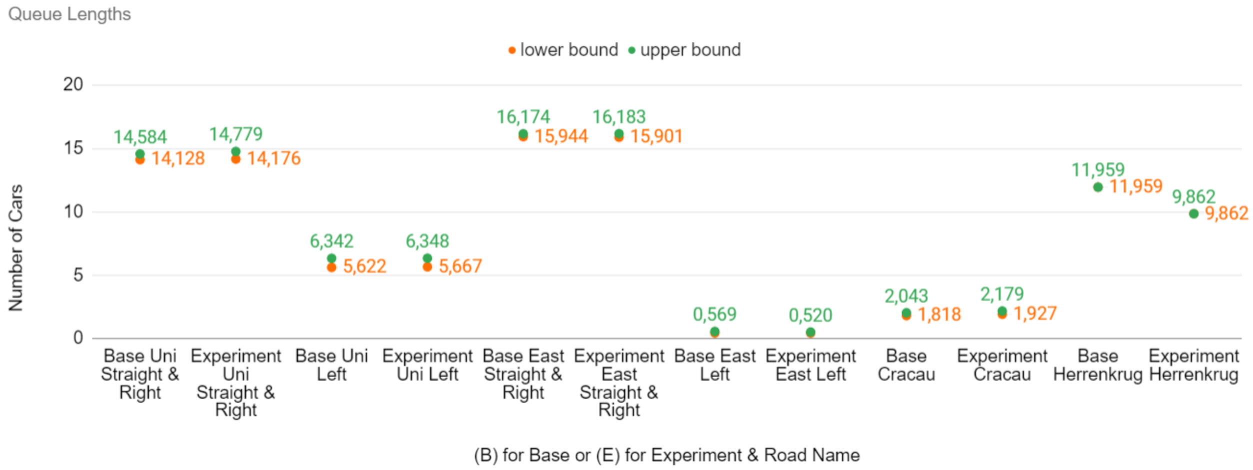

Figure 28: *Comparison of average queue length of vehicles from base model and experiment model with respective roads*

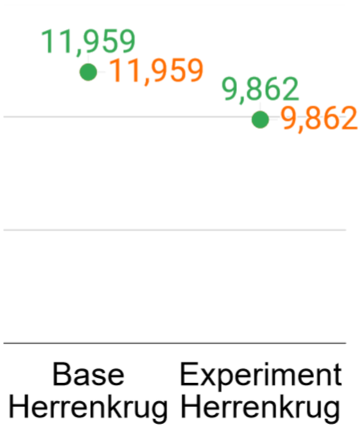

Figure 29: *Improvement in the queue length observed in the Herrenkrug road*

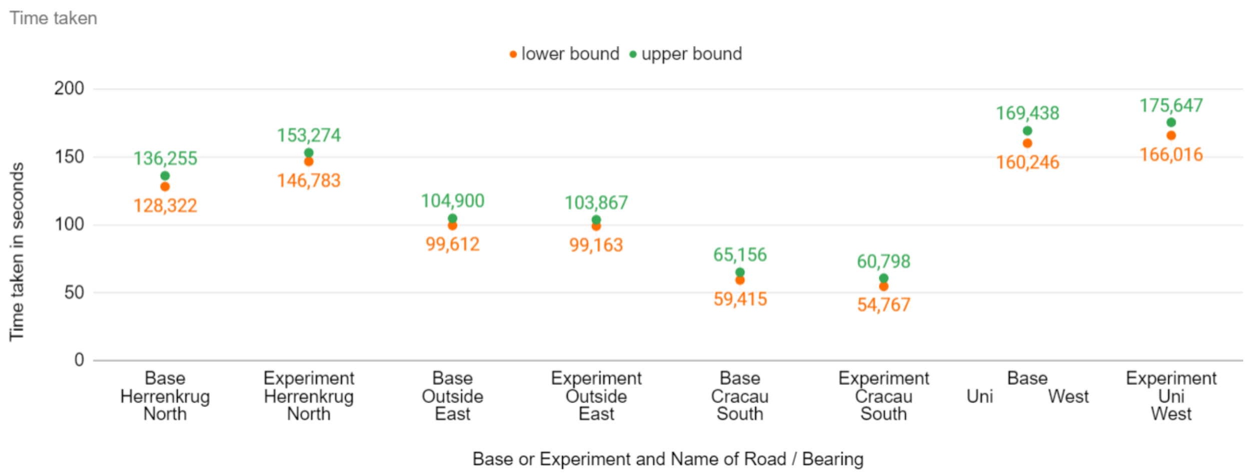

Figure 30: *Comparison of average total time taken of vehicles from base model and experiment model from respective roads*

From figure 28, a significant decrease in the average queue length can only be observed in the Herrenkrug road. All other remaining roads showed approximately same values. This happened due to the removal of vehicle yielding before the intersection by which the turning cars now does not interrupt the cars going straight. Similarly in the time taken graph also no good changes were observed.

2.7.2 Left turning lane extension

In this experiment, the left turning lanes present on both the West/University and East/Outside-city roads were extended towards back to each of the sources(region in the layout where AnyLogic starts generating vehicles from) thereby increasing the space in the area. The extension points were easily altered using simple AnyLogic features and so the lane switching regions accordingly. The figures are depicted as a mode of comparison to comprehend the changes made, where the first image shows the older and the following image shows the turn-lane elongated versions.

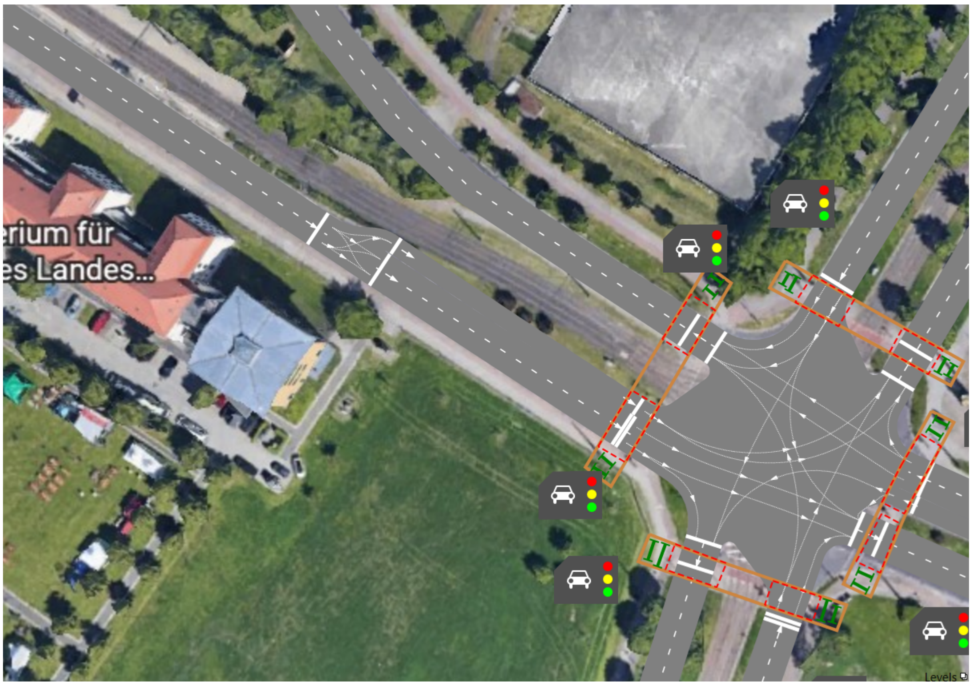

Figure 31: *Left turning lane in the actual position(in the West/University side) from base model*

Figure 32: *Left turning lane being extended or elongated towards the respective source point(in the West/University side)*

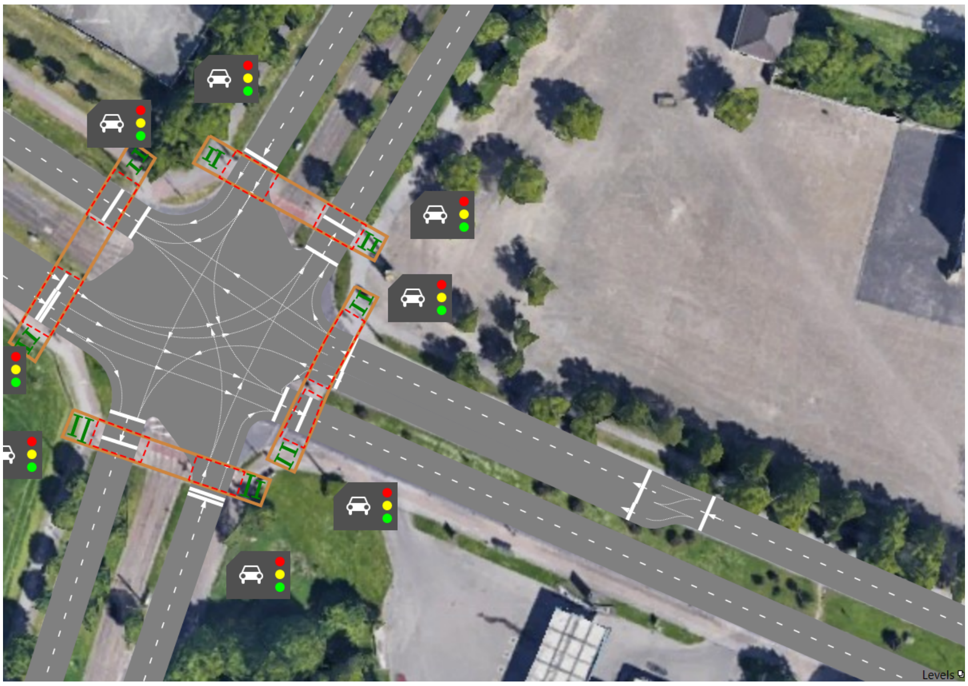

Figure 33: *Left turning lane in the actual position(in the East/Outside-city side) from base model*

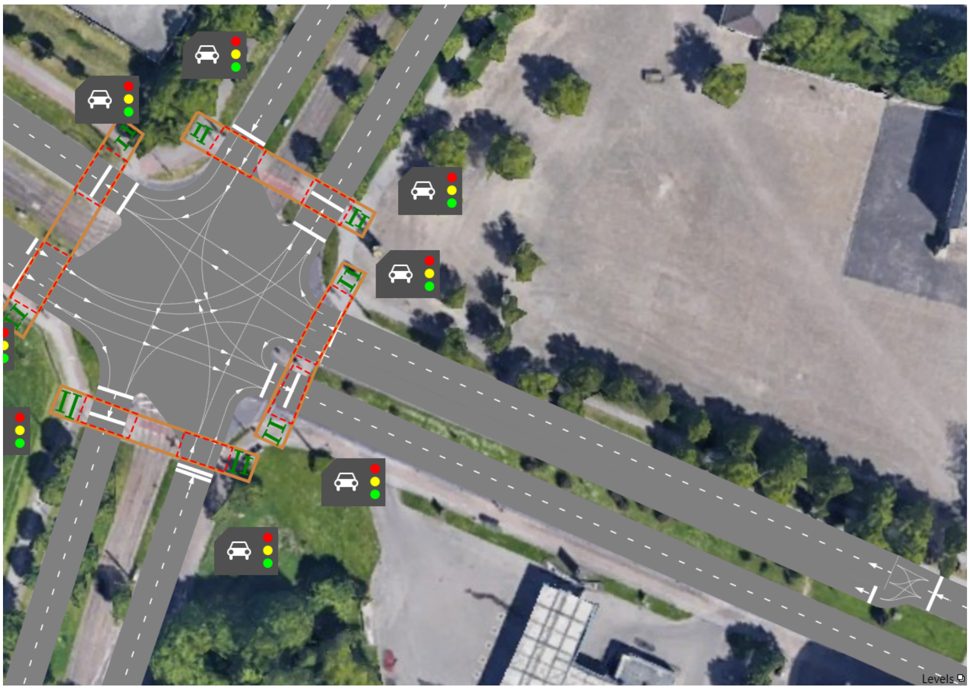

Figure 34: *Left turning lane being extended or elongated towards the respective source point(in the East/Outside-city side)*

1. **Justification**

In light of the previous records of road accidents in Jerichower intersection, one of the suggestions put forward by the city officials in order to improve the node performance and accident rate reduction was to make changes with the left turning lanes present both in the West/University and East/Outside-city roads. Inspired from this, we decided to extend the left turning lane backwards to each of its source. We expected an elongation of this lane preventing the stacking up of cars in the straight lane which was severely observed in the base model.

2. **Results and comparison with validated model**

   The following graphs show the results of the significant output parameters obtained compared with that of the base or validated model for the Left turning lane extension.

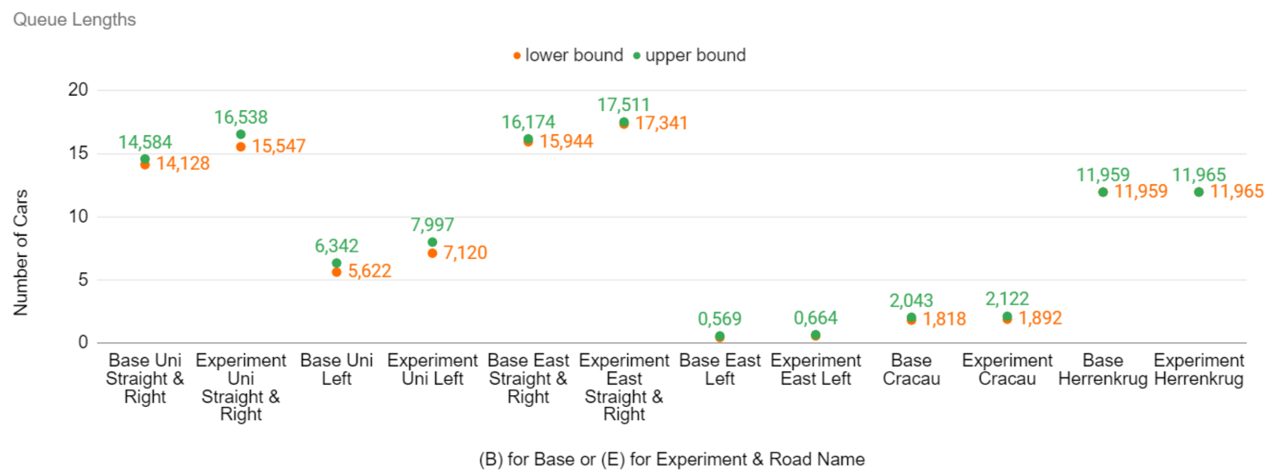

Figure 35: *Comparison of average queue length of vehicles from base model and experiment model with respective roads*

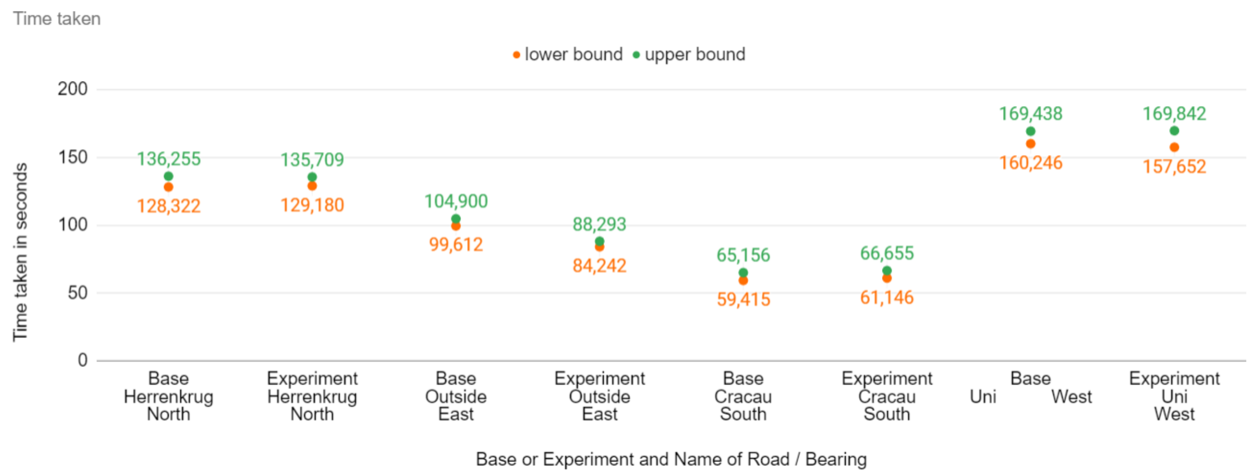

Figure 36: *Comparison of average total time taken of vehicles from base model and experiment model from respective roads*

In contradiction to the expected results, from the figure 35 it can be observed that there is a slight increase in the average queue length on all roads of the intersection. Whereas there is also a slight reduction in the total time for roads except that from University and Cracau. The increase in queue length has been resulted because of the increased lane length which is capable of fitting more cars into the queue area.

2.7.3 Tunnel or Underpass for vehicles

The experiment was done by trimming down the straight high traffic roads from West-/University and East/Outside-city, before intersection. A carExit and carEnter were added connecting the trimmed end on either sides of the intersection corresponding to their exit roads. The cars passing through this invisible lane(assumed to be the underpass) were subjected to a uniformly distributed delay of values between 10 and 12 based on the simple calculation of time taken to cover the particular distance(measured using Google Earth ruler) with the constrained speed(50km/hour). In addition to this, the left and right turning lanes were built using single one-way road element from AnyLogic. Moreover the Cracau and Herrenkrug roads were still allowed to follow the SP4 signal pattern.

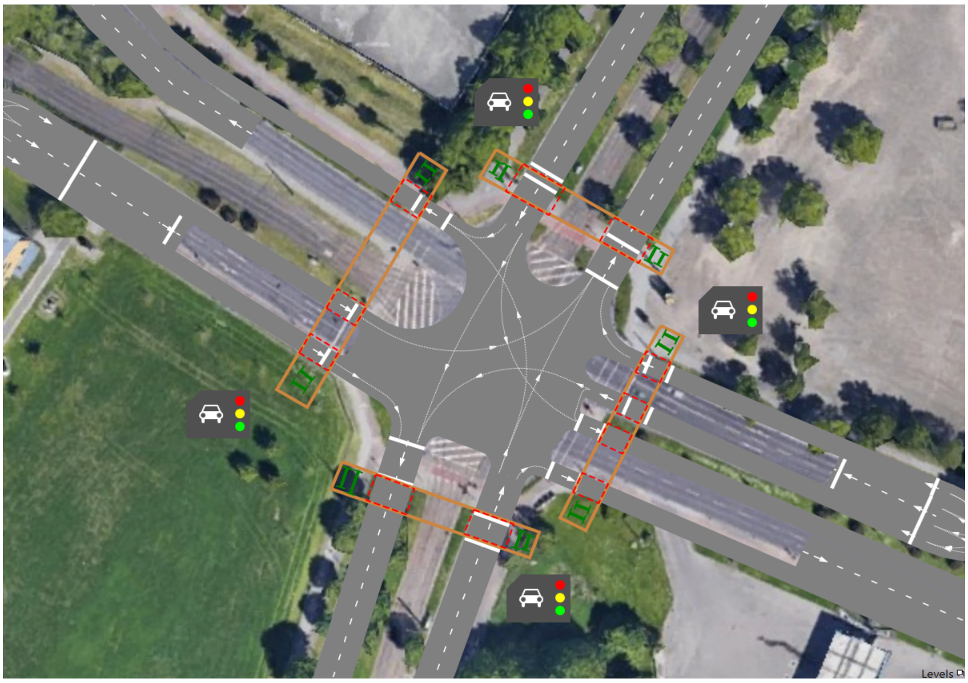

Figure 37: *Tunnel or underpass for vehicles are built beneath the existing intersection with no changes in Cracau and Herrenkrug roads*

1. **Justification**

   The Jerichower intersection is mostly affected by the heavy straight going vehicles from University and the East. Therefore relieving intersection from these cars can improve the performance of the traffic system and reduce the chance of accidents.

2. **Results and comparison with validated model**

The following graphs show the results of the significant output parameters obtained compared with that of the base or validated model for the vehicle tunnel experiment.

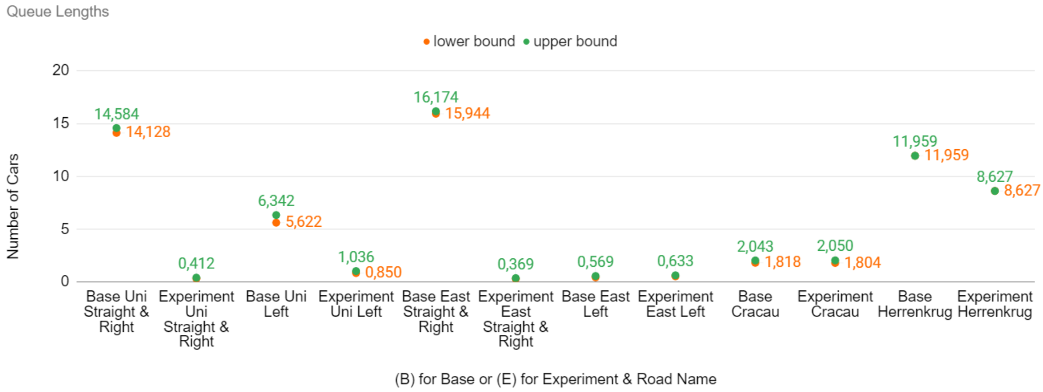

Figure 38: *Comparison of average queue length of vehicles from base model and experiment model with respective roads*

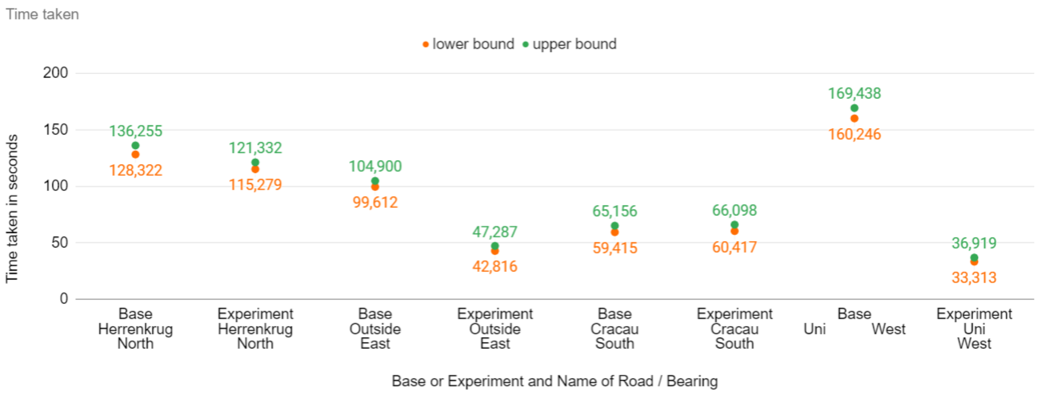

Figure 39: *Comparison of average total time taken of vehicles from base model and experiment model from respective roads*

From the figure 38, it can be observed that there is a major improvement in the average queue length on all lanes except for Cracau and East-left roads. Interpreting the figure 39, it can be noted that there is a good decrease in time taken for all lanes except Cracau which can be because of the still continuing SP4 signal pattern.

2.7.4 Vehicle tunnel and roundabout

The vehicle tunnel in the previous experiment was retained and conventional form of road intersection was removed in this experiment. Instead, a roundabout connecting the left, right lanes of West/University and East/Outside-city roads, Herrenkrug and Cracau roads was built. In addition, the U-turn from East road was removed.

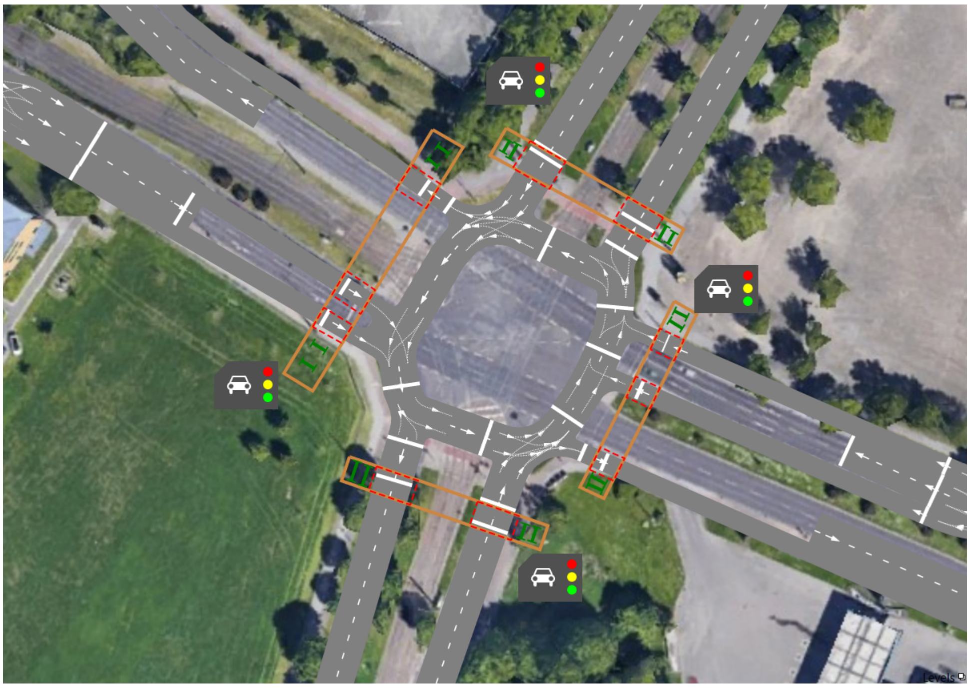

Figure 40: *Tunnel/ underpass(for straight going cars from West/University, East/Outside-city roads) and roundabout*

1. **Justification**

   It has been understood from the previous experiment that the intersection was relieved from a higher vehicle density with the help of an underpass/ tunnel. But the other two sides of the intersection were still following the SP4 signal pattern. The dynamic behaviour of highly optimized signal pattern always played a challenge in phases of customising them to improve the traffic flow. Thus we decided to completely remove the signals using a roundabout by which a continuous flow of vehicles can be ensured. We suspected that this would also reduce the chance of road accidents.

2. **Results and comparison with validated model**

   The following graphs show the results of the significant output parameters obtained compared with that of the base or validated model for the vehicle tunnel and roundabout experiment.

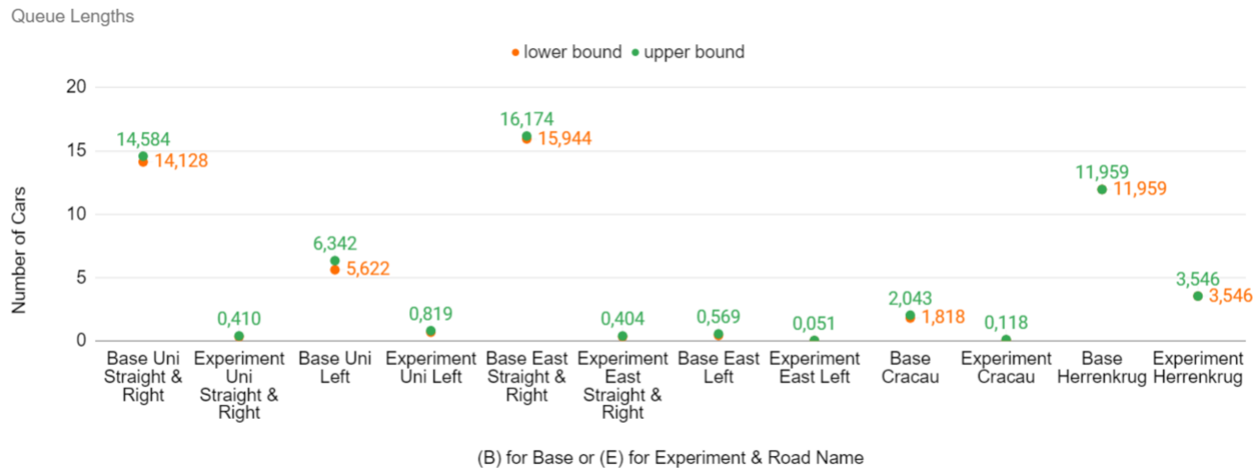

Figure 41: *Comparison of average queue length of vehicles from base model and experiment model with respective roads*

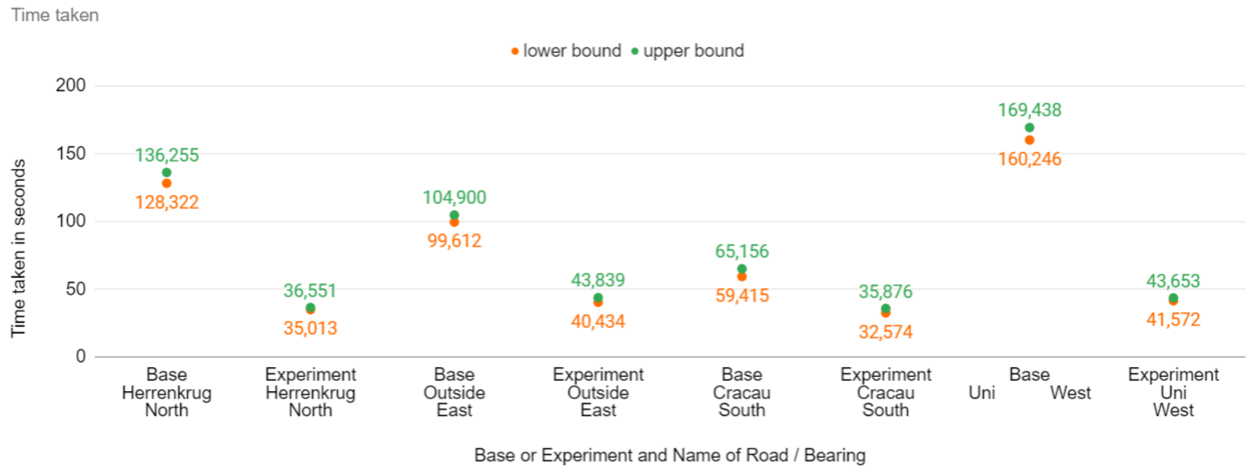

Figure 42: *Comparison of average total time taken of vehicles from base model and experiment model from respective roads*

Figure 41, shows a considerable decrease in average queue length on all roads. The figure 42 also reveals that the experiment showed a good reduction in the Total average time taken for the cars coming from all source points which is a desirable result. The application of a combined form of tunnel and roundabout has helped the intersection to cut down its overall load and vehicle density. Similarly the roundabout has replaced the need for traffic lights allowing for minimal queue length.

2.7.5 Pedestrian tunnel and roundabout

The similar form of roundabout was built replacing the normal intersection. In addition to this, we assumed the presence of a pedestrian tunnel all across the junction which is equivalent to the absence of whole pedestrians in the model. Along with pedestrian removal, separate right turning lanes were built from all the roads that are approaching the intersection. Similar to the previous experiment the U-turn from East/Outside-city road was removed due to the integration of a roundabout.

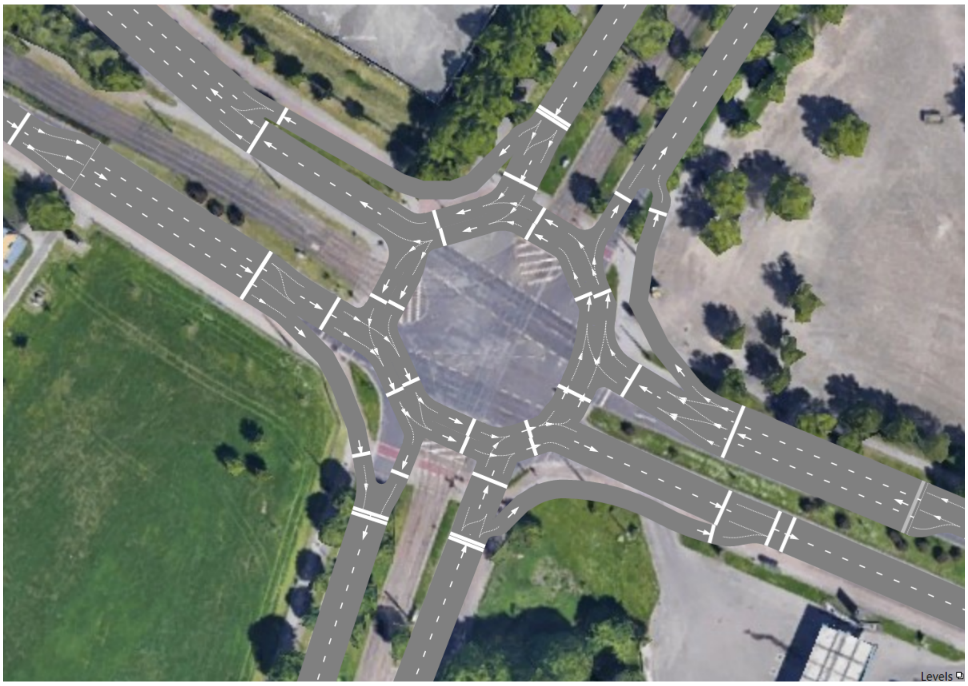

Figure 43: *Tunnel/ underpass(for straight going cars from West/University, East/Outside-city roads) and roundabout*

1. **Justification**

   As roundabouts are capable of performing well during lower traffic volumes without the need of traffic signals and their optimisation, they were adopted in this experiment too along with separate right turning lanes that can ensure reduction in road congestion inside them in cases of heavy traffic volumes. Pedestrians turn to be another vulnerable part of road accidents as per the reports from City-Office. Therefore, an independent pathway for them from the road network will ensure 100% safety from accidents.

2. **Results and comparison with validated model**

   The following graphs show the results of the significant output parameters obtained compared with that of the base or validated model for the pedestrian tunnel and roundabout experiment.

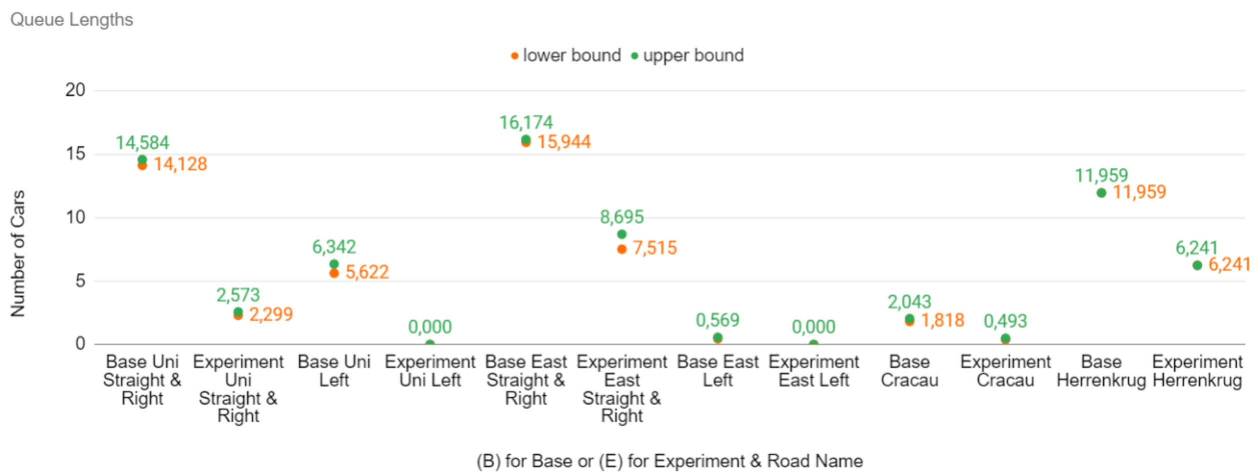

Figure 44: *Comparison of average queue length of vehicles from base model and experiment model with respective roads*

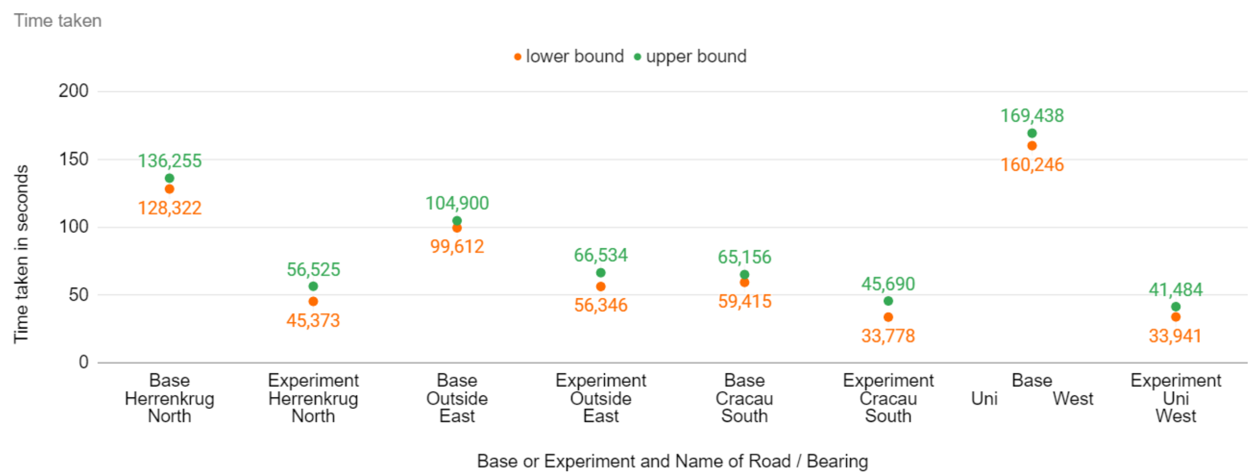

Figure 45: *Comparison of average total time taken of vehicles from base model and experiment model from respective roads*

From both figures 44 and 45, it can be acknowledged that there is a huge improvement in the traffic flow performance by decline in both average queue length and time taken for cars from each source road. As a result of making separate right lanes for turning cars, the vehicles which intend to go for a straight travel are no more interrupted on their entry in to the roundabout. Moreover an absence of traffic signal has now ensured better vehicular flow in the model.

2.7.6 Pedestrian tunnel

This experiment was carried out with only removal of pedestrians from the road network. The pedestrian sources and the previously integrated pedestrian library was removed.

Figure 46: *Tunnel for pedestrians across all roads in the model*

1. **Justification**

   The city statistics show a significant number of pedestrian accidents which have occurred previously. One major observation we perceived was the overlap of green signals for both pedestrians and the cars that take an immediate right from their source road. We expected a reduction in the time taken and an increase in the throughput on removal of pedestrians from the road network.

2. **Results and comparison with validated model**

   The following graphs show the results of the significant output parameters obtained compared with that of the base or validated model for the pedestrian tunnel experiment.

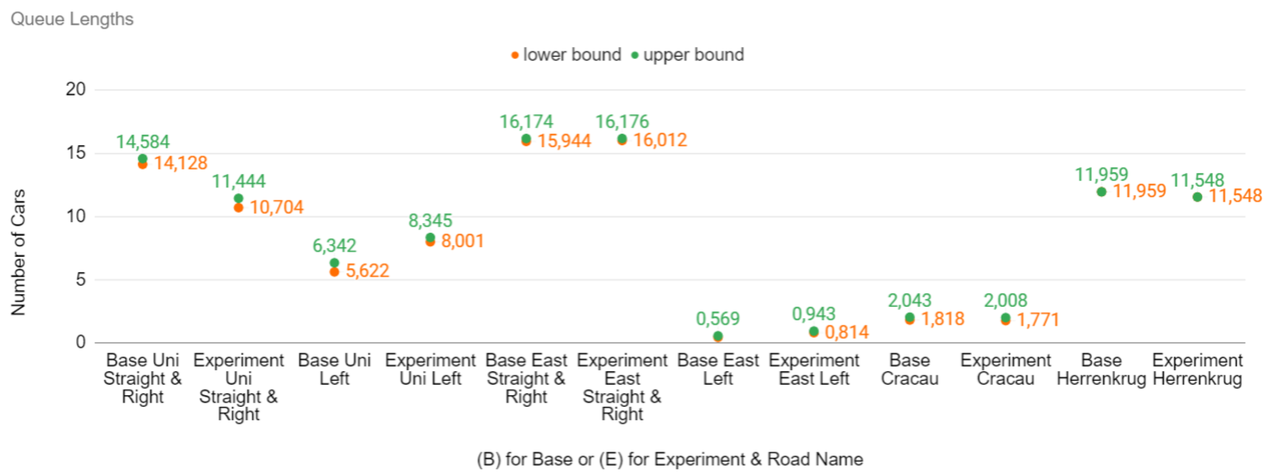

Figure 47: *Comparison of average queue length of vehicles from base model and experiment model with respective roads.*

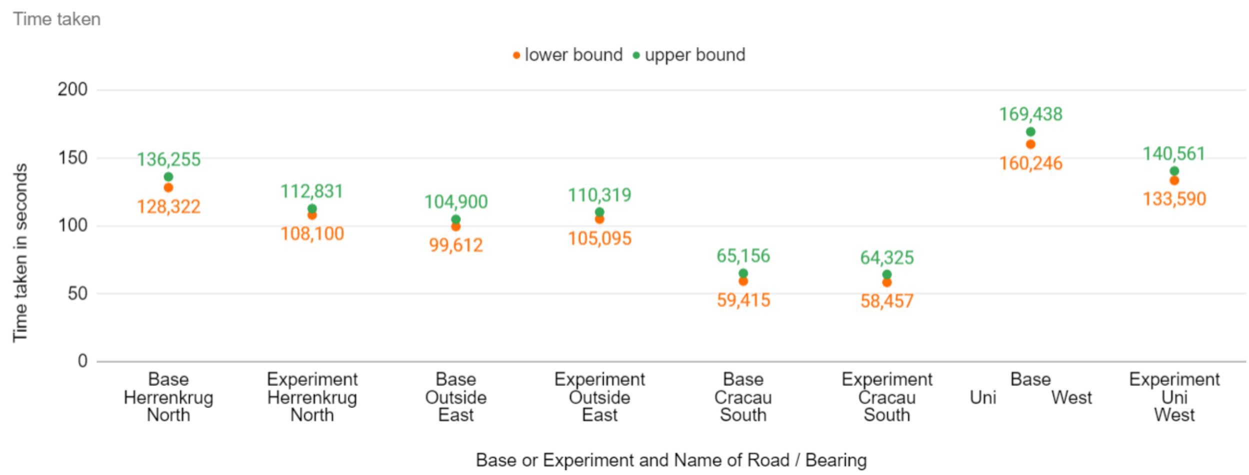

Figure 48: *Comparison of average total time taken of vehicles from base model and experiment model from respective roads*

From the figure 47 it can be remarked that even-though there is a decrease in the average queue lengths for University-right, Cracau and Herrenkrug roads, a slight increase can be observed for the West/University-left and East-left roads. Similarly, from the time taken graph(figure 48), the vehicles from the East road shows an incremented value than the model. We could analyse this behaviour and suspect it to be a result of the lane switching region of University and East roads where the cars are now able to easily turn in to their respective left lanes because of the reduced interruption caused by queue of straight going vehicles upon removal of pedestrian-set and their signals.

2.7.7 Throughput comparison

The total through put stands for the total number of cars/agents the model has produced and later destroyed measured for a time period of about 1 hour. The throughput graph was plotted with the number of cars/ vehicles in thousands on the Y-axis and the experiments following the base model data on the X-axis. From figure 49, it is evident that the experiments with a combination of roundabouts with pedestrian tunnel and vehicle tunnel respectively shows highest values compared to the base model. Among them the ”Roundabout with pedestrian tunnel” gave the peak value. Whereas, the experiments of ”Three lane roads” and ”Vehicle tunnel” produced worse results than the base model. A simple pedestrian tunnel was also successful enough in improving the base model throughput value. Even though the ”Left turn lane extension” couldn’t bring a significant rise in the throughput, the experiment showed better results than the bench mark model.

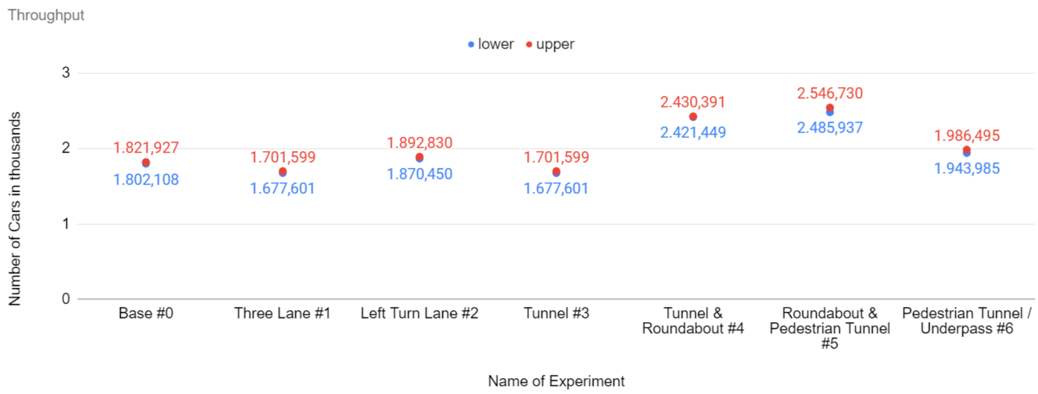

Figure 49: *Comparison of total throughput of cars from base model and experiment models respectively*

2.7.8 Pedestrian safety parameter

Upon realising the danger of pedestrians being hit by an immediately right turning car from the source road or that incoming to pedestrian crossing area having a green signal(figure 50), we decided to make simple counter variable to count such number of pedestrians. A simple condition check and counter increment was provided inside the ”Polygonal node” of the pedestrian crossing area such that it counts whenever a car approaches the crossing area while a pedestrian is still crossing.

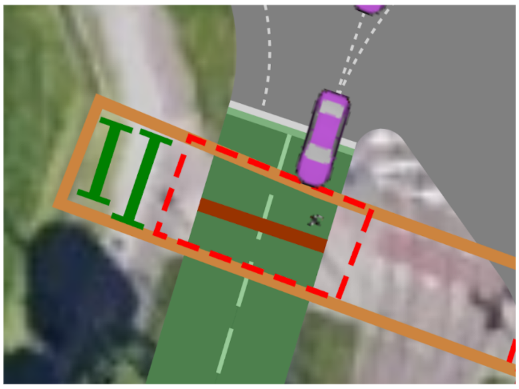

Figure 50: *Car approaching the crossing area when a pedestrian is still there*

In this perspective of pedestrian safety, we were able to distinguish the experiments which showed better and worse results compared to that of the base model. Experiments with no pedestrians directly involved with road network makes our expectation 100% correct with 0 occurrences. From figure 51, it can be understood that the experiments of ”Road widening” and ”Vehicle tunnel” produce more number of pedestrian accidents. Even though the ”Left turn lane extension” shows no great difference, the ”Tunnel and roundabout” experiment projects a considerable less number of instances.

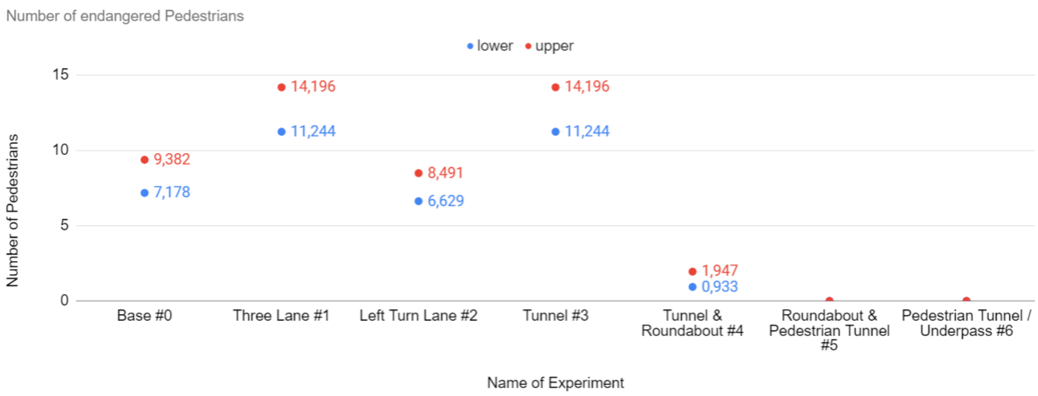

Figure 51: *Comparison of pedestrian danger instances from base model and experiment models respectively*

2.7.9 Problems encountered and lessons learned during the milestone preparation

- We were exposed to the intricate features of the Industry-specific libraries of AnyLogic software.
- Even though the modelling of roundabout and underpass was difficult because of the frequent lane connector issues, they were highly insightful in realising the choke points

of the model and understanding the deeper logic behind the same and the corresponding rectification.

- The dynamic behaviour of SP4 traffic signal added complexity in customisation of the base model for experiments. However we were able to come across with the alternative approaches that can be done to overcome the same.
- Finding reasoning for our results was not straightforward and resulted in many adjustments to the experiment models.

3 Results and recommendations

Based on the output and safety parameters measured, we decided the experiments to be sorted with a respective preference order of:

1. Traffic performance

2. Pedestrian safety

3. Cost

The experiments were remarked with low, medium and high weights. The experiments showing improved results from the base model were marked as the "Better" and those portrayed worse than base as "Worse". Those having comparatively similar performance as that of base were denoted as "Similar" models. Among the six experiments, the "Tunnel(for vehicle) and roundabout" and "Pedestrian tunnel and roundabout" showed the best results compared to the base validated model in regards of both traffic performance and pedestrian safety. Therefore we recommend them in light of the simulation results to the City-office for ensuring a better modification of the current performance of Jerichower Platz intersection. On the other hand, the experiments including "Road widening" and "Left turning lane extension" ranks the lowest position based on the before mentioned priority order and results. In addition to these factors, we also added a categorization based on the expected costs for each experiment. The experiments which ranked the lowest were the least expensive. However we decided to compromise the cost over the measure traffic performance and pedestrian safety.

1. Road widening

2. Left turning lane extension

3. Tunnel or Underpass for vehicles

4. Tunnel (for Vehicle) and roundabout

5. Pedestrian tunnel and roundabout

6. Pedestrian tunnel

	Traffic performance	Pedestrian safety		Cost
Road widening	Worse	Worse		Low
Left turn extension	Worse	Similar		Low
Tunnel	Similar	Worse		Medium
Tunnel and roundabout	Better	Better		High
Pedestrian tunnel and roundabout	Better	Better		High
Pedestrian tunnel	Worse	Better		Medium

Figure 52: *Final ranking for each performed experiment*

4 Project Tracking

4.1 Costs progress

At the beginning of the project, we were informed that we had a budget of 10.000€ per team member, where one working hour costs 100€. Since we're 9 members, the total cost should come to 90.000€, but since the project we were given was too big and it was expected to use big amount of resources, our final budget reached 98.600€. As we have shown till now in the report, we had difficulties and had to repeat some events, which were followed by increasing costs in every next connected milestone. On the image below it's shown the planned and the actual spent costs based on a milestone-by-milestone method, including work on milestone and meetings. At the end of the report, we attached the costs based on a person-by-milestone method. Our final costs at the end is 128.765€.

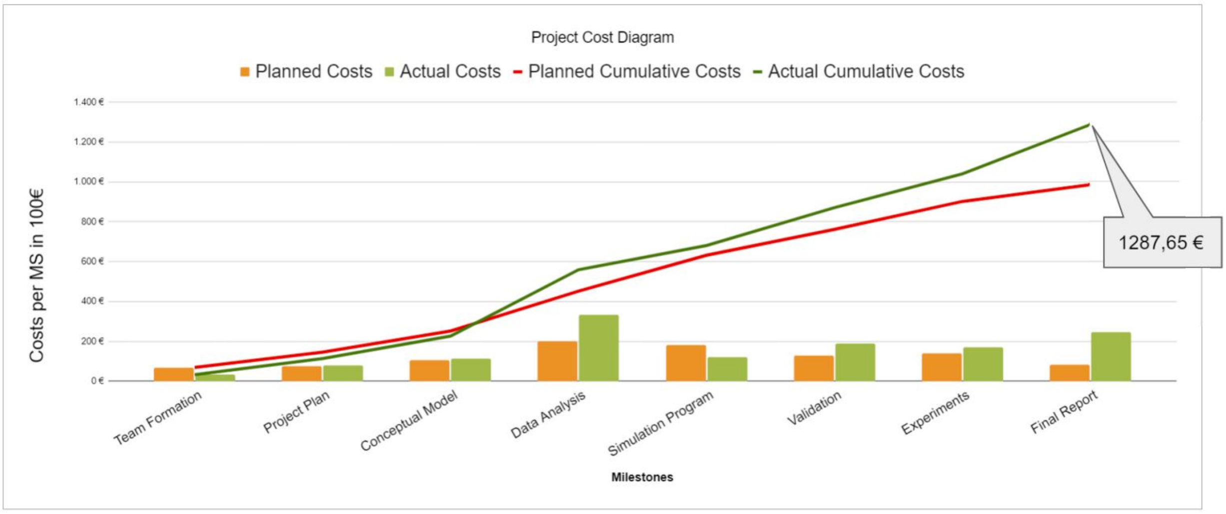

Figure 53: *Costs progress*

4.2 Project progress

Our overall goal was to complete the task within the deadline we were given, and we achieved this. As it's shown in the image below, we had timing problems after our fourth milestone, which was supposed to be done by the end of the 20th week (10.05.-16.05.2022), but after data collection, our data analysis didn't display the desired results. We re-did the data collection and the data analysis. This delay affected the next milestones as well, since they were all connected to each other. The teamwork and the guidance from our supervisors gave us power, and we accomplished the goal on time.

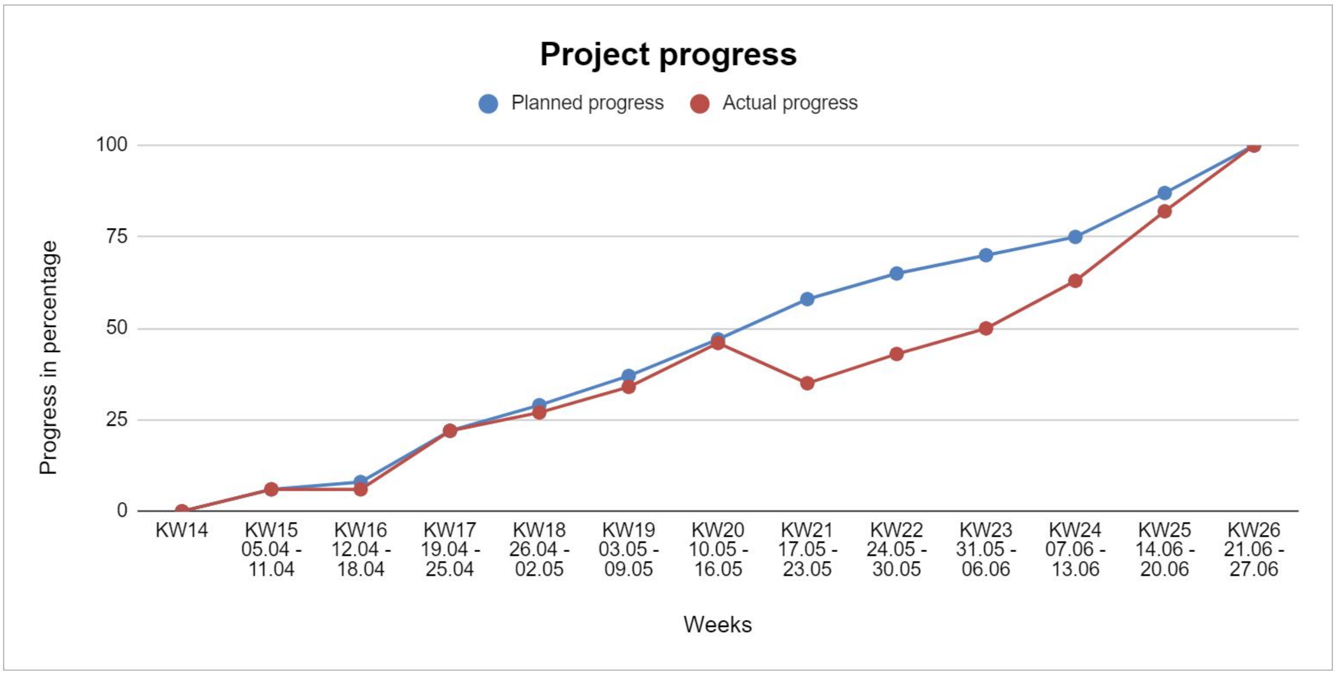

Figure 54: *Project Progress*

5 About the team

Milestone 1 - Team Forming: Even though we were in two different teams and assigned to different nodes with different goals, we nevertheless were able to form one big team with a common goal of improving the safety and performance in the node. We completed this milestone by defining a new set of goals and responsibilities along the way and tried to get used to our teammates as a whole single team **"The Simulators"**.

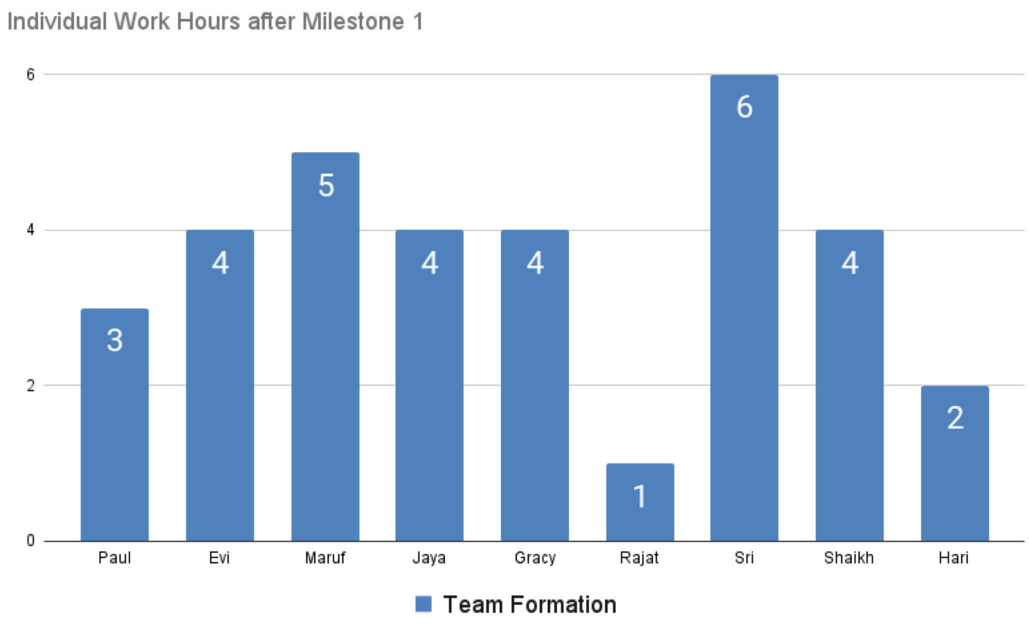

Figure 55: *Hours per Team Member after contents of Milestone 1 were fully completed*

Milestone 2 - Project Plan: This milestone week included the previous milestone for us. It gave us less time to get to know each other, which we went on to later realize that we underestimated the issues and that this is the most crucial milestone for a project.

We decided it would be best that for each milestone, those responsible would prepare and decide on the work packets and their respective costs so we could implement and assign them in the project plan.

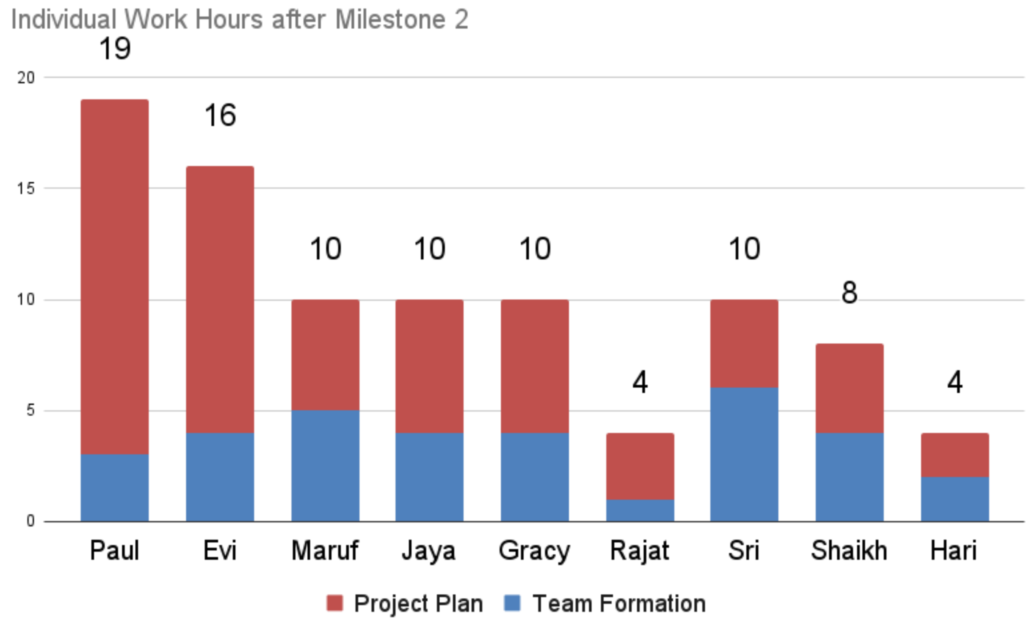

Figure 56: *Hours per Team Member after contents of Milestone 2 were fully completed*

Milestone 3 - Conceptual Model: This was so far the most successful Milestone we had in the entire Project with little hurdles and foundation for the whole project as it further made our tasks easier by clearly defining our future goals and tasks, Jaya and Maruf the responsible people for this milestone, put in amazing work and completed it without requiring much further help, as can be seen in the diagram below. In hindsight this might have given some of us a wrong signal and lulled us into a false sense of security and ease.

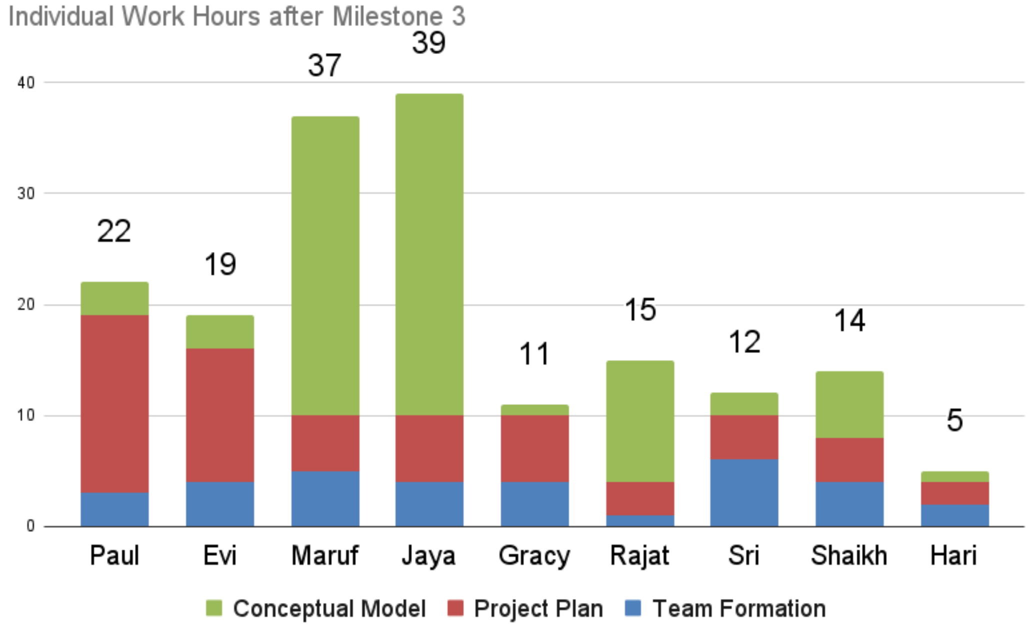

Figure 57: *Hours per Team Member after contents of Milestone 3 were fully completed*

Milestone 4 - Data Analysis: At the Meeting of the second week of the Milestone we quickly realized that we were falling behind schedule as we couldn't decide on what data to collect and how to collect it though we had decided in the previous milestone(conceptual model) on the quantities to be measured, when it came to reality we were in a dilemma on how to collect data for the quantities mentioned before. Having an emergency meeting the next day, didn't help us much as not all could attend and didn't help us to progress in the project but rather made us to work together for the first time in the project. With Pascal's(project mentor) help we were able to focus on our goal and made a final decision and planned a test and proper Data Collection. With a new ray of hope we proceeded forward. This hope did not last long as it was quickly replaced with frustration and scrambling of resources shortly after. This frustration stemmed from the difficulties encountered on what would be the longest part of the Project, finding the distributions for the Inter Arrival time and testing them statistically , or rather the goodness of fit test for the Parameters. Nevertheless after all the turmoil we would able to fix the distributions and could proceed forward.

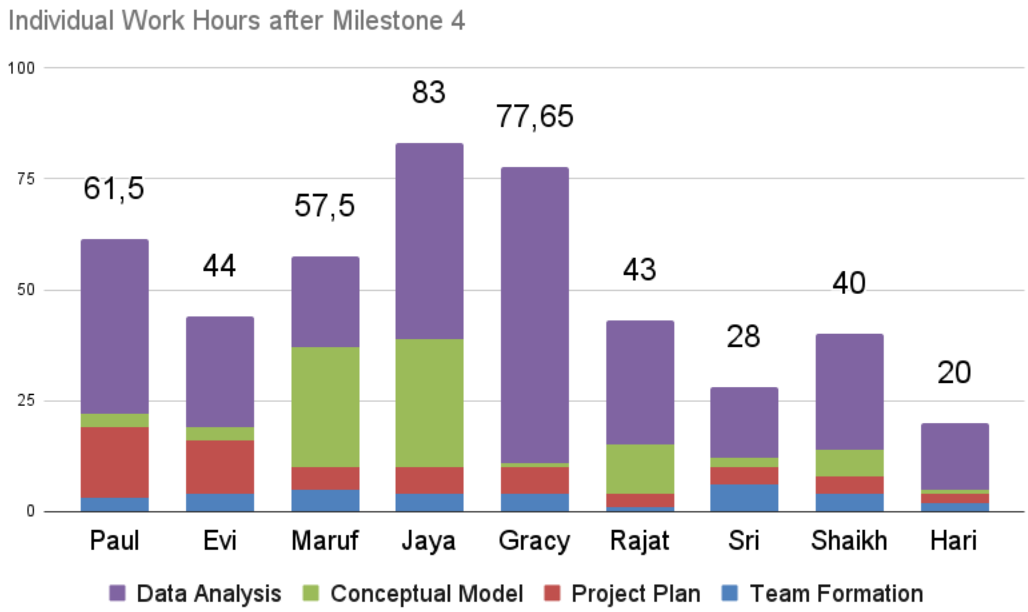

Figure 58: *Hours per Team Member after contents of Milestone 4 were fully completed*

Milestone 5 - Simulation Model: During the Preparation of the Simulation Model Sricharan and Hari had started this process in advance, thus giving us a breathe which would have allowed us to focus on the following Milestones but the rest of us had to instead focus on the mistakes we did in the Data Analysis, readjusting and reworking it. Though we have modify the model few times in order to make it consistent with the conceptual model and also for the milestones falling immediately after this, we would say it a great success for us as we have reached until this stage in the project.

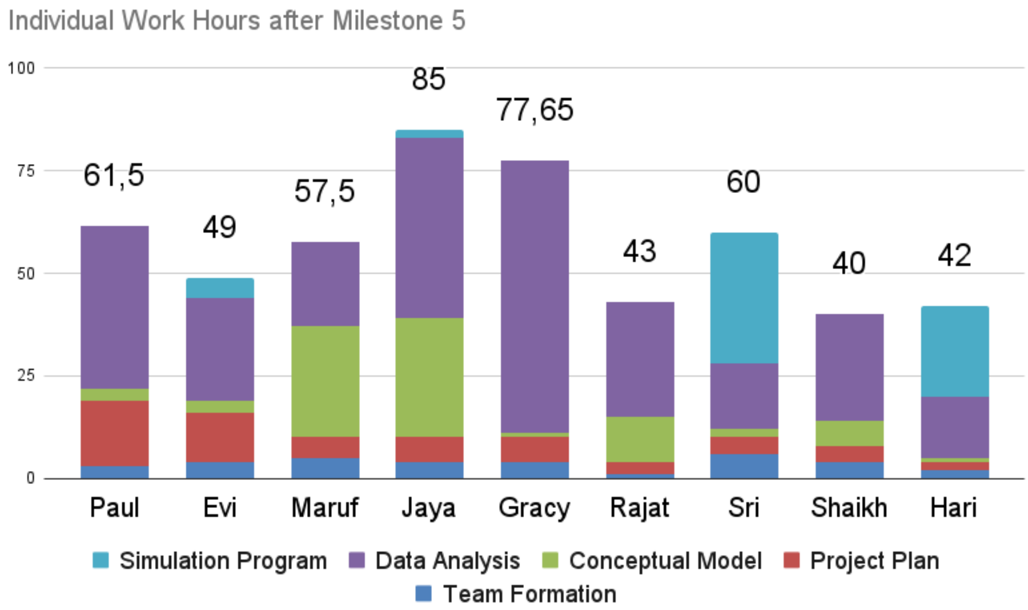

Figure 59: *Hours per Team Member after contents of Milestone 5 were fully completed*

Milestone 6 - Validation: Since we could not prepare for this milestone much during the previous weeks and also still had to work on the data during the previous milestones, we tried maintaining the schedule for the current milestone, but it was clear to us that it would be impossible here because of the dependency on the Data Analysis. We scheduled everything that needed to be done but could only spare Hari to prepare the Experiments as we noticed that this is essential. As a result of new findings, we were confident that we could make it, until we realized that our model would never be valid, which left us out of ideas once again.

Nevertheless, due to the team work, we were able to overcome this challenge in the later stages, at least by experiments phase. Paul, Sricharan, and Shaikh tried adding some changes to the model and re-iterating everything, after which we would say that we had achieved some breakthrough points to validate our model.

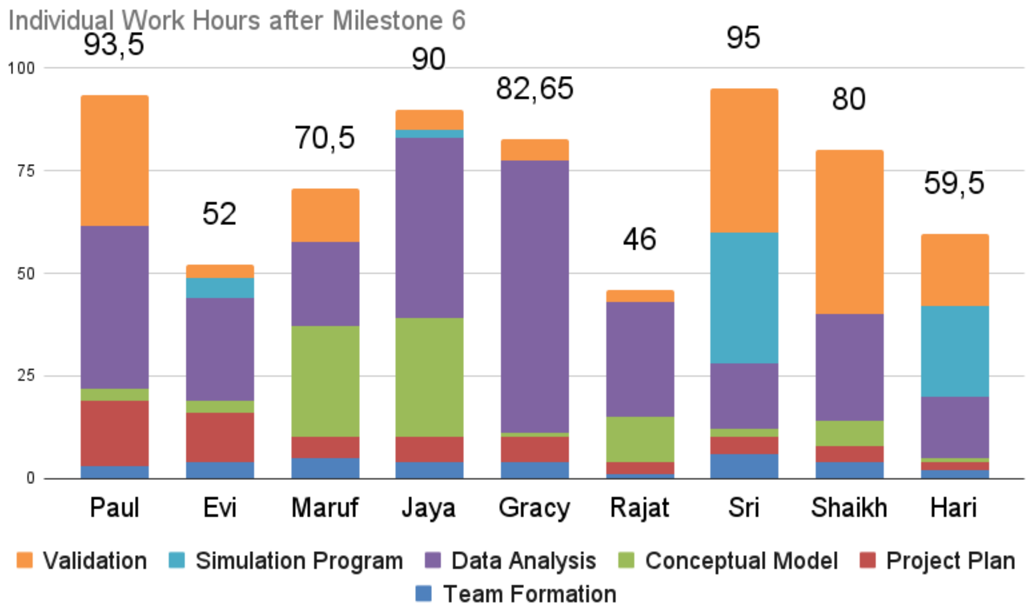

Figure 60: *Hours per Team Member after contents of Milestone 6 were fully completed*

Milestone 7 - Experiments: The start of this stage of our project was overshadowed by the results from our previous presentation. We still had work left from the Validation, had to complete the Experiment models, evaluate the results and prepare for the Final report. Evelina swiftly got to work on the report by preparing the outline while others responsible for their milestones started adding their work and findings in the Report as others like Paul, Hari started working on the Experiments, hence giving us time to complete the validation part in the mean time. Even Though some issues regarding the Models and Validation were hard to solve we managed to evaluate all the Experiments thanks to Paul, Hari and Sricharan.

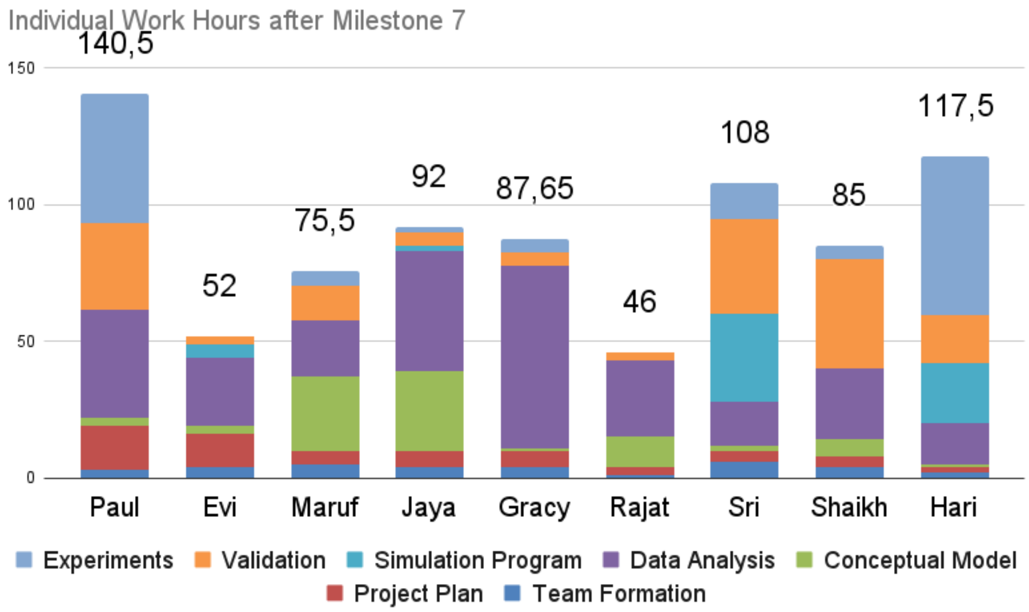

Figure 61: *Hours per Team Member after contents of Milestone 7 were fully completed*

Milestone 8 - Final Report - This is another success, we would say, as the whole team worked on it and everyone in the team tried to give their best, so we would be able to finish it in time. Even though we had to have many meetings and changes to the report, we were totally satisfied with the final outcome, as it was the last part we would be doing as a team. Hence, we would say, it is a Happy Ending.

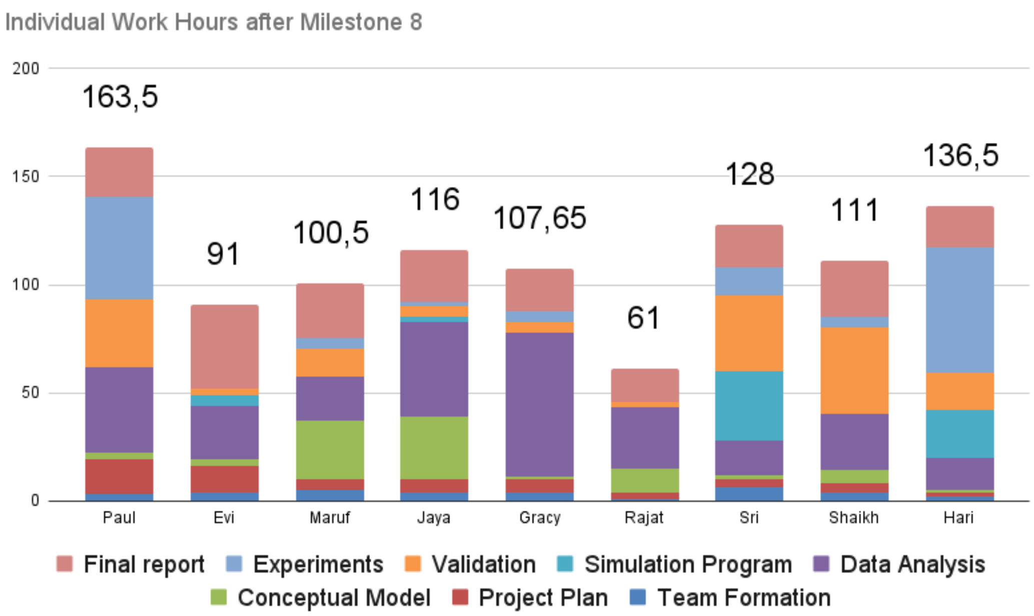

Figure 62: *Hours per Team Member after contents of Milestone 8 were fully completed*

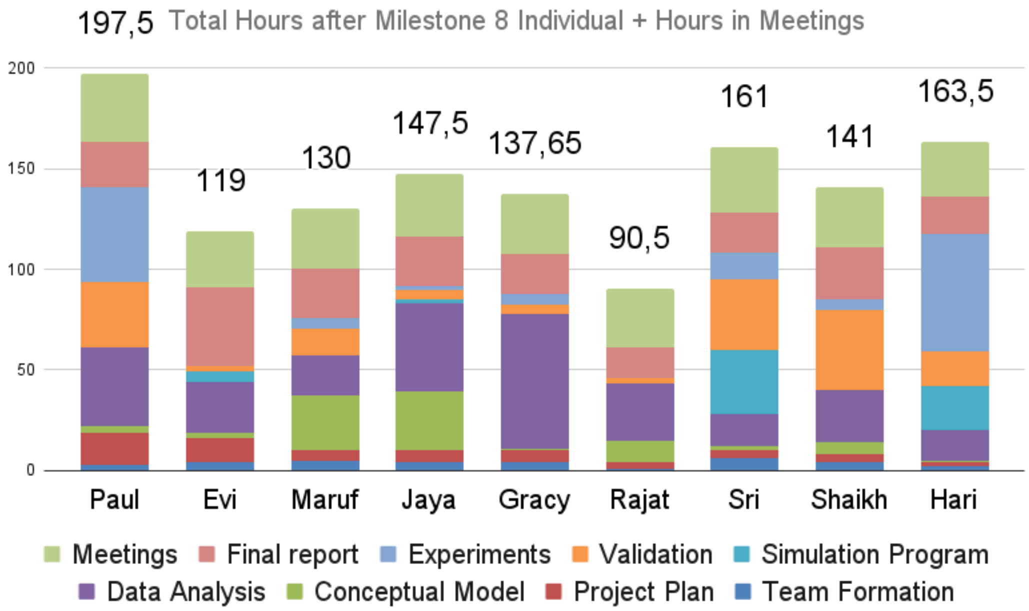

Figure 63: *Hours per Team member spent on Milestones after all Content was completed & the hours spent in meetings*

5.1 Difficulties that arose

- Adaptation to a new team and task combined with inexperience in task specifics, possible problems and time required resulted in a less reliable project plan in the beginning.
- We thought that since we were so many people if we were to split tasks too much we would waste time introducing and coordinating extra team members. This meant most tasks had double assignee's, but the result of this was a struggle with accepting responsibility for the whole task itself.
- When this was combined with an underestimation of task dependencies, we had a staggering project progress. This was nothing we had not anticipated beforehand but nothing to this extent as the delay in Milestone 4 enhanced its negative impact.
- Did not consider individual schedules in the creation of the project plan
- Unexpected issues with the traffic behaviour demotivated and frustrated the team.

5.2 Evaluation of the team

- Most of the people were willing to coach others with the different tools and methods they found for data analysis and were able to demonstrate to the team.
- Based on time availability, knowledge, and workload, we were able to identify any issue and resolve it quickly and easily as a team.
- The team leader was approachable and available for any given suggestion or assistance at all times.
- Constructive feedback was provided and accepted on each meetings by the team leader to encourage and motivate each and everyone.
- Confidence and knowledge level improved.
- Excellent work by the majority of team members in ensuring that everything is completed on time.
- There was a lot of interaction and communication within the team, which resulted in a trusted and engaged workplace.
- We tried to create an environment that encouraged new ideas and solutions.

5.3 Gained experience and learned lesson

We learnt how to analyse the data by hand and also by using OriginPro. Moreover, we mastered ourself to simulate the current model and experiments using AnyLogic software. We learnt to work as a team and collaboratively. We reviewed each of our tasks in a team to know if we are on the right track. We had a project plan and tried to complete our individual tasks within the deadline period. We learnt having a project plan is a key point of a project – helps to keep you on track pointing out at the same moment, what your next task will be so you can prepare accordingly.

5.4 Few words on project experience

"This course prepared us to have more insights into what we are up for and has consequently inspired and challenged us to work on a real-life project which we all felt was astonishingly a perfect opportunity for using our skills. Post initial disquiet of commencing this project in a large team, our realization and anxiety associated with handling this project peaked as it came with the responsibility of using our plan for the betterment of traffic safety in near future by the city. Going through an emotional roller coaster with a few of the milestones, collaborating with each of the team members, encountering uncanny situations, finding availability, and pulling an all-nighter, everything just smoothly settled with the help of a well-planned structure that the course provided. The constant supervision by our coach and advisor guided us to focus a lot more on minor but crucial details, like providing axis labels, formatting, presentation skills, et al. to be presented to the client. Unlike other projects, this course provided us with an abundance of work, and experience and we learned to work on different tools while analyzing data. We built something which we imagined within the stipulated time. This project helped us grow personally and professionally in polishing our skills, formatting and presenting, and overcoming problems within the group. Finally, we would like to sincerely thank each team members for being supportive and with whom we all were delighted to work. Thanking the faculty for providing us with this opportunity."

6 Attachments

6.1 Costs progress based on work packets and milestone-by-milestone

MILESTONE	Planned costs	Actual costs
Team Formation	**6.900 €**	**3.300 €**
Organizational tasks - roles and responsibilities, meetings slots	900 €	900 €
Assessment criteria - personal, team and project criteria	900 €	900 €
Photographs of current traffic situation and junction	900 €	400 €
Decide, print and sign team goal	900 €	300 €
Create the milestone powerpoint	600 €	400 €
Meeting hours	2.700 €	0 €

Figure 64: *Planned vs. Actual costs based on work packets for Milestone 1*

MILESTONE	Planned costs	Actual costs
Project Plan	**7.700 €**	**8.100 €**
Reorganisation of roles and responsabilities	400 €	900 €
Estimate the cost of the project	600 €	800 €
For each milestone, identify work packets {Each work packet < 7 days]	400 €	1.400 €
Assign a person responsible for each work packet and supporting members	1.800 €	1.800 €
Create the milestone powerpoint	900 €	900 €
Meeting hours	3.600 €	2.300 €

Figure 65: *Planned vs. Actual costs based on work packets for Milestone 2*

MILESTONE	Planned costs	Actual costs
Conceptual Model	**10.600 €**	**11.250 €**
Create a petri net for the model	2.400 €	3.500 €
State assumptions made with reasons and justifications	900 €	900 €
Identifying which data is required	800 €	800 €
Identify the events, their type that describe the system to be modeled	800 €	800 €
Identify the quantities to be measured and state the one to be used	600 €	600 €
State the experiments that will be performed	600 €	600 €
Create milestone powerpoint	900 €	900 €
Meeting hours	3.600 €	2.950 €

Figure 66: *Planned vs. Actual costs based on work packets for Milestone 3*

MILESTONE	Planned costs	Actual costs
Data Analysis	**20.000 €**	**33.265 €**
Data collection for input and output values	6.700 €	12.000 €
Collect and understand the data provided by the city	900 €	3.600 €
Limitations on the accuracy or validity of the data	800 €	900 €
Analyse the data and it's quality	1.800 €	7.065 €
Identify which data is required for validation and how to collect it	900 €	1.800 €
Identify if any more data is required and how to collect it for our model	400 €	900 €
Analyse the difficulties that encountered while obtaining	400 €	900 €
Create milestone powerpoint	900 €	900 €
Meeting hours	7.200 €	5.200 €

Figure 67: *Planned vs. Actual costs based on work packets for Milestone 4*

MILESTONE	Planned costs	Actual costs
Simulation Program	**18.000 €**	**12.150 €**
Define the concept & structure of the program	1.800 €	700 €
Write the program	3.600 €	1.800 €
Work on unforeseen issues	1.000 €	900 €
Identify difference as compared to the conceptual model and justify	800 €	500 €
Verification of the program	1.200 €	700 €
State the current state of the program and highlight possible changes	800 €	400 €
Analyse how the experiments planned can be executed on the program	1.000 €	500 €
Create milestone powerpoint	600 €	600 €
Meeting hours	7.200 €	6.050 €

Figure 68: *Planned vs. Actual costs based on work packets for Milestone 5*

Validation	**13.000 €**	**19.050 €**
Scope of the validity / selective validity	900 €	900 €
Provide a Statement of confidence in your simulation model	400 €	600 €
Compare real & simulated data	4.000 €	4.000 €
Identify the limitations to the scope of the validity	600 €	1.200 €
Investigate how to validate the program and validate it	800 €	2.350 €
Analyse the result of the validation	900 €	1.800 €
Make changes in the model as required as a result of validation	900 €	3.600 €
Create milestone presentation	900 €	900 €
Meeting hours	3.600 €	3.700 €

Figure 69: *Planned vs. Actual costs based on work packets for Milestone 6*

MILESTONE	Planned costs	Actual costs
Simulation Experiments	**14.000 €**	**16.900 €**
Description and justification of the validation experiments	900 €	900 €
Model and programm each experiment	6.400 €	8.700 €
Describe the experiment, state & justify the results	1.200 €	1.800 €
Make system recommendations based on the results and justify them	1.000 €	1.200 €
Create milestone presentation	900 €	900 €
Meeting hours	3.600 €	3.400 €

Figure 70: *Planned vs. Actual costs based on work packets for Milestone 7*

MILESTONE	Planned costs	Actual costs
Final Report	**8.400 €**	**24.450 €**
Prepare an argument proving the clients money was well invested	300 €	900 €
Gather and summarize overview of each milestone	600 €	3.500 €
Decisions and assumptions made with justifications	1.200 €	1.200 €
Overview of spending and statement of Profit/loss	400 €	400 €
State key learnings and experience gained	900 €	900 €
Create final report	4.200 €	11.900 €
Create final presentation	800 €	2.000 €
Meeting hours	3.600 €	3.650 €

Figure 71: *Planned vs. Actual costs based on work packets for Milestone 8*