Simulation Project

SoSe 2023

Improve Throughput of the Main Road

Hannoversche Str. / Diesdorfer / Ummendorfer Str.

Final Report

Team B

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Lastly, we would like to acknowledge and commend each member of our team. Their unwavering support, dedication, and honesty have been commendable. Despite the uncertainties, and challenges we faced, they remained steadfast and provided valuable ideas that contributed to the improvement of our project. Their support and unity have been pivotal to our success.

Once again, we express our sincere gratitude to all those mentioned above and everyone else who contributed to the realization of this project. Without their help, this accomplishment would not have been possible.

OVERVIEW

Simulation is a powerful technique that allows us to model and manipulate real-life projects using computer-based systems. It involves utilizing significant resources to create a virtual representation of the project. By adjusting variables within the simulation model, we can evaluate and predict the behavior of the system.

The main purpose of developing a simulation model is to study the performance of the system over time. Through careful validation of the model, we ensure its accuracy and reliability in representing the real-life scenario. Once validated, the simulation model can be used to conduct numerous experiments, mimicking various real-life situations, in order to predict performance and understand the potential impact of different variables.

Simulation offers several advantages. It allows us to explore and analyze different scenarios without the need for costly and time-consuming physical implementations. By running virtual experiments, we can assess the system's response, identify potential bottlenecks or inefficiencies, and make informed decisions to improve its performance.

Overall, simulation provides a valuable tool for understanding complex systems, predicting their behavior, and optimizing their performance. It helps us gain insights that may not be easily achievable through other means, enabling us to make informed decisions and improve real-life projects.

In this project, our focus was on simulating the traffic flow on Hannoversche Str. and other important roads connected to it. The objective was to enhance the throughput of Hannoversche Str., the main road under consideration. To achieve this goal, we executed four simulation experiments. Before conducting these experiments, we ensured the validation of our simulation model. Based on the outcomes of the experiments, we formulated recommendations for the City of Magdeburg.

This report follows a milestone-by-milestone format and covers various key aspects of the project, including:

Conceptual Model: We began by developing a conceptual model, outlining the main elements and interactions of the traffic system in the project area. This model provided a high-level understanding of the system dynamics.

Data Analysis: We collected and analyzed historical traffic data, which served as a basis for calibrating and validating our simulation model. This step allowed us to ensure that our model accurately represented the real-world traffic conditions.

Simulation Model: Using the collected data and the conceptual model, we constructed a simulation model that replicated the behavior of the traffic system. This model considered various factors such as traffic volume, road capacity and traffic signal timings.

Verification & Validation: To ensure the accuracy and reliability of our simulation model, we conducted verification and validation processes. Verification involved checking the correctness of the model implementation, while validation involved comparing the model's outputs with real-world observations. These steps ensured the model's fidelity and suitability for experimentation.

Experiments: After model validation, we proceeded with conducting four simulation experiments aimed at improving the throughput of Hannoversche Str. Each experiment involved manipulating different variables such as signal timings, lane configurations, or traffic diversions. The experiments allowed us to assess the impact of these changes on traffic flow and identify effective strategies for enhancing throughput.

Throughout the project, we encountered various milestones and learned important lessons at each stage. These lessons contributed to the refinement and improvement of our approach, ensuring the robustness of the simulation model and the reliability of our recommendations.

In conclusion, this report provides a comprehensive overview of the project's key features, from the conceptual model to the execution of experiments, culminating in recommendations for the City of Magdeburg. It also highlights the valuable lessons learned during each milestone, which can be applied to future projects in the field of traffic simulation and optimization.

OUR GOAL

Our team goal is to learn more about the practical application of Simulation by successfully completing a project in a real-world scenario. At the same time, we intend to practice other aspects of working together as a team such as effective communication, accountability, punctuality, adjustability, and adaptability to achieve a common goal. We are determined to complete every milestone of this project within the prescribed deadline and provide the highest quality results by means of applying our previous knowledge in the area, thinking critically and analytically in a collaborative manner. We are a team of six members and each one of us has been delegated with a role within the project to better handle the various requirements. Irrespective of this delegation we will work together in every area and make sure that the workload is distributed equally among all the team members. In the end, we will ensure that every member of our team enjoyed working on this project contributing to the infrastructural development of the city of Magdeburg and learned something that will help us in both professional and in personal life.

April 20, 2023

Signed,

1. Karthikeyan Muthukumar - Team Leader
2. Rahul Pothanchery - Conceptual Model
3. Juwana Jose - Input Data Analyst
4. Ijaaz Muhammed Mullamangalam - Chief Software Architect
5. Oleeviya Babu Poikarayil - Validation and Quality Control
6. Gregor Göpfert - Experiment Designer

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MILESTONE 1

PROJECT INTRODUCTION & TEAM FORMATION

1.1 INTRODUCTION

The objectives of this project were defined with the aim of both learning and achieving successful outcomes. The main objectives were:

1. Practical Application of Simulation: The project aimed to provide a practical learning experience by applying simulation techniques to a real-world scenario. By working on this project, the team members were able to gain hands-on experience in developing and utilizing simulation models to address real-life challenges.

2. Team Dynamics Improvement: Effective teamwork was emphasized throughout the project. The objectives included enhancing communication skills, fostering a sense of accountability, maintaining punctuality, and demonstrating adaptability and adjustability. By working together towards a common goal, the team members aimed to improve their collaboration and teamwork abilities.

3. Milestone Achievement: The project emphasized the importance of meeting deadlines and completing each milestone within the prescribed timeframe. This objective aimed to develop a sense of commitment and determination among team members to ensure timely progress and successful completion of the project.

4. Application of Previous Knowledge and Analytical Skills: The project encouraged the application of previously acquired knowledge, critical thinking, and collaborative analytical skills. The team members were expected to utilize their expertise and think critically to address challenges, make informed decisions, and deliver high-quality results.

By aligning the project objectives with these core areas, the team members were able to enhance their understanding of simulation techniques, improve their teamwork skills, demonstrate commitment to project milestones, and apply their knowledge and analytical abilities effectively. These objectives provided a clear direction and focus for the team, leading to a successful project outcome.

1.2 PROBLEM STATEMENT

The problem statement for this project revolves around the issue of traffic congestion and its negative impacts on the city of Magdeburg. Specifically, the focus is on improving the traffic flow i.e. throughput at the intersection of Hannoversche Str., Diesdorfer Str., and Ummendorfer Str. The team aims to address this problem through data analysis and the coordination of traffic lights at the intersection.

The main points of the problem statement are as follows:

Traffic Congestion: Traffic congestion is a prevalent problem in Magdeburg, leading to various adverse effects on the quality of life, the environment, and the economy. The team recognizes the significance of tackling this issue to enhance the overall transportation experience in the city.

Intersection Improvement: The specific area of focus for the project is the intersection of Hannoversche Str., Diesdorfer Str., and Ummendorfer Str. The team aims to identify measures to improve traffic flow and enhance safety at this critical junction.

Data Analysis: To address the problem, the team will analyze relevant data on vehicle counts, inter-arrival times and queue length. These analyses will provide insights into the current situation, enabling informed decision-making and the development of effective solutions.

Traffic Light Coordination: The team will explore the coordination of traffic lights at the intersection as a potential solution to improve traffic flow and safety. By optimizing signal timings and considering the effects on the side roads, the team aims to enhance the overall efficiency of the intersection.

Future Traffic Planning: The findings and recommendations derived from this project will not only address the immediate problem but also serve as valuable insights for future traffic planning in Magdeburg. The team's work will contribute to the city's ongoing efforts to optimize traffic management and enhance the overall transportation infrastructure.

By addressing the problem of traffic congestion at the specified intersection and providing data-driven recommendations, the team aims to make a positive impact on traffic flow, safety, and the overall urban environment in Magdeburg.

1.3 TEAM MEMBERS

Each team member has been assigned specific roles and responsibilities within the project.

The **team leader**, **Karthikeyan Muthukumar**, will oversee the overall coordination and management of the team, ensuring smooth progress and effective collaboration.

Rahul Pothanchery focuses on developing the **conceptual model**, which involves understanding the traffic system, its components, and their interactions to create a high-level representation of the project using petri nets.

Juwana Jose will handle the **input data analysis**, collecting and analyzing relevant data such as vehicle counts, traffic light timings, and inter-arrival times. This data analysis will form the basis for decision-making and recommendations.

Ijaaz Muhammed Mullamangalam is responsible for the **software architecture**, ensuring the development of a robust and efficient simulation model. As the chief software architect, Ijaaz will design and oversee the implementation of the simulation model.

Oleeviya Babu Poikarayil is responsible for **validation and quality control**, ensuring that the simulation model and its outputs meet the required standards and accuracy. They will verify the results, perform quality checks, and validate the model against real-life data.

Gregor Göpfert will take charge of **experiment design**, planning, and execution. This role involves identifying variables to manipulate, designing scenarios, and analyzing the outcomes of the simulation experiments.

Each team member's expertise and assigned responsibilities contribute to the successful completion of the project. Through effective collaboration and the utilization of their individual skills, the team aims to achieve the project objectives and deliver high-quality results.

1.4 PROJECT SITE

Hannoversche Str. is located in the city of **Magdeburg, Germany**. It is one of the major roads in the city and serves as a crucial transportation route. Here are some details about the location and overall traffic conditions in that area:

Location: Hannoversche Str. is situated in the southern part of Magdeburg, running approximately north-south. It starts at the intersection with Große Diesdorfer Str. and continues southward, intersecting with other important roads such as Diesdorfer Graseweg, Kümmelsberg, and Ummendorfer Str.

Importance: Hannoversche Str. is a significant thoroughfare in Magdeburg, connecting various residential areas, commercial districts, and other major roads. It plays a vital role in facilitating the movement of vehicles and commuters within the city.

Traffic Conditions: As a major road, Hannoversche Str. experiences a significant amount of traffic throughout the day. The traffic conditions can vary depending on the time of day, with peak hours witnessing higher volumes of vehicles. Congestion and delays are common during these peak periods, particularly during morning and evening rush hours. **In this project, we primarily focus on the evening rush hours.**

Intersection Challenges: The intersection of Hannoversche Str. with Große Diesdorfer Str., Diesdorfer Graseweg, Kümmelsberg, and Ummendorfer Str. poses specific challenges due to the convergence of traffic from multiple directions. These challenges may include congestion, traffic signal coordination, pedestrian safety, and the smooth flow of vehicles in different lanes.

Transportation Infrastructure: The area around Hannoversche Str. is well-served by transportation infrastructure, including traffic signals, pedestrian crossings, and public transportation options. The road is typically multi-lane, accommodating a significant volume of traffic.

Future Planning: Due to the ongoing traffic congestion issues and the importance of Hannoversche Str. as a transportation artery, the city authorities in Magdeburg may be actively engaged in planning and implementing measures to improve traffic flow, enhance safety, and address the overall transportation needs of the area.

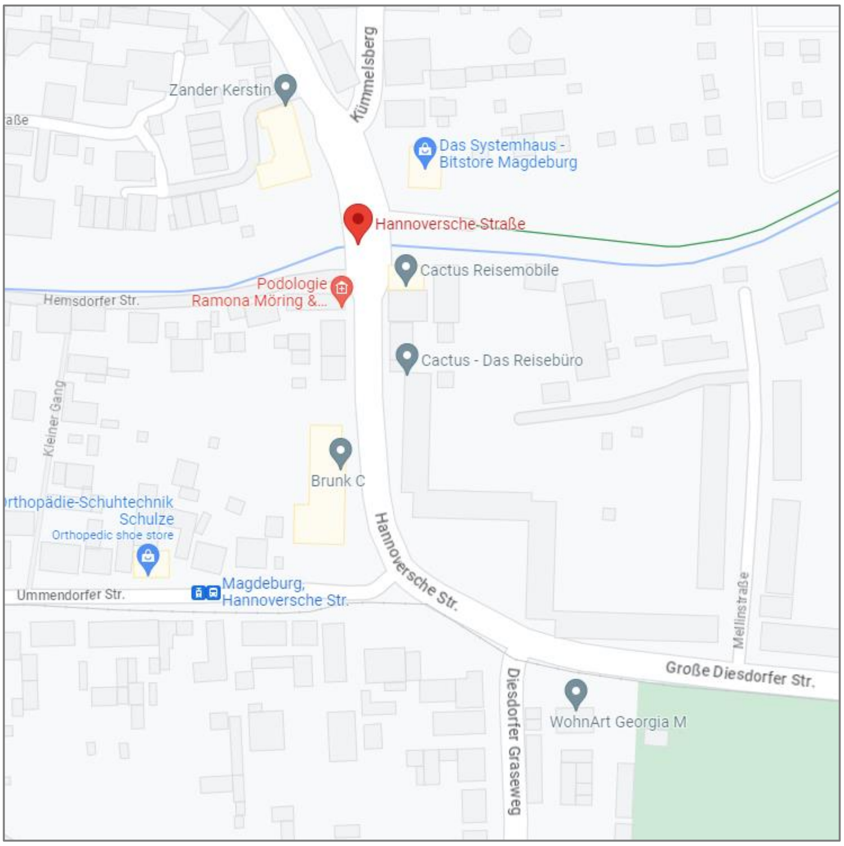


Fig. 1.1 *Map of the Project Site*

Fig. 1.2 *Aerial View of the Project Site (Satelite Image)*

1.5 DATA COLLECTION

Initially, the team planned to collect the following data for the project:

Frequency of vehicles/Types of vehicles: This data would help understand the volume and composition of traffic on Hannoversche Str. Different vehicle types, such as cars, motorcycles, trucks, etc., would be considered.

Timing of traffic signals: The team intended to collect information about the timing patterns of traffic signals at the intersection. This data would provide insights into the current signal phasing and cycle lengths.

Trams and buses timing: Data related to the timing and frequency of trams and buses along Hannoversche Str. would be collected. This information is crucial for considering the impact of public transportation on traffic flow.

Frequency of pedestrians and bikes: The team planned to observe and record the number of pedestrians and bicycles using the road. This data would be useful for understanding the interaction between different modes of transportation.

Legal parameters and other information: Parameters such as speed limits, accident reports, road regulations, and any other relevant legal information would be collected. These details would contribute to the overall understanding of the road conditions and safety considerations.

Inter-arrival time: The team aimed to measure the time gap between successive vehicles at the intersection. This data would help analyze the flow and spacing of vehicles, which is essential for modeling and simulation.

However, as the project progressed, the team might have made changes to the data collection plan based on the evolving needs and insights gained during the initial stages. Adjustments could be made to capture additional data or modify the parameters depending on the specific requirements of the simulation model and the objectives of improving traffic flow and safety at the intersection.

1.6 EXPERIMENTS TO CONDUCT

The following are the list of experiments planned by the team as we entered in to the project,

1. Removal of the Second Signal from Große Diesdorfer Str. allowing a free right access to Hannoversche Str.

2. Conversion of Double Line Tram Track into a Single line facilitating increased vehicle movement on Ummendorfer Str.

3. Installing a roundabout in the junction of Hannoversche Str., Diesdorfer Str., Diesdorfer Grasweg

4. Changing the location of Hannoversche Str. Bus Stop

These are tentative experiments that were planned at the beginning of the project. But as we progressed we were able to realize the feasibility of the experiments planned. Accordingly, a few modifications were made and some of them were added and some were removed to achieve the final goal of the project.

1.7 QUALITY CRITERIA

Completeness of Analysis: The project's analysis should be comprehensive, considering all relevant factors and data. It should provide a thorough understanding of the traffic conditions, challenges, and potential solutions at the intersection of Hannoversche Str., Große Diesdorfer Str., Diesdorfer Graseweg, Kümmelsberg, and Ummendorfer Str.

Effectiveness of Solutions: The proposed solutions and experiments should be evaluated based on their effectiveness in improving traffic flow and safety. The impact of each solution should be measurable and aligned with the project objectives.

Effective Communication Within the Team: Communication among team members should be clear, consistent, and efficient. Regular updates, discussions, and coordination are essential to ensure smooth progress and effective collaboration.

Timely Completion of Tasks: Each milestone, task, or deliverable should be completed within the prescribed deadlines. Timely completion ensures project progress and allows for necessary adjustments or refinements as needed.

Work Within the Budget: The project should adhere to the allocated budget and resources. Effective budget management ensures the efficient utilization of resources and avoids unnecessary costs or delays.

Making Reasonable Assumptions: Assumptions made during the project should be reasonable and well-justified. They should be based on available data, expert knowledge, and realistic expectations. Clear documentation and communication of assumptions will help maintain transparency and facilitate future evaluations.

By adhering to these quality criteria, the project can ensure a comprehensive and effective approach towards improving traffic flow and safety at the intersection. Regular monitoring and evaluation of the criteria throughout the project's lifecycle will contribute to its success and the achievement of desired outcomes.

1.8 GENERAL PERFORMANCE CRITERIA FOR THE TEAM

Quality of Work: Team members should consistently deliver high-quality work that meets or exceeds the established standards and requirements. This includes accuracy, attention to detail, and adherence to best practices.

Attendance at Team Meetings: Team members should actively participate in team meetings, both in person and virtually. Regular attendance ensures effective communication, collaboration, and alignment among team members.

Contribution to Team Goals: Each team member should actively contribute to achieving the team's goals and objectives. This includes sharing ideas, insights, and expertise, as well as actively participating in decision-making processes.

Meeting Personal Deadlines: Team members should be responsible for managing their tasks and completing them within the agreed-upon deadlines. Meeting personal deadlines ensures the smooth progress of the project and avoids delays in the overall team's work.

Contributing to Team Discussions: Team members should actively engage in team discussions, providing constructive input, actively listening to others' perspectives, and promoting a collaborative environment. Effective communication and active participation enhance the overall team's performance.

Showing Creativity and Innovation: Team members should demonstrate creativity and innovation in their work, bringing fresh ideas and approaches to problem-solving. Encouraging innovative thinking fosters continuous improvement and enhances the team's overall performance.

Taking Initiative: Team members should proactively take initiative in identifying and addressing project-related challenges, suggesting improvements, and seeking opportunities for growth. Taking ownership and showing initiative contribute to the team's overall success.

By evaluating team members based on these performance criteria, the team can ensure a high level of individual and collective performance, leading to successful project outcomes. Regular feedback, communication, and support from the team leader and peers are essential in fostering a positive and productive team environment.

1.9 LESSONS LEARNED

Team Formation: We learned the importance of team formation in Milestone 1. Assembling a diverse team with complementary skills and expertise was crucial for the project's success. We recognized that effective collaboration and communication within the team were essential for achieving our goals.

Setting Clear Goals: Milestone 1 taught us the significance of setting clear and specific goals. By clearly defining the objectives and deliverables for this milestone, we were able to establish a shared understanding of what needed to be accomplished. This clarity helped us stay focused and motivated throughout the milestone.

Effective Communication: Milestone 1 highlighted the value of effective communication within the team. Regular team meetings, updates, and discussions allowed us to share progress, exchange ideas, and address any challenges or concerns. Open and transparent communication fostered a collaborative environment and kept everyone aligned with the project's objectives.

By reflecting on these general lessons learned, we can improve team dynamics, goal setting, and overall project performance as we progress through future milestones. These insights will guide us in forming a cohesive and productive team, setting clear goals, and maintaining effective communication throughout the project's lifecycle.

MILESTONE 2

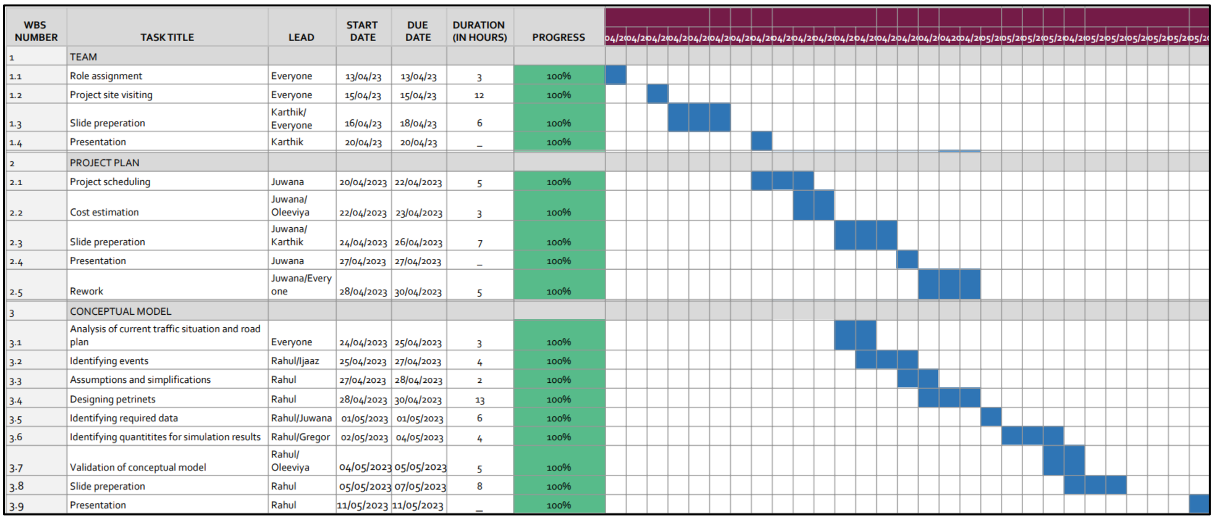
PROJECT PLAN

2.1 INTRODUCTION

The second part of the project was to devise a project plan that would effectively enable us to reach our goals at the right time. Project planning is one the key factor that helps us to identify upcoming risks, monitor the progress and delay, evaluate the performance, and stay within the budget. Hence, this milestone held us responsive with some crucial tasks and decisions that required great coordination and time.

2.2 PROJECT SCHEDULE

Project plan mainly includes procedures like project scheduling, budget estimation, project progress monitoring etc. Project schedule shows the tasks to be completed in each milestone in the form of work packets, duration of these tasks, people involved in each task etc. We used a Gantt chart to represent the project schedule. Also, a Gantt chart helps us to monitor the progress and understand the future changes in the project that could arise in case of a lag in any milestone or tasks. We were able to stick on to the project schedule to an extent, however we had a few ups and downs as well. We had a few deviations in terms of duration of the tasks but in the end, we were able to stay on track. The image below shows a small part of our project schedule.



WBS NUMBER	TASK TITLE	LEAD	START DATE	DUE DATE	DURATION (IN HOURS)	PROGRESS
1	TEAM					
1.1	Role assignment	Everyone	13/04/23	13/04/23	3	100%
1.2	Project site visiting	Everyone	15/04/23	15/04/23	12	100%
1.3	Slide preperation	Karthik/ Everyone	16/04/23	18/04/23	6	100%
1.4	Presentation	Karthik	20/04/23	20/04/23	_	100%
2	PROJECT PLAN					
2.1	Project scheduling	Juwana	20/04/2023	22/04/2023	5	100%
2.2	Cost estimation	Juwana/ Oleeviya	22/04/2023	23/04/2023	3	100%
2.3	Slide preperation	Juwana/ Karthik	24/04/2023	26/04/2023	7	100%
2.4	Presentation	Juwana	27/04/2023	27/04/2023	_	100%
2.5	Rework	Juwana/Every one	28/04/2023	30/04/2023	5	100%
3	CONCEPTUAL MODEL					
3.1	Analysis of current traffic situation and road plan	Everyone	24/04/2023	25/04/2023	3	100%
3.2	Identifying events	Rahul/Ijaaz	25/04/2023	27/04/2023	4	100%
3.3	Assumptions and simplifications	Rahul	27/04/2023	28/04/2023	2	100%
3.4	Designing petrinets	Rahul	28/04/2023	30/04/2023	13	100%
3.5	Identifying required data	Rahul/Juwana	01/05/2023	01/05/2023	6	100%
3.6	Identifying quantitites for simulation results	Rahul/Gregor	02/05/2023	04/05/2023	4	100%
3.7	Validation of conceptual model	Rahul/ Oleeviya	04/05/2023	05/05/2023	5	100%
3.8	Slide preperation	Rahul	05/05/2023	07/05/2023	8	100%
3.9	Presentation	Rahul	11/05/2023	11/05/2023	_	100%

Fig 2.1 *Project Plan - Gantt Chart*

2.3 BUDGET ESTIMATION

The budget allotted for the project was 60,000 euros with 100 euros for each working hour. We had a total of 600 working hours and each person had a 10,000 euros budget with 100 working hours. We estimated a total budget of 55,800 euros that was distributed according to the difficulty of each milestone and number of hours required for the same. Estimating the right budget not only helps us to calculate the profits but also helps to measure the progress and regress that we encounter throughout the project. The table below shows the budget that we estimated for each milestone:

Milestone #	Milestone	Estimated budget
1	Team formation	2100 €
2	Project plan	2000 €
3	Conceptual model	5000 €
4	Data analysis	16,700 €
5	Simulation program	11,300 €
6	Validation	8600 €
7	Experiments	2100 €
8	Final report	8000 €

Table 2.1 *Estimated Budget*

2.4 PROJECT PROGRESS

The project progress is analyzed based on the number of working hours allotted for each milestone, actual hours spent on each milestone associating deviation between planned and estimated working hours. The Gantt chart was used to monitor the progress and the progress after each milestone was represented using a project progress diagram. A clear representation of this data not only helps us to stay on track but also helps us to convince the client about our working plan and efficiency.

2.5 LESSONS LEARNED

- Scheduling a project for a long-term period requires research and accurate planning. We learned more about this process
- Creation of work packets according to the requirements in every milestone is a very important factor of project planning
- Estimation of cost for task or procedure is based on several factors including the difficulty of the task, time and human resource required etc. The project cost estimation was a very important lesson we learned in this milestone
- Estimation of project progress is directly linked with the working hours. Project progress helps to keep a track of our performance and the possible risks that may arise in the future. Learning how to compute project progress benefited us in a great way throughout the project

MILESTONE 3

CONCEPTUAL MODEL

3.1 INTRODUCTION

In this milestone, we have developed a conceptual model for the system. The purpose of a conceptual model is to represent a system using assumptions and abstractions, allowing us to gain knowledge, understanding, and simulate the behavior of the real system. While the complete modeling of the real-world system is not achieved, we have maintained a certain level of abstraction. During the modeling process, we made certain assumptions and identified specific quantities to be used as input and output parameters. To construct the model and provide a clear representation of the system, we employed the Stochastic Petri Net (SPN) modeling technique. This technique allowed us to create the model through idealization and simplification.

3.2 ASSUMPTIONS

The following assumptions were made while modelling the SPN,

Neglected the Hermsdorfer straße: We saw that the vehicle movement through Hermsdorfer staße is very minimal and it has no much effect on the traffic on the main road, so we have neglected this street from our system.

Traffic lights functioning based on fixed timings: The traffic lights in our system is really dynamic, therfore it will be very difficult to incorporate it into our system. So we assumed that the traffic lights for roads and pedestrians function based on fixed timings.

Types of vehicles: We assumed that every vehicle will be a car having same length and will be moving with the same speed through the system.

Tram as a custom agent: There is a tram line through our system. Since it runs through the road we planned to model the tram as a custom agent with a length of 30m.

Modelled for the evening rush hour: The system we modelled is designed to mimic the evening rush hour of a regular day, based on the fact that the performance of the nodes throughout the day is always better than or equal to that during its peak hours.

Everyone follows the rules: We assumed that everyone in the system follows the rules. That is no one takes u-turns, violates traffic rules etc; thus preventing any kind of accidents in the system.

3.3 PETRINET

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

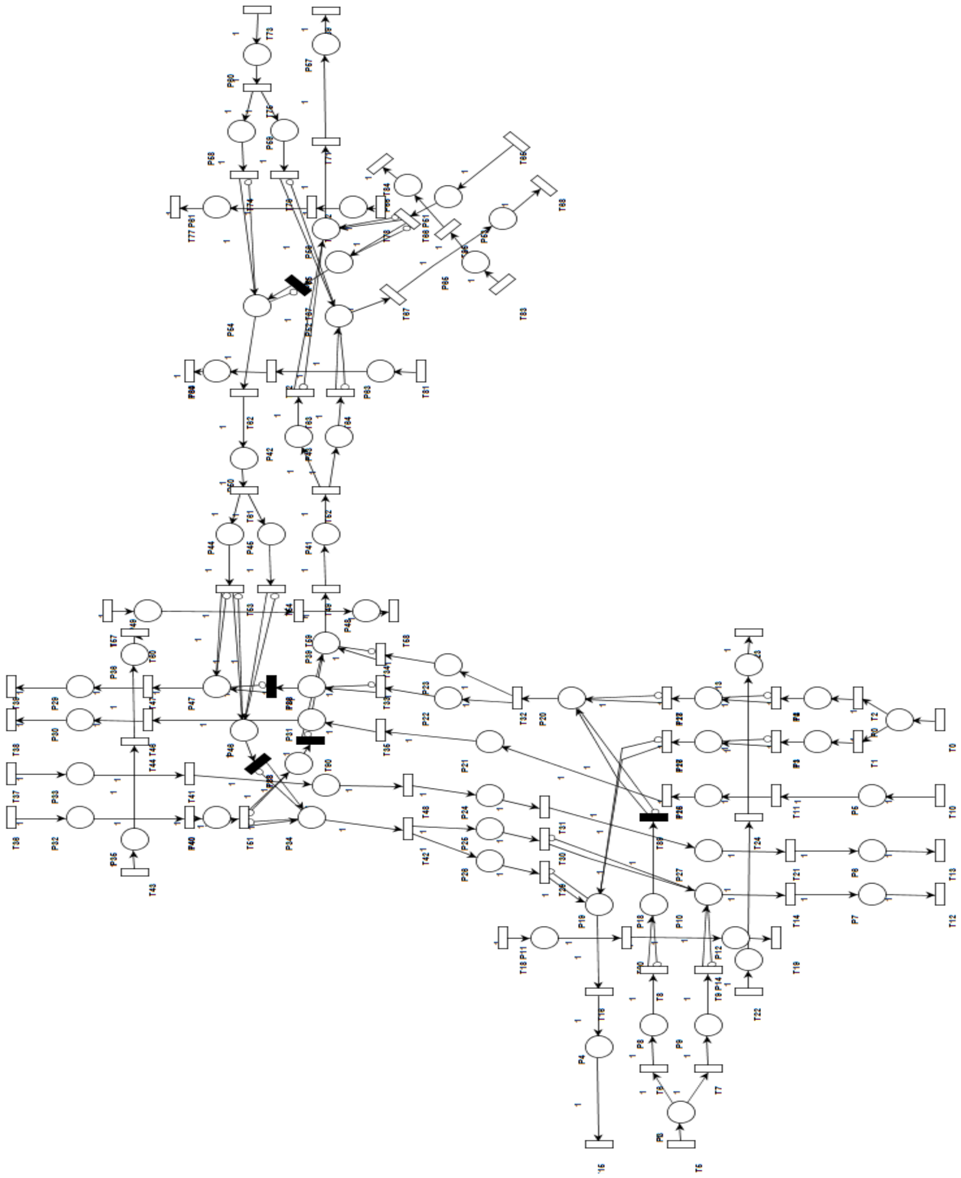


Fig 3.1 *Conceptual Model using SPN*

3.4 EVENTS, TYPES AND DISTRIBUTIONS

Arrival of vehicles/trams/pedestrians: The arrivals at the nodes are considered as a primary event and as it is very random, it is of stochastic distribution type.

Traffic lights changing colors: It is also considered as a primary event. Since we are considering fixed timings for traffic lights it is of deterministic distribution type.

Vehicles/trams/pedestrians moving to the next place: It is a secondary event as this event can only happen after some conditions are met like the signal turning green etc; Since this is also random it is of stochastic distribution type.

Vehicles/trams/pedestrians exiting the system: It is a secondary event as it can happen only if there is a vehicle to exit the system. It is also random and is of stochastic distribution type.

3.5 QUANTITIES TO BE MEASURED

With the goal of improving the throughput of the main road, we identified quantities that would be required as input to the model and the ones that we intended to use as simulation results

Input variables

1. Inter-arrival time of vehicles/trams/pedestrians on all nodes
2. Average length of vehicles
3. Probability of vehicles turning to different lanes
4. Average speed and acceleration of vehicles
5. Traffic light phase timings

Output variables

1. Average queue length
2. No. of vehicles exiting the nodes
3. Average time spent by vehicles in the system

Quantities to be used for simulation results

As results of our simulation, we decided to we use the variables ’Average queue length’,

‘No. of vehicles exiting the nodes’ and ’Average time spent by vehicles in the system’ as these data could be easily recorded in our simulation model and also collected from the real-world, thus enabling us to validate the model.

3.6 EXPERIMENTS PLANNED

As a part of this milestone, we planned for some experiments to be implemented in the later stages of the project. We realized that only on analysing the simulation data we would have a better understanding of the problems that may be affecting the system. 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 later stages of the project. The experiments agreed upon at this stage are listed below.

Removing a traffic signal: We plan to remove the second signal while coming from the Große Diesdorfer straße, thus allowing a free right and reducing the waiting time in the node. The vehicles will stop whenever there is a pedestrian who wants cross the road.

Combining tram lanes into one: There are two lanes for trams on the road. Since there are only two stops for the tram to end its journey we plan to combine the two lanes into one, thereby the tram goes and comes through same lane.

Subway for pedestrians: We plan to build a subway for pedestrians across the Hannoversche straße. So it eliminates the need of two traffic light on the node.

Optimizing the traffic signals: We plan to optimize the traffic light timings to get the best possible output

3.7 LESSONS LEARNED

- We learned to model a real life system
- We understand that the model should be flexible, so that we can accommodate the changes made later in the project
- We realized that the conceptual model is the stepping stone for the project
- Pool knowledge and skills with better teamwork improves the quality

MILESTONE 4

DATA ANALYSIS

4.1 INTRODUCTION

The basic goal of this milestone was to collect the data required for parametrization of the simulation model. Since it is the first important step towards building the simulation model, this milestone required a lot of work and coordination between the group members.

The Magdeburg city officials provided us with data from 2019 that included traffic light timings, site plans of each road including the details of the traffic detectors, number of vehicles exiting from each road and entering to each road during the morning and evening rush hour timings, accident data on each road etc. In addition to the data available we had to collect some data considering the present real-world scenarios, requirements for the simulation program and validation. Our system consists of five streets including Hannoversche Straße , Große Diesdorfer Straße, Kummelsberg, Ummendorfer Straße and Diesdorfer Grasseweg. Our main goal was to improve the throughput of Hannoversche Straße, which is the main road of all intersections. We mainly focused on the evening rush hours between the timings 3pm and 6pm.

4.2 INPUT DATA

The input data is the data that is given as input to the simulation program to replicate the real-world system. Most of our required input data was provided by the city officials but we also had to collect some data ourselves considering the requirements for high accuracy and novelty. Mentioned below is the input data we required for this project:

1. **Probability of taking a direction:** The probability of vehicles coming from each road and turning to each road was obtained from the city data. We extracted this data by carefully analyzing the city data regarding the number of vehicles exiting or entering each road during the evening rush hours. We could find that most of the vehicles turned towards the Hannoversche Straße and hence it is the region of highest traffic.

2. **Speed:** The initial speed of the vehicle is set to 10km/hour and maximum speed is set to 60 km/hour

3. **Average length of vehicles:** Our system mostly included automobiles and hence we assumed the average length of vehicles as 5 meters.

4. **Traffic light timings:** Our system included 7 traffic lights which operated on detectors. We obtained data from the city that included the traffic light timings of each signal group and the associated site plans with detailed information of the detectors and connecting signal groups.

5. **Inter-arrival times:** This data was collected by us since we required accurate and detailed information as it was the key factor for parametrization of the simulation model. We collected the inter arrival time of vehicles at each node using a stopwatch for 2 hours between 3pm to 5pm.

4.3 OUTPUT DATA

Output data is the data we obtain from the simulation program. This data is required to validate the simulation model and decide the closeness of the model with real-world system. We collected all this data ourselves to compare it with data obtained from the model. Fortunately, we were able to create a valid model. Mentioned below is the output data we required to successfully achieve the goal of this project:

1. **Average queue length:** The average queue length refers to the number of vehicles on the road when the traffic light turns red. This data clearly provides an idea about the throughput of the road and hence it was also used for validation. We collected this data ourselves during the evening rush hour between 3pm to 5pm on a weekday. Our group members split into teams of two and noted the queue lengths at each node in the system.

2. **Average time spent by vehicles in the system:** The information regarding the time taken by a vehicle to travel through the system is very important to decide upon the validity of the simulation model created. Since our goal was to improve the throughput of the road, this data required a very accurate and correct approach. We collected this data ourselves using a stopwatch. Fortunately, the data we collected was in close proximity to the data we obtained from the simulation program.

3. **Number of vehicles exiting the node:** The number of vehicles exiting the node is an important validation data that requires to be considered when it comes to successfully simulating a real-world system. Although we could deduce this information from the data given by the city officials, we needed a much more accurate and recent data set. Hence, we collected this data ourselves during the evening rush hour 3pm to 5pm on a weekday. Each of us stood at a particular node and noted this number.

4.4 ANALYSIS OF THE DATA

The data requires to be properly analyzed before being given as input to the simulation program. Since our system of consideration was huge, we had large amounts of data and deciding upon which data is required, which data given by the city officials can be used and what data needs to be collected were the main challenges we encountered. Finding the distribution of inter-arrival times of vehicles from each node, analyzing the traffic light timings of different signal groups, and finding out the probability of vehicles turning in a particular direction were the most important factors. Most of the input and output data required proper deduction and analysis by careful examination. Mentioned below are the steps we adopted to analyze the data associated:

a) Inter-arrival times of vehicles

a.1 Creating histogram: To guess the distribution type of data, the first step is to draw a histogram. From the shape of histogram, we can guess the distribution type to a great extent. A histogram was created based on the inter-arrival time of vehicles at each node. We generated a histogram in excel for each node. The figure below represents the histogram created for Hannoversche Straße:

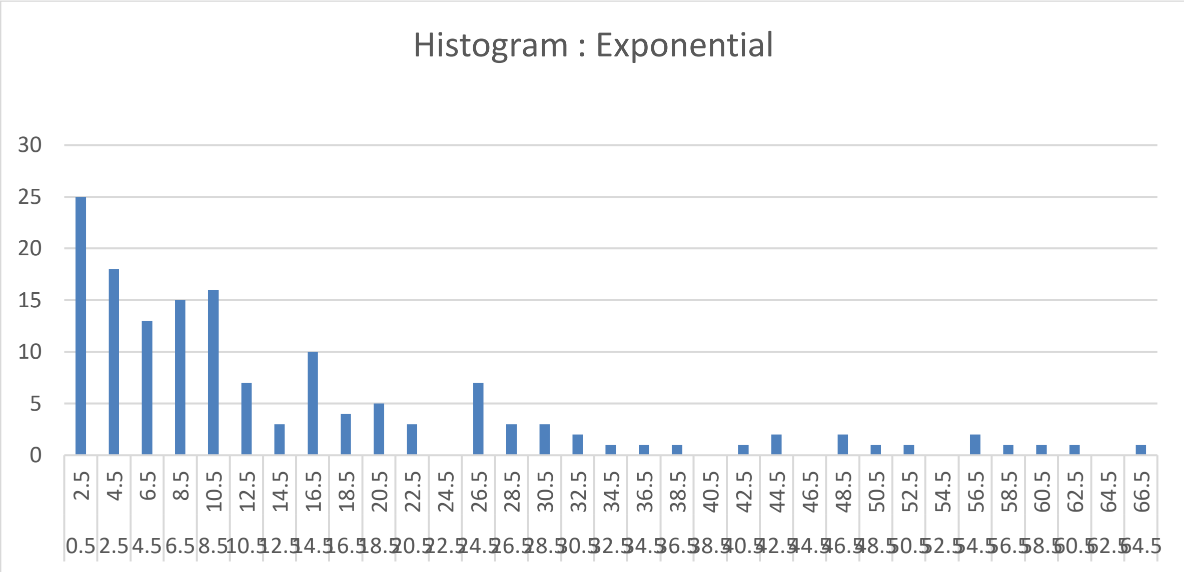


Fig 4.1 *Histogram of Inter-Arrival Times at Hannoversche Str.*

From the shape of the histogram, we could predict that the inter-arrival times at Hannoversche Straße follows an exponential type of distribution. Likewise, we could predict the distribution type for other streets as well.

a.2 Creating quantile-quantile plots: After drawing the histogram, the next step is to generate a quantile-quantile plot (QQ plot). QQ plots are used to access the closeness in agreement of two data sets by graphically plotting their quantile with each other. We generated the QQ plots for each node. The figure below represents the QQ plot for inter-arrival times at Hannoversche Straße:

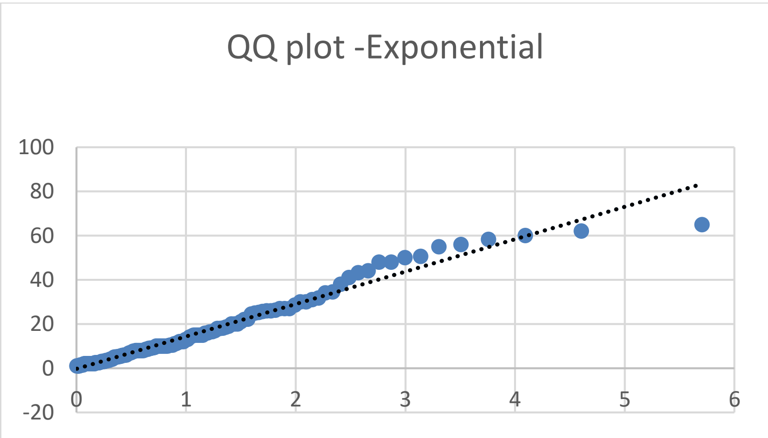


Fig 4.2 *QQ Plot – Hannoversche Str.*

From the histogram we could predict that the type of distribution for Hannoversche Straße could exponential. Hence, we generated the plot the quantile for an exponential distribution. If the two data sets are in close agreement, then the plotted points will lie on the 45-degree line otherwise most of the points do not fall on this line. In this case almost all the points lie on the 45-degree line and hence we could confirm that data follows an exponential type of distribution. Like wise we generated the QQ plots for other nodes as well in order to confirm the distribution type.

a.3 Goodness of fit Chi-square test: Goodness of fit Chi-square test is a type of statistical test used to determine whether the data corresponds to the hypothesised distribution. We adopted the following steps to do the Chi-square test:

* Dividing the data into k classes

* Counting the amount of data in each class (i) and finding the observed (Oi) amount of data

* Determining the expected amount of data (Ei) in each class according to the hypothesised distribution.

* Computing the test static using the formula

* Choosing the level of significance α

* Find the value of χ^2 f, α, where f = k-s-1 and s represents the number of parameters of the distribution

* If $\chi^2 0 > \chi^2$ f, α, then the hypothesis is rejected otherwise accepted. It is important to note that acceptance is not a proof that the hypothesis is right, it means that we are not able to disprove it.

We did the goodness of fit chi-squared test for all the nodes and were able to fit in the distribution except for Große Diesdorfer Straße. Since we have a real-world system under consideration the chances for a data set to not fit in any type of distribution is quite understandable. Hence, we created a custom distribution for this street while giving input in the simulation program.

The figure below represents the results of Chi-squared test for inter-arrival time of vehicles at Hannoversche Straße

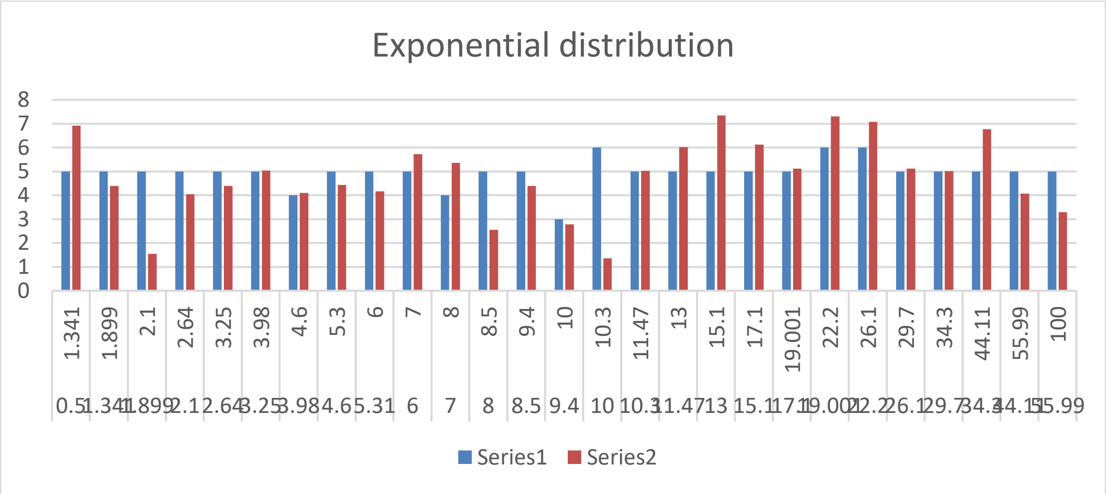


Fig 4.2 *Chi-Squares Test – Hannoversche Str.*

The type of distribution obtained, and the associated parameters were given as input in the simulation program.

The table below represents the overall results of data analysis for each node:

Street	Distribution	n	f	α	Parameters	Chi_0	Chi_stat
Hannoversche	Exponential	134	25	0.9	Mean = 15.3422 λ= 0.06518	34.38159	30.89538
Ummendorfer	Exponential	67	11	0.9	Mean= 35.82433 λ= 0.027914	17.27501	11.1751
Diesdorfer Grasseweg	Gamma	159	7	0.05	α= 3.75 β= 0.8	14.07	8.26
Kummelsberg	Lognormal	120	12	0.05	Mean= 0.931317 Standard deviation= 0.607715	21.03	13.751
Große Diesdorfer	Custom distribution	-	-	-	-	-	-

Table 4.1 *Results of Data Analysis*

4.5 DIFFICULTIES ENCOUNTERED WHILE COLLECTING DATA

- Since we had a huge amount of data from the city officials, we initially faced some difficulty on deciding upon which data we actually require and what data needs to be collected more.
- Collecting the data and converting it to a form as per the requirements is a tedious task especially when we have a large system under consideration. It is difficult to do these tasks alone and dividing these tasks amongst the team members required calls in good communication. This was one the difficulties we faced in the beginning of this milestone and which we eventually tackled really well.
- Most of the data were collected manually using a stopwatch or by noting down in a book. This task required many considerations like the health of team members, weather, communication, coordination etc.
- Determining the type of distribution for a particular data was a time-consuming process that required accuracy and patience as well.

4.6 LIMITATIONS ON ACCURACY AND VALIDITY

- Since we considered only the evening rush hours, a small sample size was a limitation to the accuracy.
- Most of the data was collected manually and are likely to human errors

4.7 LESSONS LEARNED

- We learned how to collect and organize real-world data.
- We learned that organizing the available data in a form understandable to everyone and especially in a way that can be utilized easily for further milestones is a very important factor.
- We learned that as the sample size increases the accuracy of output and the closeness to which the simulation program represents the rea-world system also increases.
- Data analysis is a complex procedure that requires a lot of hard work and time-consuming procedures. This milestone requires the most of teamwork and coordination which we were fortunately able to build and acquire.

MILESTONE 5

SIMULATION PROGRAM

5.1 INTRODUCTION

The objective of this milestone was to create a simulation model that closely resembles our given intersection. To create the simulation model, Anylogic Simulation Software (Personal Learning Edition Version : 8.8.2) is used. The following libraries of Anylogic were employed in designing the model,

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

5.2 PROGRAM CONCEPT AND STRUCTURE

We divided the design into different parts,

- Modeling Vehicles
- Modeling Trams
- Modeling Traffic lights

The design process commenced by constructing a road network based on a scaled map obtained from Google Earth. The Road Traffic Library's space markup elements were utilized to accurately outline the roads and establish the intersection, with the number of lanes on each arm reflecting real-world conditions. Lane Connectors were employed to regulate the permissible directions for vehicles at the intersection's arms.

The space markup shapes used for the construction of road network were,

- Road
- Intersection
- Stopline

Fig 5.1 *Graphical representation of the intersection*

The subsequent step involved creating vehicular traffic. A custom agent named "Car" was developed to represent all the vehicles within the intersection. The flow of vehicle movement was designed using the Road Traffic Library's "Blocks" elements. The "Car-Source" element was used to generate vehicles of the custom agent type and position them at the beginning of each forward lane. The "CarMoveTo" elements were responsible for guiding the cars from one arm of the intersection to another. Upon reaching the end of the road network, vehicles (agents) were removed using the "CarSink" element. The "SelectOutput5" block was utilized to direct incoming vehicles (agents) to specific directions based on probabilities calculated during the input data analysis phase.

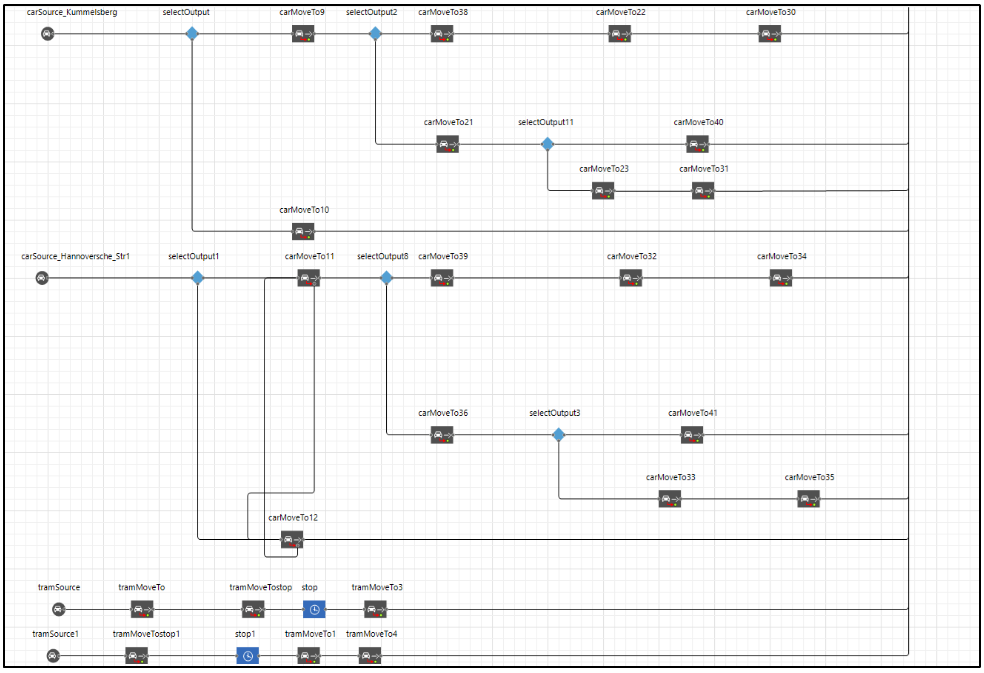


Fig 5.2 *Control Flow logic of Vehicles*

5.3 MODELING TRAFFIC LIGHTS

To model the traffic signals, the city office's SP 4 VA-Nachmitagspitze and SP 5 signal programs were employed.The traffic light patterns were meticulously designed by implementing separate traffic light nodes for each road at the intersections. This allowed for precise control over the timing and sequencing of the traffic lights, ensuring smooth and efficient traffic flow.

To regulate the vehicle flow, a combination of stop lines and traffic light nodes was implemented. Stop lines served as checkpoints where vehicles had to come to a halt when signaled, while the traffic light nodes managed the transition of vehicles based on the programmed signal patterns.

By incorporating these elements, the simulation effectively simulated the behavior of traffic signals and provided an accurate representation of the vehicle flow at the intersection, enhancing the overall realism and accuracy of the model.

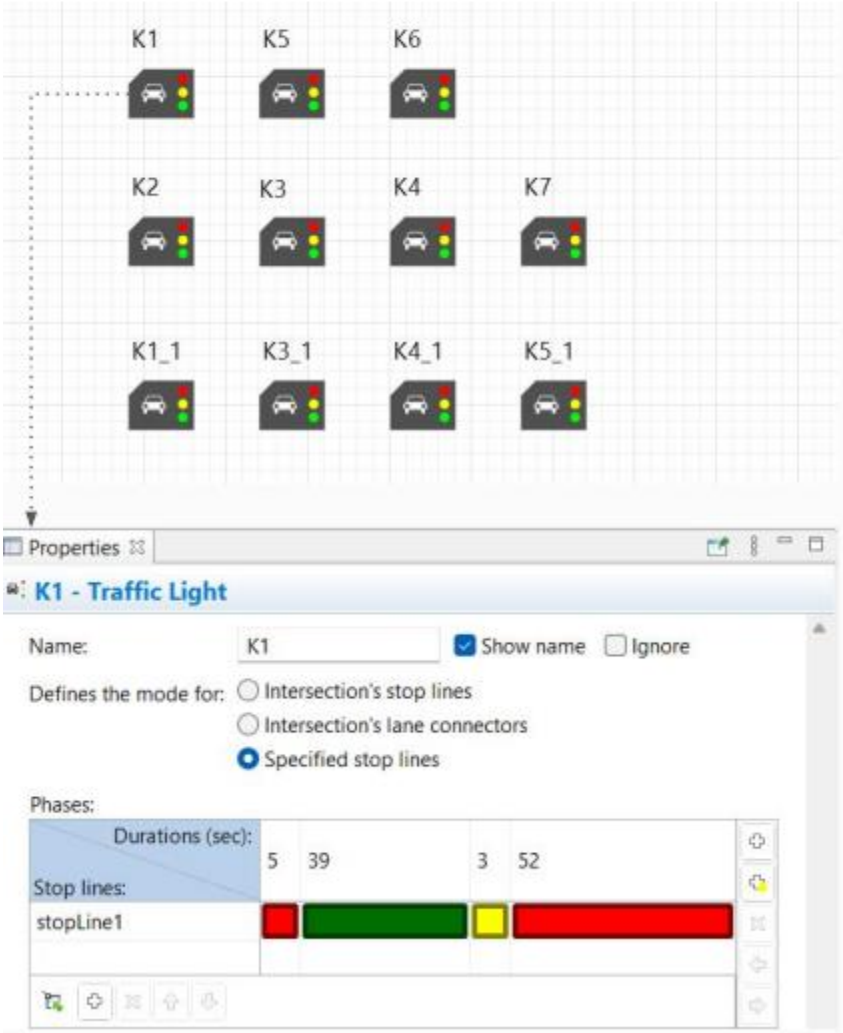


Fig 5.3 *Traffic light representation*

5.4 MODELING TRAMS

A custom agent called 'Tram' was created to represent tram behavior. This agent was created particularly to depict trams in the simulation. Several nodes were used to design and regulate tram movement ,including 'Car Source,' 'Car Move To,' and 'Car Dispose.' These were the same nodes that were also employed in the simulation of vehicle traffic.

The 'Car Source' node was responsible for generating trams, while the 'Car Move To' node facilitated their movement along designated routes within the simulation. Once the trams reached their destinations or completed their assigned tasks, the 'Car Dispose' node was used to remove them from the simulation.

To introduce a realistic waiting time for trams at stops, the 'Delay' feature from the Process Modeling Library was utilized. This allowed for the simulation to accurately represent the pause experienced by trams at designated stops before continuing their journey.

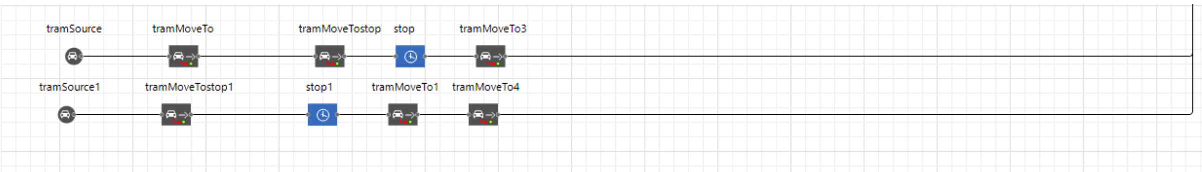


Fig 5.4 *Control Flow logic of trams*

5.5 MODELING PEDESTRIANS

In order to simulate pedestrian behavior, Space Markup elements from the Pedestrians library were employed to define the areas of movement within the road network. A custom agent named "Pedestrian" was developed specifically for representing pedestrians within the simulation.

To generate pedestrians, the "PedSource" element was utilized. This element facilitated the creation of pedestrians at specified locations within the simulation. To direct the movement of pedestrians, the "PedGoTo" element was employed, which allowed pedestrians to be guided to designated target lines.Once pedestrians reached their respective destination points, the "PedSink" element was used to remove them from the simulation.In our system there is 7 different pedestrian crossings present.

To ensure the safety and controlled crossing of pedestrians, separate signals were implemented. These signals were specifically designed to regulate and manage pedestrian crossing within the simulation.

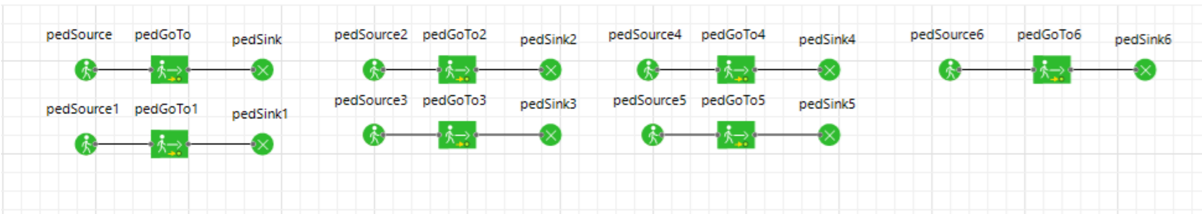


Fig 5.5 *Control Flow logic of pedestrians*

5.6 MODULARIZATION IN THE SIMULATION MODEL

Creation of two intersections in Hannoversche Str-Both the roads in Hannoversche Str. connecting north to south and vice versa, split into two lane roads from a single lane road. 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.

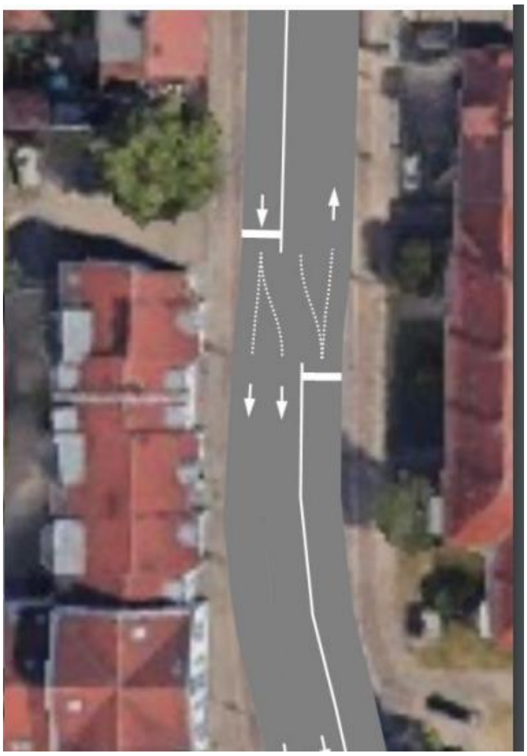


Fig 5.6 *Splitting of a single lane to a two lane road*

- Tram signals were not included in the simulation.In the real world system trams have a separate traffic signals to that of the vehicles but in the simulation model the trams followed the same signals as that of the vehicles
- In our system, trams did not follow the exact path as in the real system due to certain constraints. Instead of having dedicated paths, trams shared the same roads as vehicles. Typically, trams would travel through the leftmost lane of the two-lane road on Grosse Diesdorfer Str., proceed towards Hannoversche Str., and then exit at Ummendorfer Str. However, in our system, vehicles in the left lane were only allowed to make a left turn and exit at Diesdorfer Grasweg Str. Since trams did not have separate signals and followed the same signals as vehicles, they would spawn in the leftmost lane of Grosse Diesdorfer Str. but would switch to the right lane near the intersection, continue towards Hannoversche Str., and exit at Ummendorfer Str., similar to the real system.
- Buses were not included in our model.

5.7 DIFFERENCES BETWEEN THE SIMULATION MODEL AND THE CONCEPTUAL MODEL

The conceptual model did not consider the possibility of vehicles moving forward from the intersection at Ummendorfer Str. Vehicles coming from Hannoversche North in the left most lane had the possibility to turn left and exit at Ummendorfer Str. as well as move forward and exit at Diesdorfer Grasweg Str. In the simulation model, this aspect was rectified and accurately represented.

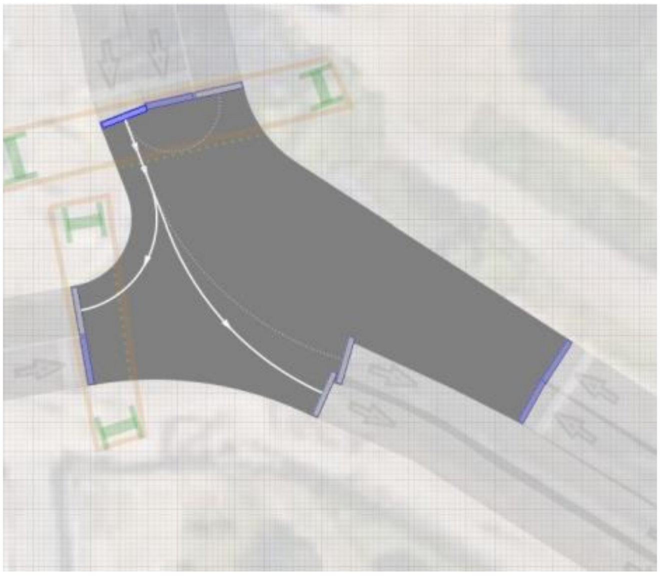


Fig 5.7 *Lane connectors from the left lane at Ummendorfer Intersection*

Discrepancies between the Simulation Model and the Conceptual Model: During milestone 5 of our project, it was observed that the pedestrian crossing feature was not fully implemented in the simulation model. Initially, the conceptual model included pedestrian crossings, but they were not accurately simulated at that stage. However, it is important to note that subsequent progress was made, and the pedestrian crossing feature was later included in our model. We took the necessary steps to represent pedestrian behavior and movement accurately, ensuring a more comprehensive and realistic simulation.

These discrepancies highlight the areas where the simulation model deviated from the conceptual model, indicating the need for further refinement and adjustments to ensure a more comprehensive and accurate representation of the real-world system.

5.8 VERIFICATION OF THE PROGRAM

To ensure the reliability and validity of the simulation program, several steps were taken to verify its functionality and accuracy.

First, a thorough code review was performed, methodically inspecting the program's code. The goal of this study was to uncover possible mistakes, increase efficiency, and assure adherence to recognized best practices.

In addition, the model's face validity was evaluated. This included carefully examining the output of the simulation and comparing it to real-world expectations and observations. Any contradictions or irregularities were recognized and resolved to improve the program's trustworthiness.

Furthermore, extensive testing was performed to ensure that the program was free of compilation issues. This entailed performing thorough compilation tests and error handling in order to discover and address any flaws that may affect the program's performance or operation.

We assured that the simulation program was accurate, dependable, and aligned with the desired objectives by completing these verification processes. This enhanced trust in the program's capacity to precisely depict and simulate the provided junction scenario.

5.9 CHALLENGES ENCOUNTERED

Several issues arose during the project that needed careful examination and problem-solving. The challenges included:

Getting familiar with Road Traffic and Pedestrian Libraries: Understanding the functions and capabilities of the AnyLogic software's Road Traffic and Pedestrian Libraries. This entailed learning how to successfully use these libraries to model and simulate vehicle and pedestrian traffic situations.

Integration of Libraries: Combining the Road Traffic and Pedestrian Libraries to produce a complete simulation model that properly represented vehicle-pedestrian interactions. To achieve smooth integration and accurate simulation results, the two libraries needed to be carefully coordinated and synchronized.

Accurate Traffic Light Modeling is the process of creating an accurate and realistic representation of traffic signals within a simulated intersection.

By addressing these issues, the project team was able to overcome difficulties and effectively construct a robust simulation model that properly portrayed the dynamics of vehicles and pedestrian traffic at the specified intersection.

5.10 LESSONS LEARNED

We got useful insights and lessons during the process that have improved our understanding and approach to simulation modeling. These are some examples:

Real-Life System Modeling: Successfully converting a real-life system into simulation software necessitates thorough consideration of its complexities and dynamics.

Flexibility of the Simulation Model: Creating an adaptable and flexible simulation model enables for simple tweaks and adjustments to correctly reflect real-world scenarios.

Traffic Signal Pattern Complexity: Managing and recreating the complexity of traffic signal patterns proved to be a substantial problem, emphasizing the importance of rigorous analysis and attention to detail.

The Value of Collaboration: Collaborative teamwork was critical in improving the quality of our work, encouraging effective communication, and capitalizing on varied viewpoints to overcome obstacles

By applying these lessons learned, we can further refine our simulation modeling techniques and approach future projects with increased efficiency and effectiveness

MILESTONE 6

VALIDATION

6.1 VERIFICATION

To confirm the accuracy of our simulation model, we went through a rigorous verification process. Our goal was to ensure that the model appropriately captures the behavior of the entities in the conceptual model while taking the underlying assumptions into account. We discovered no contradictions between the behavior of agents in the simulation software and their equivalents in the conceptual model after rigorous study. This procedure of verification proved that our simulation model closely resembles the real-world system.

6.2 VALIDATION

Validation is critical in assessing the accuracy of the simulation model we created. The validation procedure entails comparing simulation results to real-world data in order to evaluate the model's performance within a given range of accuracy. We ran validation experiments with real-world input data to establish that we had really created the correct model. We thoroughly examined the model's validity by comparing the model outputs to our own obtained outputs fromthe nodes. Using this method, we were able to determine if the simulation outputs corresponded to the actual outcomes observed in the real-world system for a given set of inputs.

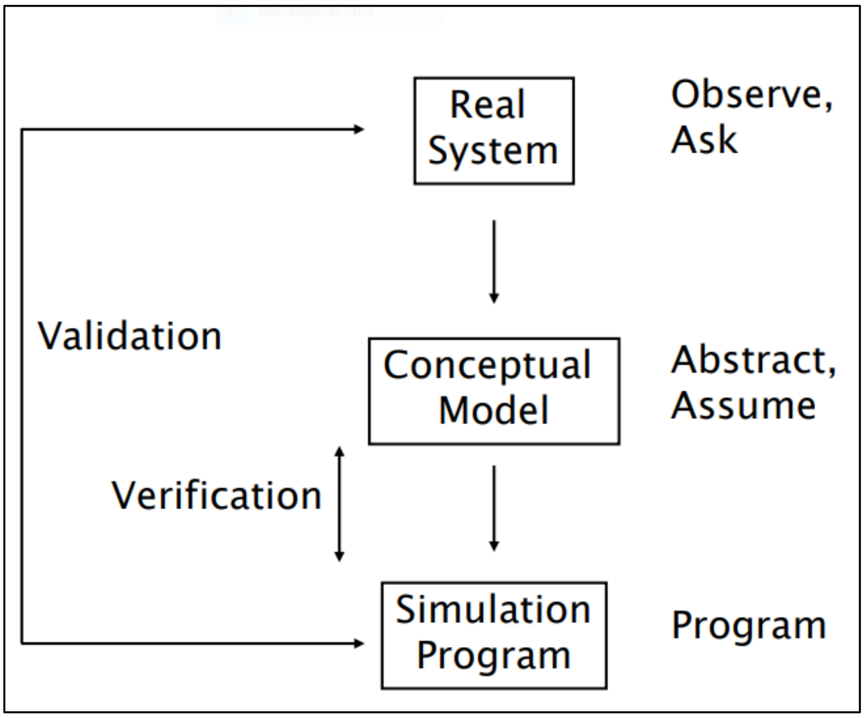


Fig 6.1 *Verification & Validation*

We investigated numerous output variables to assess the validity of our simulation model in contrast to the real world. These factors enabled us to evaluate our model's performance and its alignment with the actual outcomes seen in the real-world system. For this examination, the following output variables were carefully chosen:

1. Throughput: The total number of cars exiting the node is referred to as throughput. We collected data on the number of cars exiting the route during the evening rush hour during the data analysis phase. We were able to calculate throughput by counting the total number of vehicles exiting the node. This measure provides information on the road network's capacity and the model's efficiency in handling traffic flow.

2. Queue Length: This variable counts the number of cars that have accumulated in a street during the time that the traffic light has been "RED" for each cycle. We observed the wait length during an evening rush hour to determine it. We tallied the number of cars gathered in a queue in the respective lane whenever the signal went red. We counted the number of automobiles waiting in line just as the signal turned green again. This gave us important insights on traffic congestion and the effect of traffic signals on queue lengths.

3. Time spent by Vehicles in the system: This variable is concerned with the total amount of time spent by a car within the simulation model. To investigate this element, we focused primarily on the important route known as Hannoversche. We were able to compute the time taken by each car in the system by tracking the entry and exit times of vehicles on this road. This data assists us in understanding the model's overall efficiency and traffic flow.

We were able to completely assess the validity and performance of our simulation model by examining and evaluating these output factors, confirming its correctness in recreating real-world scenarios and offering significant insights for traffic management and planning.

6.3 CONFIDENCE INTERVAL OF VALIDATION RESULTS

To assess the reproducibility of our validation results, we ran 100 replications of the simulation, each lasting an hour. We estimated the upper and lower confidence intervals for each output variable related to each street with a confidence level of 99% (alpha = 0.01).

The mean values of the real-world measured variables were then compared to the confidence intervals produced from the simulated model. The goal was to see if the mean data from the real world fell within these confidence ranges. If the real-world mean data came inside the confidence intervals, it would suggest that the simulation model and the real-world were successfully aligned. However, if the real-world mean data differed from the confidence intervals, further analysis would be required to determine why. It would be important to examine the various variables impacting the variance and consider making appropriate changes to the model.

We hoped to confirm the quality and dependability of our validation results by doing this research and evaluating the relationship between real-world data and confidence intervals derived from the simulation model. This detailed methodology enabled us to discover any differences between simulated and real-world outcomes, providing useful insights for refining and strengthening the model.

6.4 COMPARISON OF REAL-WORLD AND SIMULATED DATA

Based on our validation experiments, we observed that the mean values obtained from the real-world data are generally consistent with the confidence intervals derived from the simulation model. However, there were some discrepancies noted specifically for the queue length and throughput of Ummendorfer Street. For all other streets, the real-world data fell within the upper and lower bounds of the respective confidence intervals.

To present our findings, we have prepared tables and visualizations that illustrate the comparison between the real-world and simulated data.

STREET	LOWER	UPPER	REAL WORLD THROUGHPUT
Hannoversche str.	400.362	428.898	420
Kummelsberg	534.987	574.533	542
Diesdorfer Graseweg	377.768	407.892	404
Große Diesdorfer Str.	255.081	272.739	266
Ummendorfer Str.	43.233	47.567	51

Table 6.1 *Validation Results - Throughput*

Upper and Lower bound of the confidence intervals and real-world mean of Throughput for individual streets.

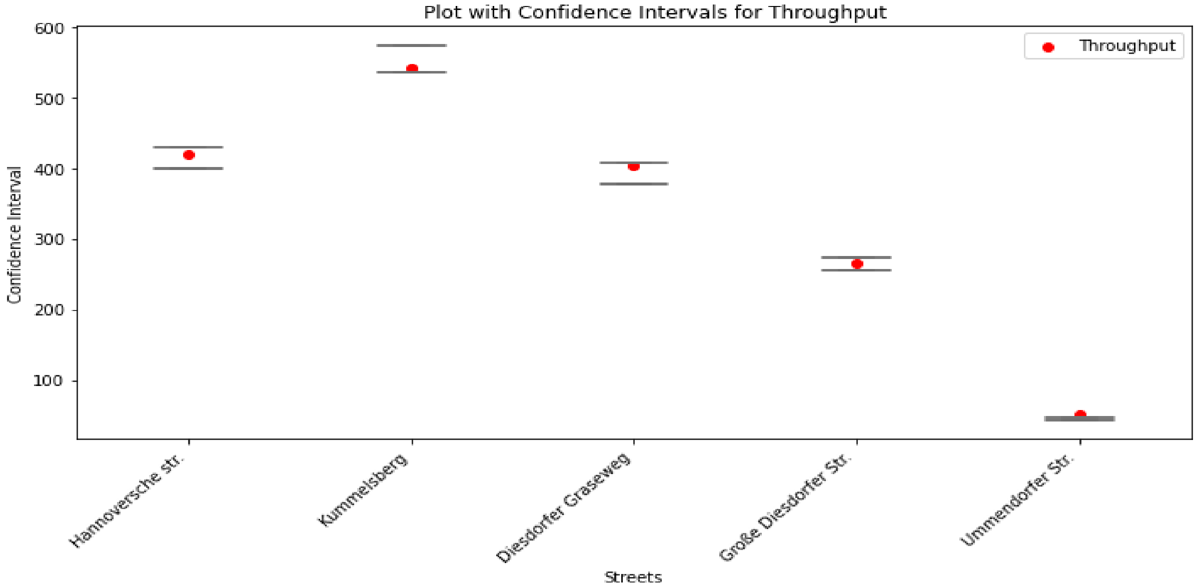


Fig 6.2 *Validation Results - Throughput*

According to the table, the majority of the streets studied in the validation experiments fell between the lower and higher boundaries of their respective confidence intervals. This implies that the simulated and real-world data for those streets correspond well. Throughput statistics for Hannoversche Strasse, Kummelsberg, Diesdorfer Graseweg, and Große

Diesdorfer Strasse all fell within their respective confidence ranges, confirming consistency between simulation findings and actual observed values.

However, there is a slight deviation for Ummendorfer Str. In this scenario, the estimated confidence interval of 43.233 to 47.567 falls beyond the real-world throughput number of 51. This indicates a difference between the simulated and actual Ummendorfer Str data. To understand why the observed value surpasses the upper bound of the confidence interval, it is necessary to further analyze the causes affecting this deviation.

Overall, the results show that most streets' real-world data falls within the expected range given by the confidence intervals, indicating that the simulation model was validated successfully.

STREET	LOWER	UPPER	REAL WORLD AVERAGE QUEUE LENGTH
Hannoversche South	3.564	4.022	3.714
Hannoversche North West	1.761	1.954	1.857
Kummelsberg	17.237	17.31	17.294
Diesdorfer Graseweg	27.445	27.8	27.525
Große Diesdorfer Str.	6.839	7.381	7.138
Ummendorfer Str.	0.314	0.5	1.4166

Table 6.2 *Validation Results – Queue Length*

Upper and Lower bound of the confidence intervals and real-world mean of Queue Lengths for individual streets.

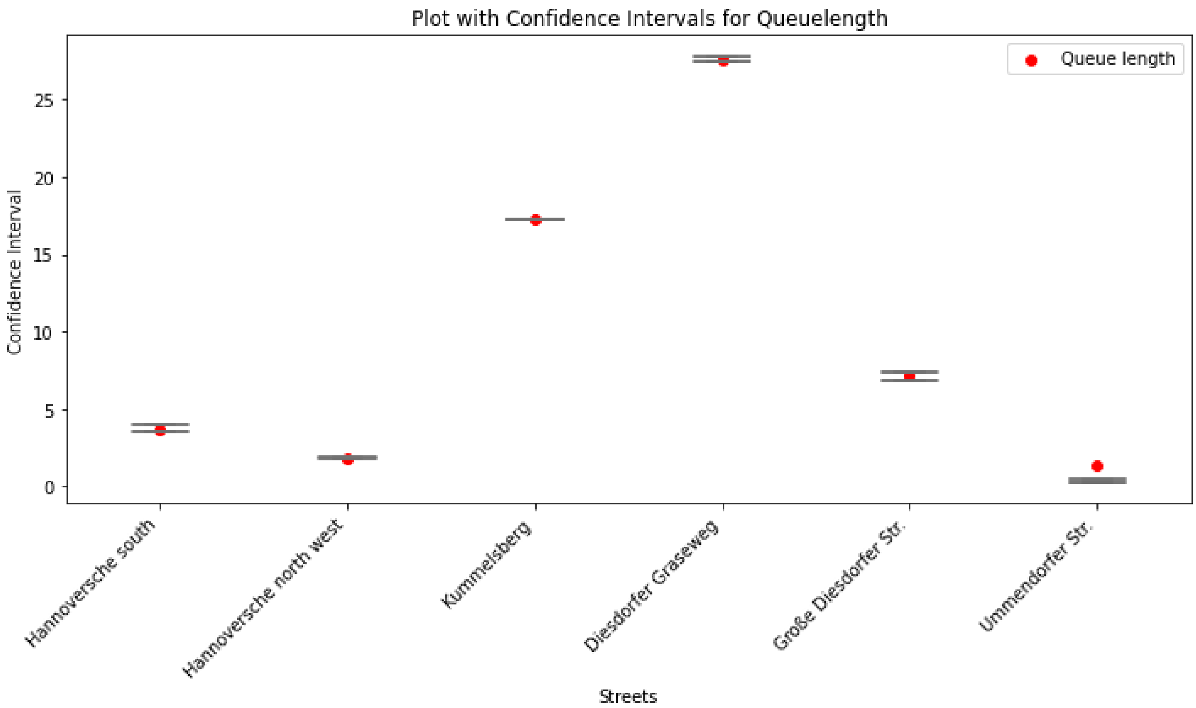


Fig 6.3 *Validation Results – Queue Length*

With the exception of Ummendorfer Street, all of the other streets studied in the simulation fall between the lower and upper levels of the relevant confidence intervals, according to the table supplied. This shows that the real-world average line lengths and the simulated results for most streets are very close.

However, the average line length on Ummendorfer Street differs. The actual result is 1.4166, which is deviated from the confidence interval's lower bound of 0.314 and upper bound of 0.5. This indicates a mismatch between the simulated and real-world observations for this specific street.

Overall, the findings from this analysis highlight the effectiveness of the simulation model in representing the real-world behavior of traffic queues for most streets.

STREET	LOWER	UPPER	REAL WORLD AVERAGE TIME (in seconds)
Time Spent North	26.186	26.989	26.78
Time Spent South	27.716	29.04	28.12

Table 6.3 *Validation Results – System Time*

Upper and Lower bound of the confidence intervals and real-world mean of Time spent by the vehicles in the system.

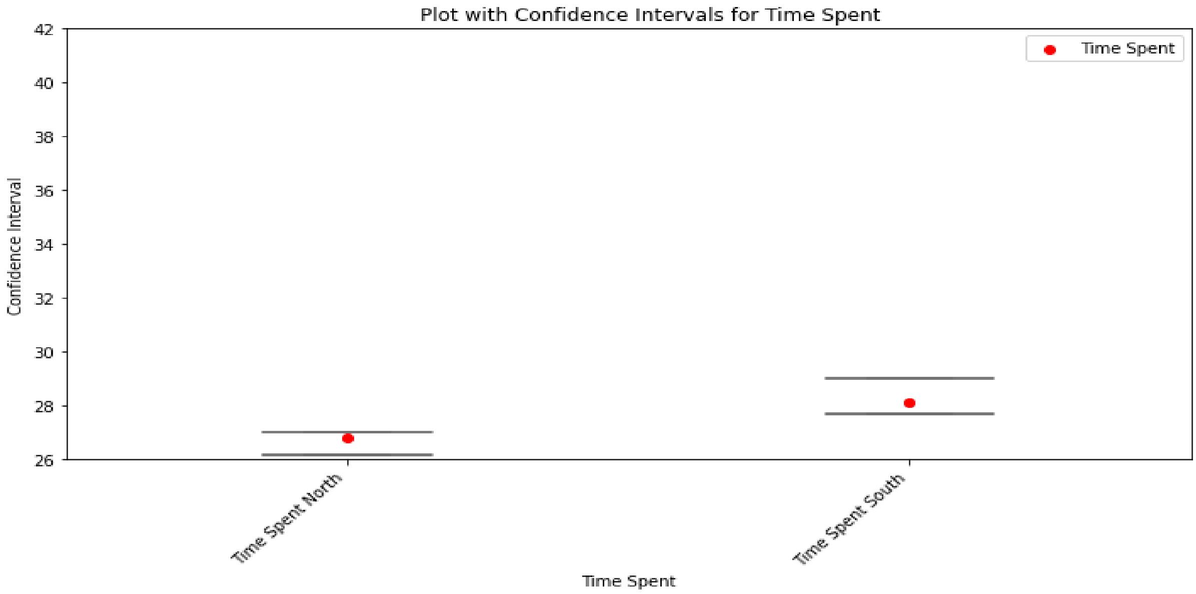


Fig 6.4 *Validation Results – System Time*

The table and graph summarizes the comparison between the real-world average time spent by cars in the system and the simulation model's lower and higher confidence ranges.

We may conclude from this data that the time spent by vehicles in the system, as observed in the actual world, corresponds well with the confidence intervals produced from the simulation model. This implies that the model accurately captures vehicle behavior and offers credible estimates for time spent in the system.

6.5 CHANGES MADE TO THE MODEL

Several improvements were made to the model during the validation phase to address the differences between the real-world mean values and the confidence intervals generated from the simulation results. These changes seek to increase the simulation model's accuracy and alignment with real-world observations. The following modifications were made:

1. Addition of Pedestrian Crossings To better simulate real-world settings, we added pedestrian crossings to the model. We accounted for the presence of people and their impact on traffic flow by including these crossings, which could possibly affect queue lengths and overall system performance.

2. Adjusted the road length: We increased the length of the highways in the simulation model to accommodate a bigger volume of vehicles. This change allowed for a more realistic portrayal of traffic circumstances, as well as an increase in the number of cars that might spawn within the system, potentially altering measured factors such as queue length and throughput.

3. Corrected the turning probabilities: We examined and corrected the turning probabilities used in the model's input data. We wanted to increase the model's ability to capture the dynamics of traffic movement by ensuring the proper modeling of turning behaviors at crossings, hence increasing the trustworthiness of the simulated findings.

4. Changed the car properties like acceleration and initial speed: We changed the acceleration and starting speed of the car, among other things. These changes were based on real-world data insights and attempted to better align the behavior of simulated cars with their real-world counterparts. We hoped to improve the accuracy of the simulation outcomes by fine-tuning certain parameters, particularly those linked to time spent in the system.

5. Created a custom distribution for Große Diesdorfer straße: Within the simulation model, we generated a bespoke distribution for Große Diesdorfer Straße. This roadway most likely has distinct traffic features that need a customized strategy to adequately reflect its activity. The tailored distribution allowed us to account for the street's unique traffic patterns and flow dynamics, boosting the fidelity of the simulation findings.

6.6 PROBLEMS ENCOUNTERED

1. Traffic signal patterns varied significantly during data collection, deviating from a fixed plan.

2. Because of reasons such as low traffic flow, ineffective signal timing, and other real-world limits on the road's capacity, the data from Ummendorfer Street did not fit within the confidence interval.

3. In order to address potential dependability issues, additional data was collected to enhance and evaluate the city data used in the simulation.

6.7 SCOPE OF VALIDITY

1.Cars initial speed is set to 10 km/h and max preferred speed of 60 km/h

2.Traffic lights use fixed time plans

3.All cars have the same length

4.All cars follow the traffic rules

6.8 STATEMENT OF CONFIDENCE

We validated our model by running 100 simulation replications across an hour of simulation time and calculating confidence intervals with a 99 percent confidence level (alpha=0.01). When the measured output parameters are included, the validation process indicates that the model is mathematically correct. According to the analysis of the offered illustrations and conclusions, a major amount of our real-world mean data falls inside the confidence ranges produced from the replications. As a result, we can conclude that our simulation model is correct and mimics the real-world system.

6.9 LESSONS LEARNED

- Traffic signals are very complicated, very precise timings are needed.
- Rectification of model takes very long time.
- Replications have long run time, so planning must be done accordingly.

MILESTONE 7

EXPERIMENTS

7.1 INTRODUCTION

During the project we decided to change the experiments, since we saw that the previous weren't beneficial towards improving the throughput of the Hannoversche Straße once we looked at the finished model. So, we decided to come up with new or changed versions of the experiments.

7.2 EXPERIMENTS DESCRIPTION

The first experiment we conducted was moving the tramlines further south so that they take up less space in the lower intersection *(seen in Fig. 3.1)*. The expected result was an increase in throughput of Große Diesdorfer Straße and Diesdorfer Graseweg.

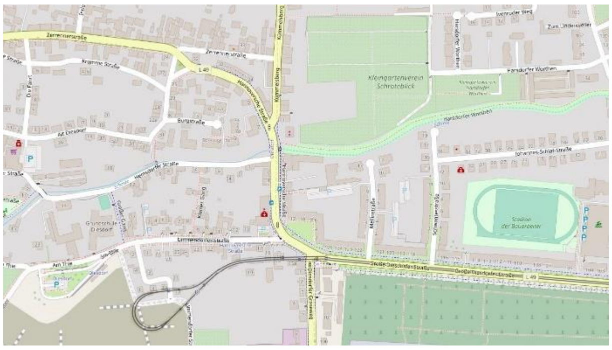


Fig. 7.1 *Map showing the moved tram lines*

In the second experiment we merged the Hannoversche Straße and Kümmelsberg (seen in Fig. 7.2). We expected that the cars need less time to move up, since the northern intersection becomes less complicated. We also expected an increase of throughput for Kümmelsberg, Große Diesdorfer Straße and Diesdorfer Graseweg.

Fig. 7.2 *Map showing the merged intersection*

For the third experiment we changed up the traffic lights at the lower intersection so the incoming cars from Große Diesdorfer Straße and Diesdorfer Graseweg each have a greenphase for half the period of their traffic lights. Furthermore we removed the traffic light (K21) from the lower intersection for turning right into the Hannoversche Straße. This should result in shorter queues for Große Diesdorfer Straße and Diesdorfer Graseweg as well as an increased throughput for the Hannoversche Straße and Kümmelsberg.

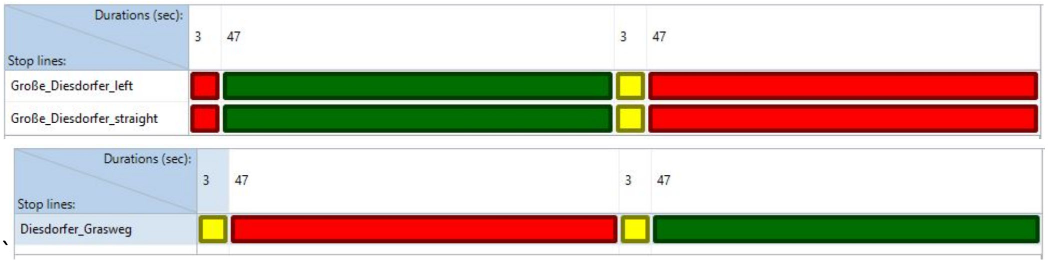


Fig. 7.3 *New Phases for the affected traffic lights*

The fourth experiment was about building an underpass for cars coming from Große Diesdorfer Straße and Diesdorfer Graseweg *(seen in Fig. 7.4)*. This would allow these cars to completely bypass the lower intersection. For that the Ummendorfer Straße has to lose its left turn. The expected result was an increase of the througput for Hannoversche Straße and Kümmelsberg.

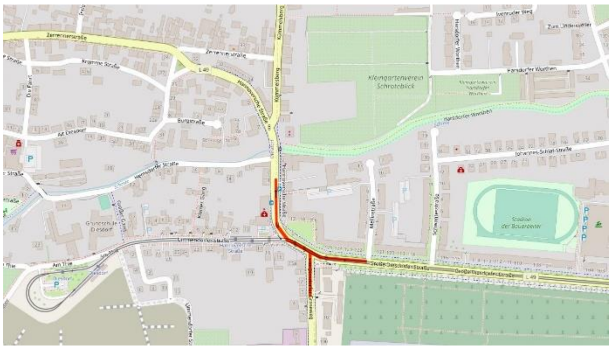


Fig. 7.4 *Map showing the proposed underpass*

7.3 METHODOLOGY

The results of the experiments were confidence intervals (significance level of 99%) of the difference between variables of interest of the experiment system and the normal system. To reduce the width of those intervals we used correlated sampling with 100 replications. We also looked at how the experiment system would behave at higher traffic volumes compared to the normal system.

7.4 RESULTS

The first experiment showed no difference to the normal model in terms of time spent in the model, since the confidence interval included 0 for both north and south *(seen in Fig. 7.5)*.

For the same reason you cannot derive a difference in throughput for Große Diesdorfer Straße and Diesdorfer Graseweg *(seen in Fig. 7.6 and 7.7)*. Therefore, it can be concluded that the proposed experiment has no effect on the throughput of the main road.

In the second experiment you can see a decrease in time spent in the model going north at normal traffic volume *(seen in Fig. 7.8)*. The displayed increase of time needed to go south results from the way of measuring that time. It is measured as the time the cars stay in between the two intersections and due to the change more cars wait at the lower intersection resulting in a higher waiting time.

Considering the effects of higher traffic volumes on the traffic on the experiment compared to the normal model you can see a slight increase for Diesdorfer Graseweg until 150% of the normal traffic volume *(seen in Fig. 7.9)*. After that there is no difference between the normal model and the experiment. Furthermore, there is no improvement or decline of throughput on the Große Diesdorfer Straße compared to the normal model when increasing the traffic volume *(seen in Fig. 7.10)*.

The third experiment has a positive effect on the queue lengths on both Große Diesdorfer Straße and Diesdorfer Graseweg *(seen in Fig. 7.11)*.

Higher traffic volumes result in an improved throughput for both Hannoversche Straße and Kümmelsberg compared to the normal model *(seen in Fig. 7.12 and 7.13)*.

Hence it can be concluded that this experiment has a positive effect on improving the throughput of the main road.

The effect of the last experiment at normal traffic volume is a decrease in time needed to go north and no effect for going south *(seen in Fig 7.14)*.

When increasing the traffic volume, you can see an increase in throughput compared to the normal model for both Hannoversche Straße and Kümmelsberg *(seen in Fig. 7.15 and 7.16)*.

The experiment has a positive effect on the throughput.

7.5 RECOMMENDATIONS

The change represented by the first experiment cannot be recommended, because there is no improvement of the throughput of the main road.

The same goes for the second experiment since the slight increase of throughput at around 150% of the normal traffic volume is not beneficial when related to the costs of this change.

The third experiment can definitely be recommended since it’s the cheapest change with the best effect on the system. The only downside is that the cars from Ummendorfer Straße that want to go north have to go through the side streets.

The last experiment does have a positive effect on the system but is probably the most expensive and time-consuming change. Therefore, we will not recommend the change presented.

Experiment 1

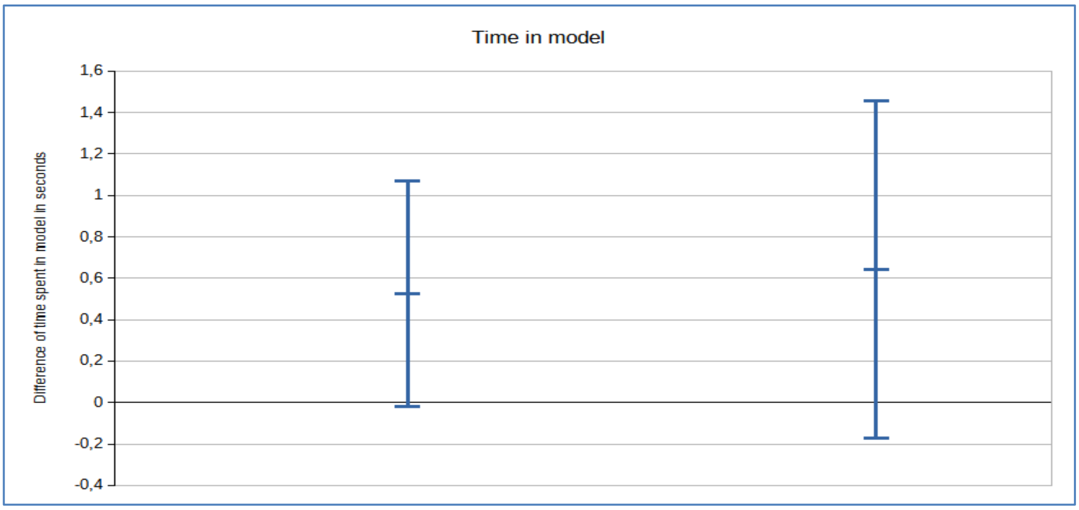
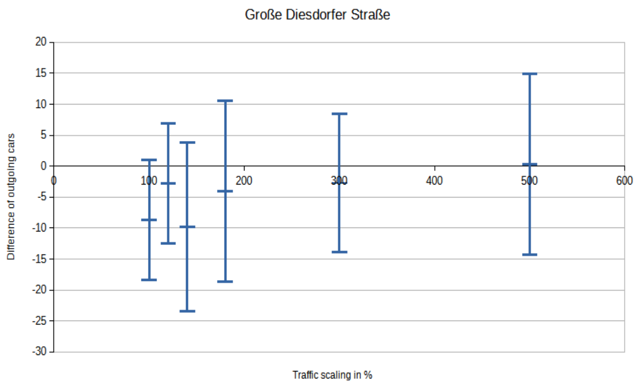


Fig. 7.5 *Confidence intervals of the difference of the time cars spent in the model (experiment – normal system). The left confidence interval is the time going north the right the time going south.*



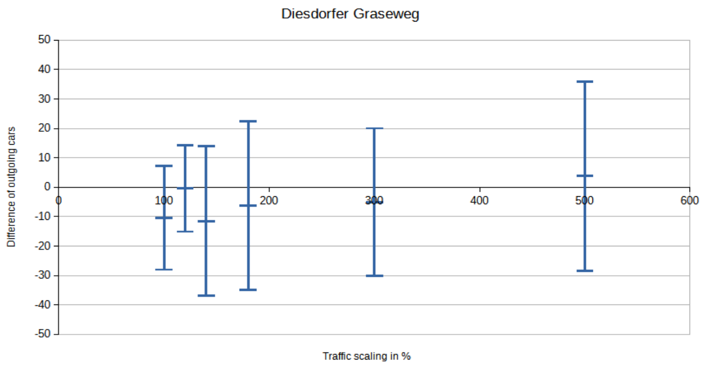


Fig. 7.6 and 7.7 *Confidence intervals of the difference of the throughput of Große Diesdorfer Straße and the model and respectively Diesdorfer Graseweg (experiment – normal system) at different traffic volumes.*

Experiment 2

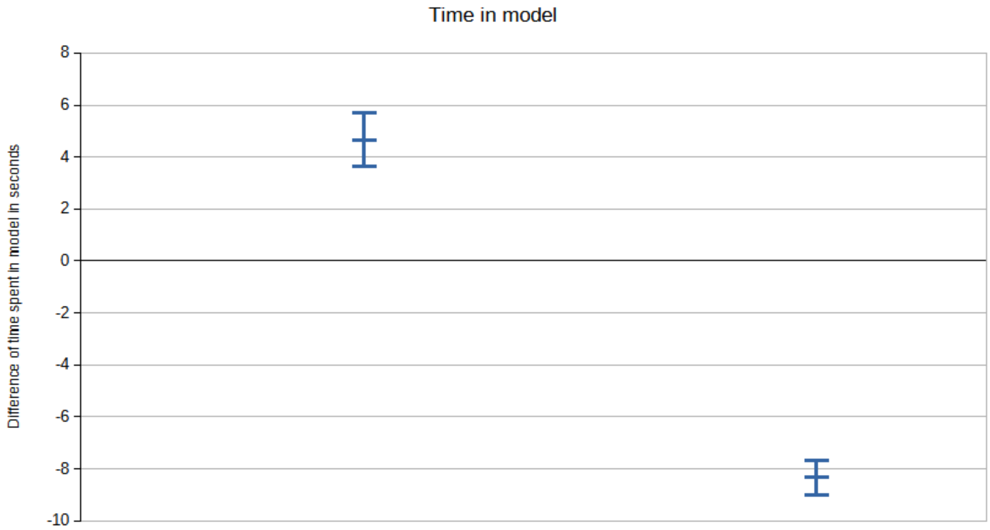
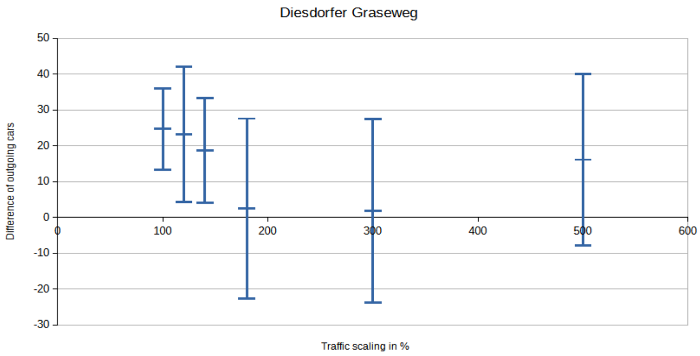


Fig. 7.8 *Confidence of the difference of the time cars spent in the model (experiment – normal system). The left confidence interval is the time going north the right the time going south.*



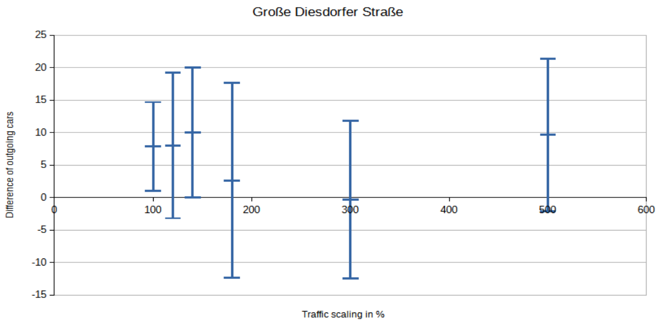


Fig. 7.9 and 7.10 *Confidence intervals of difference of the throughput of Große Diesdorfer Straße and the model and respectively Diesdorfer Graseweg (experiment – normal system) at differenct traffic volumes.*

Experiment 3

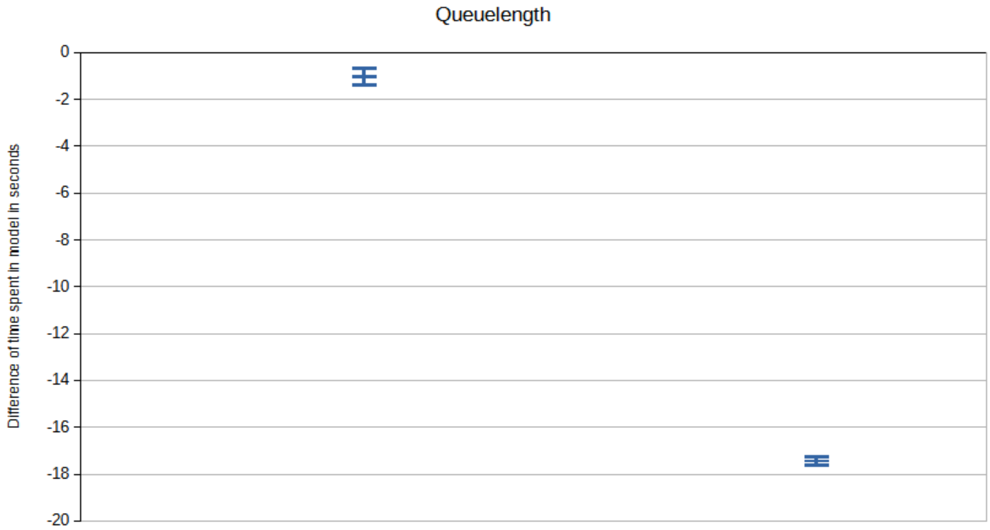


Fig. 7.11 *Confidence intervals of the difference of the queue lengths (experiment – normal system). The left confidence interval shows the difference of queue lenghts on Große Diesdorfer Straße and the right one on Diesdorfer Graseweg.*

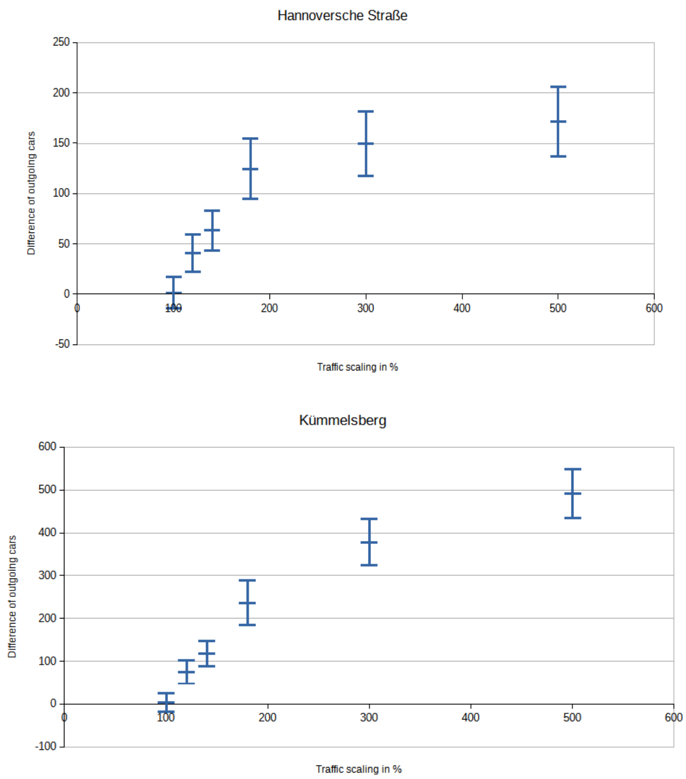


Fig. 7.12 and 7.13 *Confidence intervals of difference of the throughput of Hannoversche Straße and the model and respectively Kümmelsberg (experiment – normal system) at differenct traffic volumes.*

Experiment 4

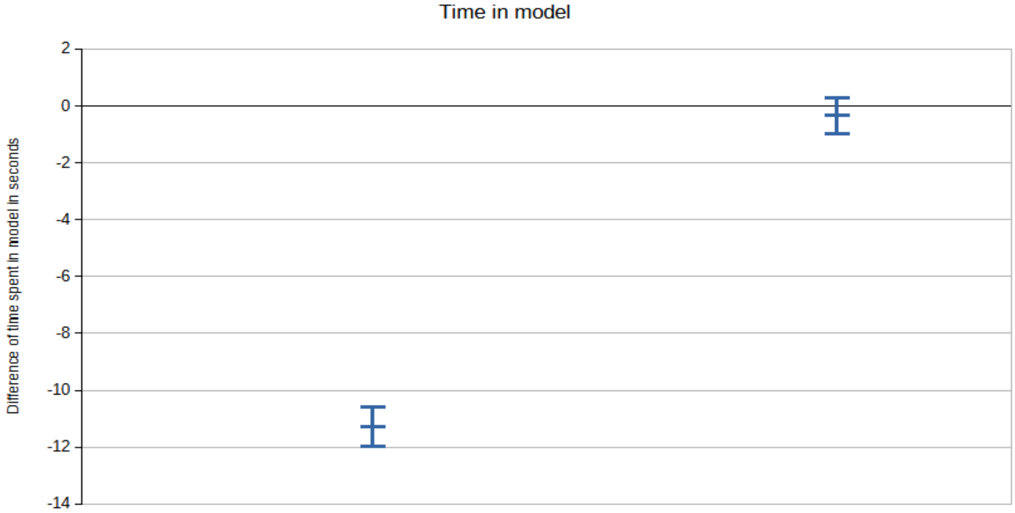
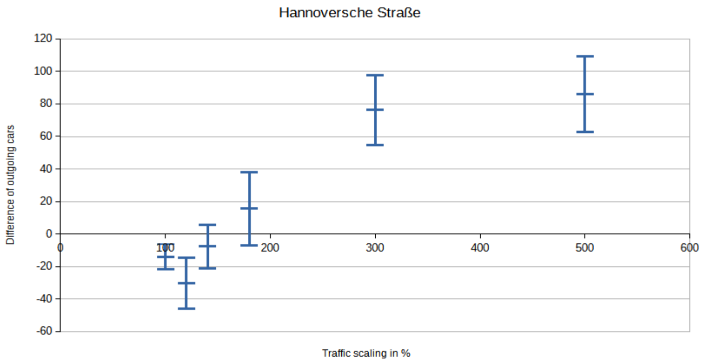


Fig. 7.14 *Confidence of the difference of the time cars spent in the model (experiment – normal system). The left confidence interval is the time going north the right the time going south.*



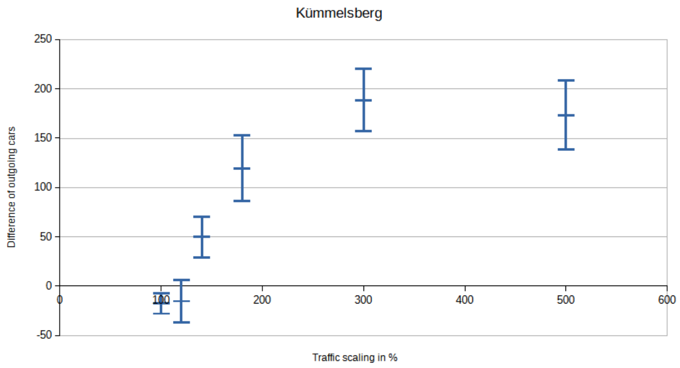


Fig. 7.15 and 7.16 *Confidence intervals of difference of the throughput of Hannoversche Straße and the model and respectively Kümmelsberg (experiment – normal system) at differenct traffic volumes.*

7.6 LESSONS LEARNED

The lessons we learned during this milestone were that the experiments should be clearer from the beginning, so there is no time loss due to changes, and that running/rerunning of experiments takes up a lot of time.

CHAPTER 8

PROJECT TRACKING

8.1 PROJECT COST

At the commencement of the project, we were assigned a total budget of 60000 € for a total of 600 working hours. As we planned the project, we divided the available hours according to the designed work packets and assigned it to the designated individual. By that calculation, we estimated a total of 558 working hours which gave us an estimate of 55800 € for the entire project. As the project progressed, we faced some difficulties during the milestones 4, 7 and 8, which in turn increased the planned working hours by around 39 hours resulting in a total 597 working hours and hence a spending of **59700 €** by the end of the project. Even if we had exceeded the estimate, still we were able to finish the project under the initial budget assigned by the client.

Below is the graph that shows the planned cost and actual cost of each milestone along with the cumulative cost.

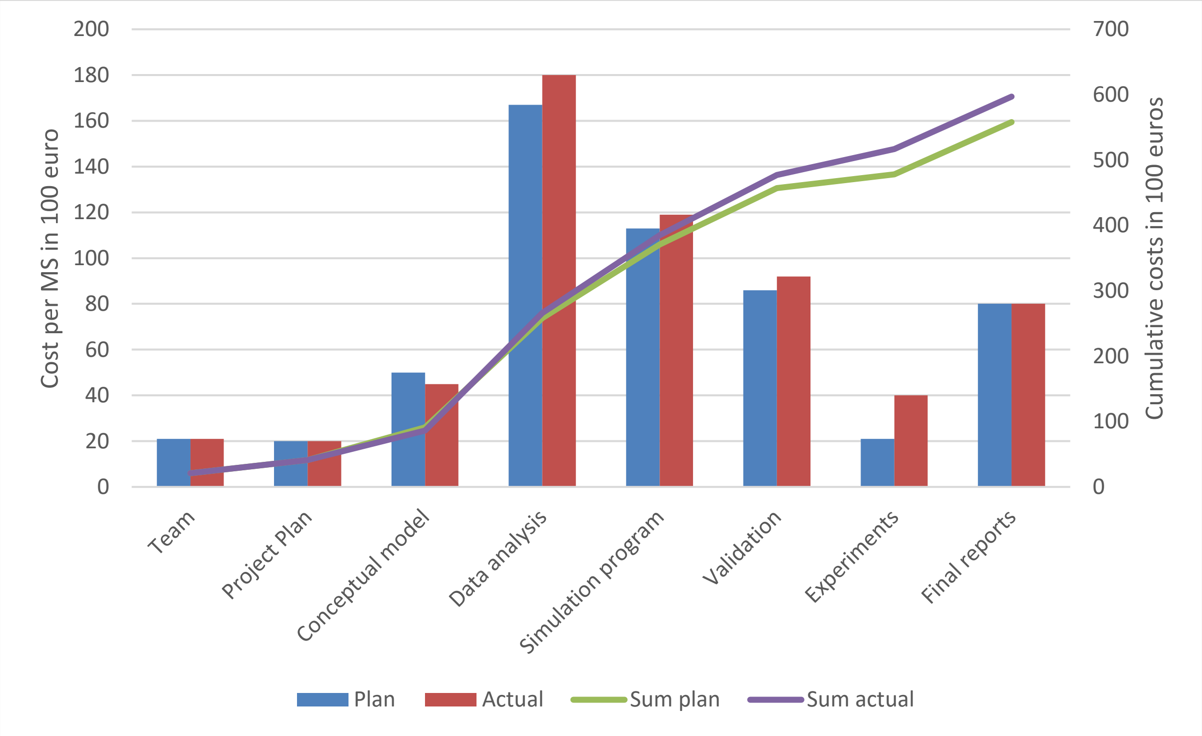


Fig 8.1 *Project Cost Diagram*

8.2 PROJECT PROGRESS

One of our main objectives throughout the project was to complete the planned and given tasks within the prescribed deadlines. Fortunately, we were able to do that almost every milestone during the course of the project. We effectively tracked our progress which helped us to make sure that we do not lack at any point and helped evaluating our overall performance.

Below is the graph that shows the planned versus actual progress during the course of the project,

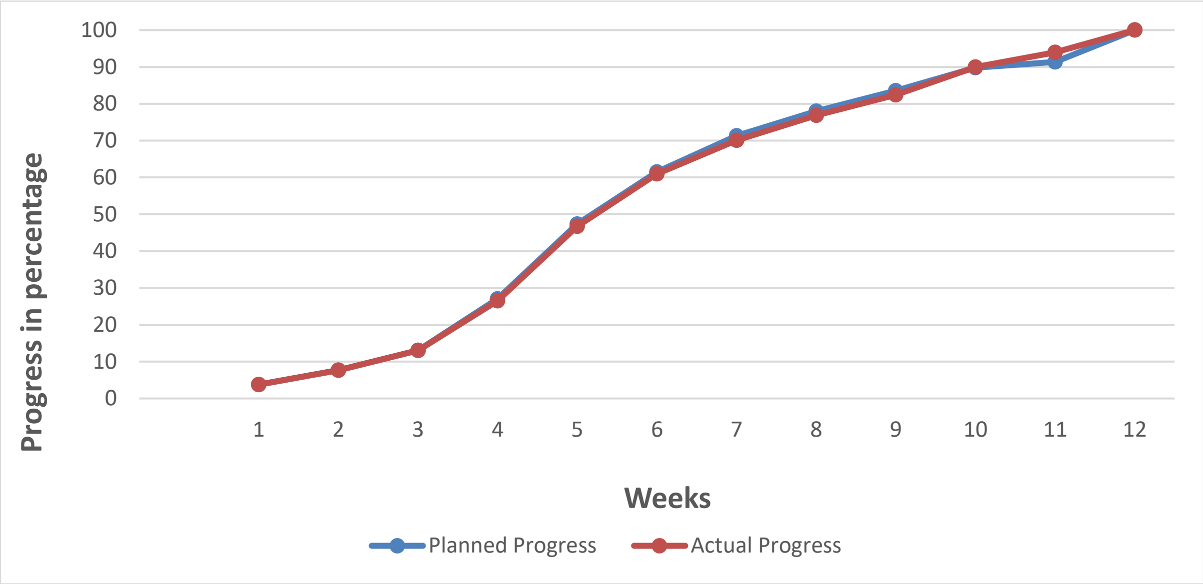


Fig 8.2 *Planned Progress vs. Actual Progress*

Deutsche Zusammenfassung

Einleitung

Wir haben das Verhalten der beiden Kreuzungen *Gr. Diesdorfer Str./Diesdorfer Graseweg/Hannoversche Str.* und *Hannoversche Str./Kümmelsberg* simuliert und vier Experimente mit dem Ziel, den Durchsatz entlang der Hannoverschen Straße zu verbessern, durchgeführt.

Beschreibung der Experimente

Das erste Experiment war das Verschieben der Straßenbahnlinien nach Süden, sodass diese nicht durch die gesamte untere Kreuzung verlaufen *(siehe Abb. 1)*. Das erwartete Ergebnis ist ein höherer Durchsatz an Autos in der Großen Diesdorfer Straße und im Diesdorfer Graseweg.

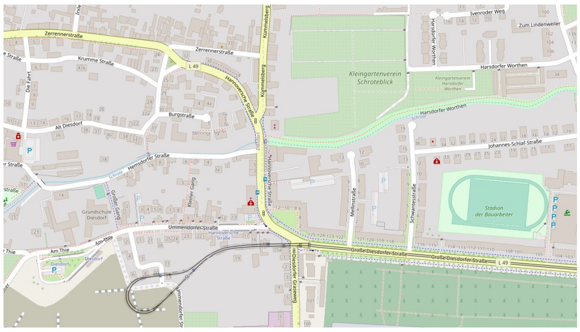


Abb. 1

Im zweiten Experiment haben wir die Hannoversche Straße und Kümmelsberg vor der oberen Kreuzung verbunden *(neuer Straßenverlauf siehe Abb. 2 in rot)*. Wir erwarten, dass die Autos in kürzerer Zeit das System nach Norden verlassen können, da die Kreuzung weniger komplex wird. Außerdem erwarten wir einen höheren Durchsatz an Autos in der Großen Diesdorfer Straße und im Diesdorfer Graseweg.

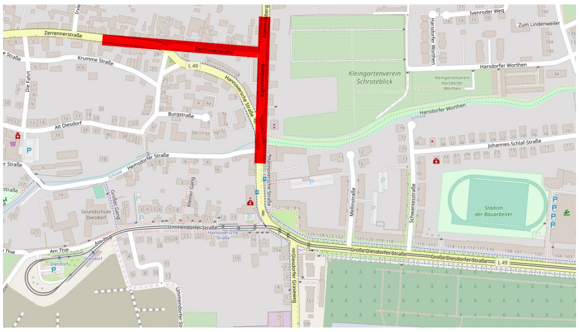


Abb. 2

Für das dritte Experiment haben wir die Lichtsignalanlagen der Signalgruppen K1 und K6 für die Große Diesdorfer Straße und Diesdorfer Graseweg so verändert, dass deren Grünphasen jeweils die Hälfte der Umlaufzeit einnehmen *(siehe Abb. 3)*. Zusätzlich wurde die Lichtsignalanlage K21 entfernt. Der erwartete Effekt sind kürzere Warteschlangen an der Großen Diesdorfer Straße und am Diesdorfer Graseweg sowie ein höherer Durchsatz für die Hannoversche Straße und Kümmelsberg.

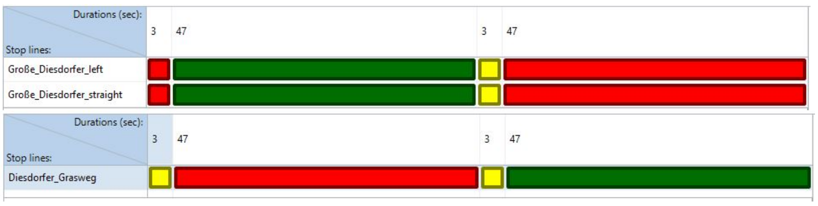


Abb. 3

Das vierte Experiment simuliert eine Unterführung für Autos kommend von der Großen Diesdorfer Straße und Diesdorfer Graseweg *(Verlauf siehe Abb. 4 in rot)*. Somit können diese Autos die untere Kreuzung vollständig umgehen. Dafür können Autos aber nicht mehr von der Ummendorfer Straße nach links einbiegen. Wir erwarten eine positive Auswirkung auf den Durchsatz für die Hannoversche Straße und Kümmelsberg.

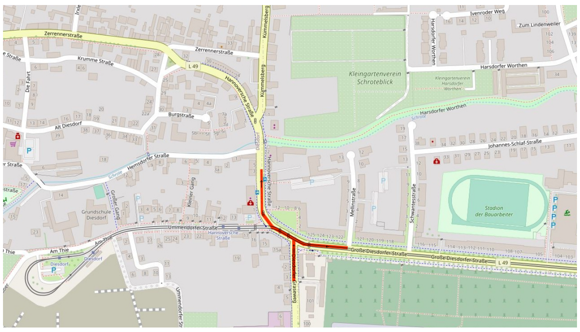


Abb. 4

Methodik

Die Ergebnisse der Experimente sind Konfidenzintervalle (beidseitiges Intervall mit Konfidenzniveau 99%) *(Beispiel siehe Abb. 5)*. Diese stellen die Differenz der jeweiligen Variablen dar (Experiment – Normalsystem). Dabei wurden jeweils beide Systeme mit denselben Startwerten für die Zufallsgeneratoren bei 100 Replikationen ausgewertet. Weiterhin haben wir das Verhalten des modifizierten Systems bei höherer Verkehrsbelastung betrachtet *(Beispiel siehe Abb. 6)*.

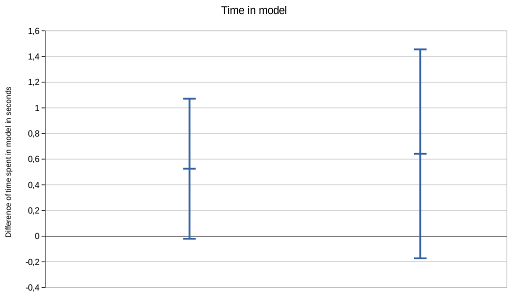


Abb. 5: Konfidenzintervall für benötigte Zeiten

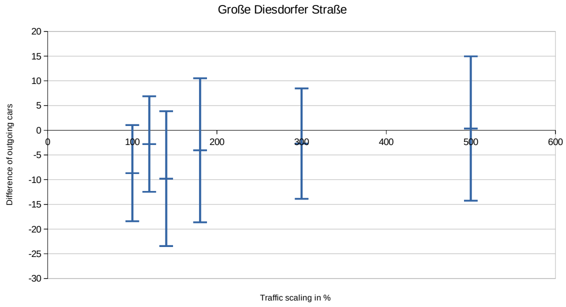


Abb. 6: Konfidenzintervalle für Differenz des Durchsatzes bei unterschiedlichen Verkehrsbelastungen

Ergebnisse

Das erste Experiment hat keinen Einfluss auf den Durchsatz genommen.

Das zweite Experiment zeigt, dass die Autos weniger Zeit benötigen, um durch die Kreuzungen nach Norden zu gelangen. Weiterhin gibt es einen leichten Anstieg des Durchsatzes bei leicht höherem Verkehrsaufkommen (150%).

Die Ergebnisse des dritten Experimentes sind kürzere Warteschlangen an den betrachteten Straßen und ein deutlich besserer Durchsatz bei steigendem Verkehrsvolumen.

Das vierte Experiment hat einen positiven Effekt auf den Durchsatz bei höherer Verkehrsbelastung sowie einen positiven Effekt auf die benötigte Zeit nach Norden im Normalzustand.

Empfehlungen

Wir empfehlen die ersten beiden Veränderungen/Experimente nicht, da sie keinen oder nur geringen Einfluss auf den Durchsatz des Systems haben.

Wir empfehlen die Veränderungen des dritten Experimentes, da sie einen positiven Effekt auf den Durchsatz haben und auch die günstigsten sind. Der einzige Nachteil ist, dass die Personen, die von der Ummendorfer Straße nach Norden fahren wollen, durch Seitenstraßen dahin gelangen müssen. Dies ist aber annehmbar, da auf dieser Straße nur wenige Autos durchfahren.

Wir empfehlen das letzte Experiment trotz der positiven Effekte nicht, da die vorgeschlagenen Veränderungen die zeit- und kostenintensivsten sind.