

**Volkswagen Connected Vehicles
Senior Design Report**

Submitted By:

Jared Barber
Brooke Hagan
David Herberich
Amber Nixon
Nevin Sawyer

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Dr. John Kobza - Professor
Dr. Mingzhou Jin - Professor
The University of Tennessee, Knoxville

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0. EXECUTIVE SUMMARY

The purpose of developing the traffic simulation for Volkswagen's Connected Vehicles Project is to develop an ideal framework to be used by graduate students to further research and test particular algorithms for connected vehicles. The purpose of the physical simulation is to provide Volkswagen with new insights for their connected vehicles - a feature they hope to have in their future automobiles. This connected vehicle feature will allow people to see the traffic around them in real time. To allow this, a group of graduate students are going to produce a simulation to model connected vehicles traveling through a network of roads. They will be developing policies and algorithms to help drivers make decisions on speed, route, and signals in order to improve mobility and energy consumption. Therefore, to serve as a secure framework for this simulation, our group will research and develop a simulation model depicting conventional or connected cars in travel with the ability to receive a set of inputs and report all outputs. This includes programming four traffic intersections. To ensure the simulation model developed satisfies all requirements, the project advisor has specified two rules. These rules are as followed:

- **Rule 1: Green Phase Skip**
 - If the queue is empty and no cars are expected to arrive at the intersection in this direction, the green light should automatically switch to red.
- **Rule 2: Phase Plan Change**
 - If the average waiting time for vehicles of one direction over the last 15 minutes is 20 seconds longer than the average waiting time of all vehicles of all directions at the intersection, increase the green phase by 10 seconds for that direction.
 - In reverse; if the average waiting time for vehicles of one direction is 20 seconds shorter, the green phase will then be decreased by 10 seconds for that direction. However, the duration of the green phase should NOT be shorter than 15 seconds.
 - You may change the plan every 15 minutes

1. CONCEPTUAL DESIGN

1.1 INTRODUCTION

In order to make the team's goal of building a model for Volkswagen realized, our team began building a conceptual design. Conceptual Design is the first phase of design before the detailed design process starts. This process, laid out in the following section, is where our team identified the needs and specifications of our design. By doing this at the beginning of our project we ensured the satisfaction of both Volkswagen and our advisers, in addition to forming a deeper understanding of the project. It also laid the metrics for which we would judge our final product by, created preliminary testing procedures, identified strengths and weaknesses within our design, detailed the feasibility of our design, and laid a timeline for all of the

activities of the project.

1.2 BACKGROUND

In the Industrial and Systems Engineering curriculum at the University of Tennessee, the senior students must complete the senior design course to graduate. Within this course, students are expected to not only integrate all the courses within the curriculum from the leadership seminars, project planning, and statistics courses, but to apply them within a final project given by real-world companies/sponsors to stimulate the student's mind as an engineer. Volkswagen has been exploring their options of manufacturing vehicles with the ability to have connected travel. In order to help develop the research and framework of these endeavors, they have reached out to the students of The University of Tennessee, Knoxville to help further their research and to begin to develop a higher understanding of the constraints, requirements, and process of connected vehicles. To satisfy these requirements, the goal for the senior design group is to develop a simulation of a traffic intersection representing various traffic and driving behaviors. In order to do this, the design team (research team) will need to use their understanding of project management, conceptual design, preliminary design, and systems engineering. Given the expectations, the research team developed project plans, timelines, constraints and restrictions, as well as a simulation to present to the sponsors at the completion of the course.

1.3 NEED IDENTIFICATION

1.3.1 SYSTEM MANAGEMENT PLAN (TYPE A SPECIFICATION)

In order to develop an accurate and ultimately useful representation of connected vehicles, certain requirements must be followed. Specifically designing to all of the proper requirements laid out for the project will end up saving time, money, or other resources used. Throughout the conceptual design process, the team can formulate exactly what technical needs should be addressed so that the model will be one that Volkswagen can operate and use for future research into these vehicles.

1.3.2 SYSTEM DESCRIPTION

The usefulness of our model to the researchers of Volkswagen is reliant on the realism of the connected vehicle intersection patterns developed and the consistent ability to represent it. The team used some of the different techniques and methods learned in the university curriculum to help accomplish the envisioned model. By collecting various data associated with intersections and driving patterns and integrating them within the detailed model built in AnyLogic, it was hopeful that the simulation would be able to accurately show how these connected vehicles can interact with each other for the benefit of the driver.

1.3.3 FUNCTIONAL REQUIREMENTS

1.3.3.1 PHYSICAL

It is important for the simulation model to depict a typical intersection in the real world. This will allow for a more familiar visual representation of the intersections and in turn provide more accurate tests or results associated with the traffic. The team shall start by modeling one certain intersection and developing that into two consecutive intersections later. Finally, this is developed into a traffic grid of four intersections. It shall have eight different entry locations of possible drivers and animate them proceeding through their desired route.

1.3.3.2 DATA COLLECTION

The patterns and drivers themselves are depicted best by a data collection process of actual traffic. Documentation of intersections and data collecting software were options to be used to aid the team's compilation of data. Specifically, the GPSTrackit software was intended to provide the team with accurate driving styles and routes taken; however for time and monetary constraints this software was not used (see section 1.3.11.2). Instead, existing data was retrieved from actual Los Angeles intersections on travel volume [5]. Driver data from a MIT research on acceleration and other statistics was used as well to validate the simulation design input data [1].

1.3.3.3 AFFORDABILITY

Given that this project is through the university but sponsored by Volkswagen, there was a small budget that needed to be accounted for. Volkswagen may potentially invest more money in the future towards their research, however the simulation model itself would not require a large amount of funds. The simulation software being utilized is a free student download from the AnyLogic website without any need for funds. The overall model is affordable for the team and anyone that Volkswagen wants to operate the model.

1.3.3.4 RELIABILITY

Perhaps most importantly, the simulation model must be one that is reliable. Volkswagen requires a product that may be counted on to operate as it is designed as well as properly represent the intersections. It was important that the team constantly saved and documented the progress of the model and project as a whole. The team desired to construct a model that would run properly without errors. AnyLogic gives the ability to save periodically and the model should run as it is meant to be, provided that there are no software malfunctions.

1.3.3.5 FLEXIBILITY

The simulation model was built to model the depicted intersections and output the probabilities associated with the waiting and driving patterns of drivers. This will provide Volkswagen with a good base for further research. In addition, the team used the functions of AnyLogic to create a model that could be flexible to other analyzing. Different input options of probabilities and the functions of AnyLogic such as delay, hold, selected outputs, and others were used to produce a simulation model that is able to conform to other driving types or data that is desired to be simulated.

1.3.3.6 USABILITY

This model was designed and used by the senior design team initially before being presented to classmates and sponsors. The team looked to members with simulation experience and located existing information concerning AnyLogic or simulation models on the internet to help in the development of a simple and functioning simulation. It was important that the simulation be understood by the team first and foremost, as they are the designers. It will later be used by Volkswagen or potentially others, and it must be a model that is easily used by all.

1.3.3.7 TEST AND EVALUATION

The last step of the project was the testing and evaluation of the model and results from it. The team conducted final details to the model and ran multiple simulation tests to analyze the data studied. Multiple runs provided the best representation of the driver patterns. Animation of the intersection on real-time will provide Volkswagen with a visual representation that is easy to watch and understand. The final project follows all other specifications and correlates with the overall plan designed. It was then presented to the sponsors and instructors where it will be passed on to Volkswagen for potential further use in connected vehicle research.

1.3.3.8 INPUTS

This project is very driven and reliant on the data collected, so the ways that it is organized and analyzed are extremely important. The inputs and outputs of the simulation model are what will help illuminate the relations between drivers and vehicles. To help with the flexibility requirements and usefulness of the model, several different inputs into the system were needed. These inputs reflect the data collected and are able to be altered to fit any future uses of the simulation. Inputs include data on:

- Volume of traffic entering system
- Speed of cars
- Acceleration of cars
- Probabilities of their specific directions traveled

- Length of traffic light phases
- Alternate traffic light phases

1.3.3.9 OUTPUTS

When the simulation is run, the system is animated and shows real time analysis of the data and interactions within the intersections. This is where patterns of how the vehicles are interacting are displayed in a way that is informative to the user. Multiple charts and time studies are analyzed for different statistics. It was important to be consistent with the data inputted into the simulation, and this include statistics on:

- Average travel time through the system
- Net change on traffic rules to average TIS
- Environmental impact incurred from traffic rules

1.3.3.10 SUPPLIED INSTRUCTIONAL GUIDE

At the conclusion of our simulation design, the team constructed an instructional guide on the operation and use of the model (see Appendix A2). This helps to improve the usability of our model by the various users, and it aims to help answer any questions or potential troubleshooting that may occur. It acts as a step-by-step guide to help with any issues and lay out the basic uses and abilities of our simulation. It includes information on, but not limited to:

- Basic design of model
- Broken down functions of the model
- Input instructions
- Various outputs given
- Additional questions that may be raised

1.3.4 ADVANCED SYSTEMS PLANNING

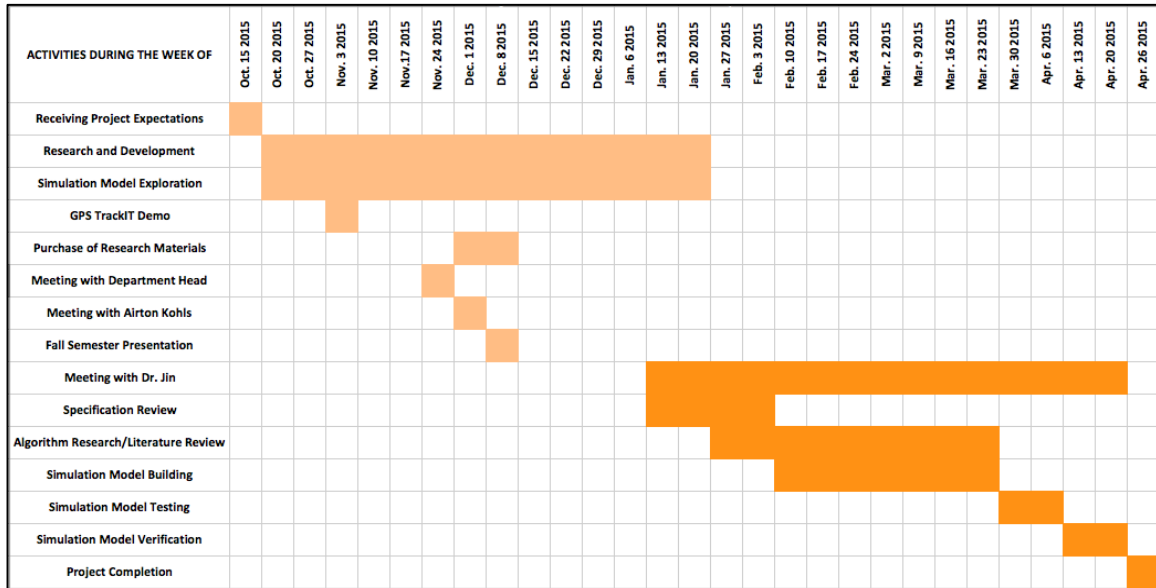


Figure 1: Gantt Chart

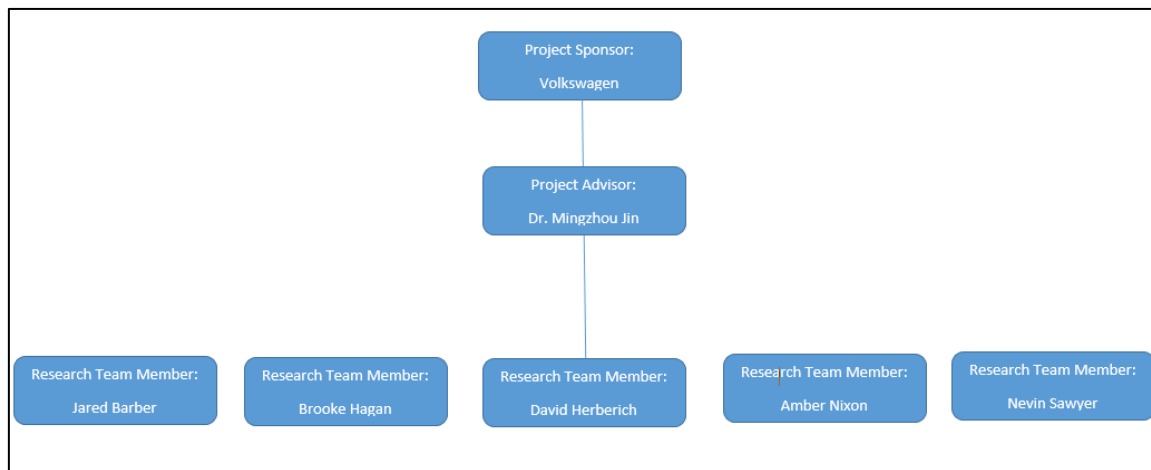


Figure 2: Team Structure

Project Sponsor	Provides research team the approval and sponsorship for the project. Due to the needs and opportunities of traveling, specifically traffic and various available routes, Volkswagen has a desire for a way to have vehicles interactively connected to provide the fastest or shortest route desired. It has budget ownership for the project and is the major stakeholder and recipient for the project deliverables.
Project Advisor	Assists team in any way needed for modeling and simulation purposes. Provides extra ideas and direct knowledge on the model desired. The team can turn to the advisor for questions on the simulation model or probability distributions associated with driving. Also participates in meetings.

Research Team Member	Responsible for all acts of research and data collecting to create simulation model for project. Gathers information available about interconnected vehicles and modeling of driving styles to create an appropriate real-life representation of traffic in Anylogic. The members must reach out to supervisors to present potential ideas or questions. Analyzing these patterns and metrics of driving can lead to future discoveries and innovation for Volkswagen.
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1.3.5 FEASIBILITY ANALYSIS

Completed December 8, 2016 in planning phase of system.

Technical Feasibility:

Do we have a high enough level of expertise in mathematical modeling to complete the model?

Though none of us have previously modeled a traffic light system before, two of our team members have taken a simulation modeling course. As senior industrial engineering students, we are all competent in high level mathematical skills which will give the students who have not completed the simulation course a base of knowledge to aid in the process. Yes, we are confident we have enough expertise to be able to complete the assignment.

Are we able to access the information that we need to learn the modeling skills necessary?

There is plenty of information online on how to effectively use AnyLogic such as technical documents from AnyLogic, YouTube videos explaining modeling, and example models from AnyLogic. Furthermore, we have a textbook on simulation modeling for AnyLogic in addition to professors and graduate students who will be available to help us. Yes, we have access to sufficient information to learn the necessary modeling skills.

Operational Feasibility:

Are we able to make progress in a steady manner without significant regression issues?

Regression issues would only exist on this project if we were unable to save our files reliably or if our work was performed unsteadily to the point where information was forgotten between each working session. AnyLogic is able to save our files reliably. However, there might be slight regression issues if we are not diligent to make consistent progress in our model. Yes, we can make progress steadily without significant regression as long as we stay diligent in our work.

Do we have access to enough resources?

The resources required for this project include computers for every student, AnyLogic software for all students, a place to meet regularly, platforms for communication, data collection software/ hardware, access to professors and graduate students, and information on simulation modeling. Every one of these items is accounted for except the data collection software/ hardware which we are

in the process of buying. We have enough money available to purchase this equipment, so yes we do have enough resources.

Timeline Feasibility:

Do we have enough time to complete our project up to the standards of the requirements?

The project must be completed by April 29, 2016. That gives us approximately 6 months from now to complete the project. Though we have not completed simulation models of this magnitude, we predict that we will have sufficient time to finish the model as well as a technical report and presentation by the due date.

Financial Feasibility:

Do we have enough money and a strong enough economic engine for our workers to complete the project?

The money awarded to us from Volkswagen is near \$5,000. The only potential costs that have been located are the costs to buy the software/ hardware for data collection. We predict it will only cost us a few hundred for this equipment. Though there might be other costs on the horizon that have not been foreseen, we predict will have more than enough money to complete our project.

Organizational Feasibility:

Are our workers organized in such a way that there are not any significant barriers opposing the completion of work?

Due to the fact that our team is relatively small (5 members) with a flat hierarchical system, we see no reason to believe there will be any significant work barriers between our team members. Our sponsor and professor in charge of assigning the project are both cooperative, so yes we believe our workers are organized in a way to prevent opposition from our work due to worker organization.

Do we have enough position power to complete this project?

Though we are still only undergraduate students, we have been given authority to access a computer lab for most hours of the day with little restrictions. We also have the authority to meet with professors and use the appropriate software, so yes we do have enough position power to complete the project.

Legal Feasibility:

Can we do everything legally?

The only issue raised as far as legality was in the data collection process for driver behavior. If our work were to be published, then data collection volunteers would need to be examined, documented, and potentially paid for their efforts in the study. However, since we are not planning on publishing our work or selling it, all of our work will be within the bounds of the law.

SWOT Analysis	
<u>Strengths</u> Experience in using AnyLogic as well experience in group projects, data collection, and data analysis	<u>Weaknesses</u> Inexperience in modeling driving and traffic light behavior; Inexperience in working on projects of this magnitude
<u>Opportunities</u> We may use the expertise of professors and graduate students to aid in our simulation modeling efforts	<u>Threats</u> Significant interference on work flow due to work demands from other classes as well as part-time jobs

Figure 3: SWOT Analysis

1.3.6 FEASIBILITY ANALYSIS REVIEW

The aforementioned feasibility analysis was conducted and evaluated during the conceptual design phase of the project. Although certain criteria and information have not changed, after doing an analysis from then versus now, there are some feasibility specifications that have been updated over time.

Within the technical feasibility, during phase two of the project, all group members have now experienced an introductory level or more of the simulation curriculum. This gave the group an upperhand on the simulation design portion in regards to expertise and knowledge of the software. In regards to the timeline feasibility, the simulation was due on April 29, 2016, but was not fully completed until May 10, 2016. Lastly, as far as the financial feasibility, there were several financial resources offered that we were not able to utilize due to unforeseen bureaucratic and monetary constraints on the GPS TrackIt devices.

1.3.7 OPERATIONS REQUIREMENT DEVELOPMENT

Operational requirements are those statements that "identify the essential capabilities, associated requirements, performance measures, and the process or series of actions to be taken in affecting the results that are desired in order to address mission area deficiencies, evolving applications or threats, emerging technologies, or system cost improvements. Operations requirements are the basis for system requirements." (*Kossiakoff, A., and N. Sweet, 2003, Systems Engineering Principles and Practices, Hoboken, N.J., John Wiley & Sons.*)

- Design for functional capability
- Design for reliability
- Design for maintainability
- Design for usability and safety

- Design for supportability and serviceability
- Design for producibility and disposability
- Design for affordability

The goal is to create a vehicle that can participate in connective traveling. This vehicle will have technology that will gather data about the user and the user environment to present information about the traveler and where they are traveling.

This product will be present within the vehicle. Using technologies like GPS devices that collect user data, and devices that transmit information from and to other devices will be integrated into the vehicle.

Since the main goal of this team is to research and create a simulation model of the product we will focus on the requirements to do this. Some things to consider are: cost of equipment, cost of equipment maintenance, how well the technology we receive currently records user driving techniques, current laws for communicative travel, and how to connect this all together with a nationwide map. This equipment needs to be affordable for the user, work well for the user, not offer any threats to the user, and comply/work with traffic regulations.

1.3.8 TECHNICAL PERFORMANCE MEASURES (TPM)

In order to produce accurate Technical Performance Measures (TPM) it was required to establish the customer requirements, meaning what Volkswagen wants most from our simulation. These were defined as usability, output data quality, affordability, and reliability of the simulation. Reliability was defined here as providing a simulation with consistent and accurate data. Usability included that the simulation would not only be easy and simple to start, but also easily track the data being outputted. The TPM diagram can be seen Figure 8 below.

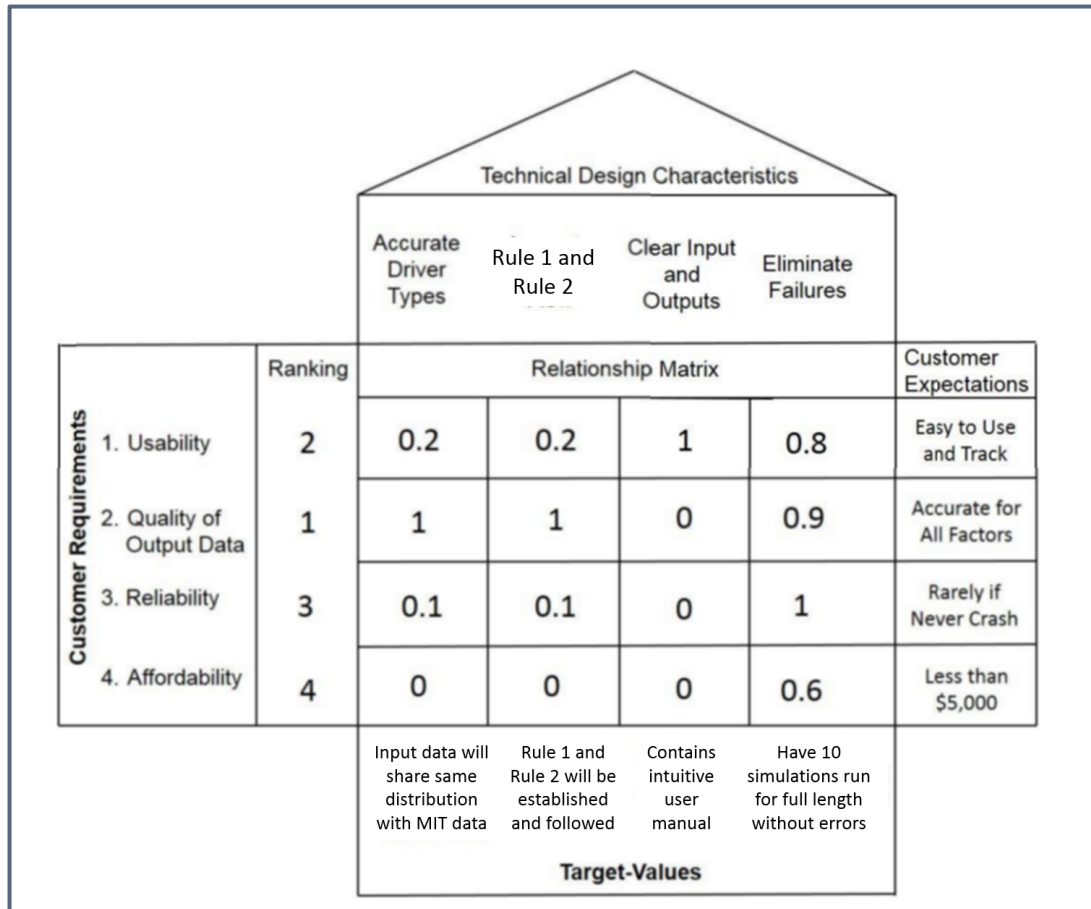


Figure 4. The Technical Performance Measures and Relationship Matrix

As you can see, the customer requirements were ranked from most important to least as quality of output data, usability, simulation reliability, and affordability. This is because the most important characteristic of our simulation is its quality in relation to the statistical traffic output data. Having a cheap and reliable simulation that never crashes is a given if the inputs and outputs are all incorrect. Once trust in the simulation is established, usability is then the most important because Volkswagen or any other users must be able to understand our simulation. Likewise this understanding should be attained with as little training as possible since their employee's time is valuable.

The next important customer requirement is that the simulation will not crash. This includes reliable data as well as the simulation itself, which may experience bugs that cause it to fail. This was put as third important because a simulation failing may be inconvenient, however it can be run again until the desired results are found. The least important requirement is affordability. This is because the scope of the project implies that the simulation cost will not be an issue for Volkswagen. Any driving data software used would also be an additional cost. This would at most be a couple thousand dollars, which is almost negligible.

The next required input for our TPM diagram is the technical design characteristics. These are defined as the performance characteristics that cause the desired customer attributes that our group will measure. These characteristics were

defined as accurately depicted drivers, satisfying the two basic rules, clear inputs and outputs, and eliminate failures. These were chosen because they are factors we can control quantitatively. As Figure 5's relationship matrix shows, many of these technical design characteristics have little relation to certain customer requirements. This is because having accurately modeled drivers and satisfied rules are necessary to providing reliable data, however they have no relation to the simulation's affordability.

In order to quantitatively measure our design characteristics it is necessary to have target-values. Many of these target values include current or future data. For example, establishing that we have accurate data regarding driver types and traffic flow required comparing our simulation outputs to driver and traffic data that we found. With our traffic rules, we established the two rules and ensured that they were followed. Analyzing the output data gives information on the potential improvements of traffic flow times and waiting times at specific intersections.

The target value for having clear inputs and outputs included having a hypothesis test to ensure that the rules were followed. This was measured by using mean values of traffic flow to compare them to the hypothesis that the rules were satisfied. In addition, a user manual is provided along with the simulation to give users a step-by-step guide on operating the simulation. It provides overviews to the various displays, input options, and additional output help that is needed.

The desired failure rate for our simulation is 3.4 failures out of a million runs. This is following the six sigma rate, meaning that the percentage of failures fall outside of six standard deviations. For the scope of our product this failure rate will be difficult to measure since we do not have the time to test our simulation a million times. Therefore we will shoot for a simulation that produces zero failures over a prolonged run time.

1.3.9 SYSTEM LEVEL FUNCTIONAL ANALYSIS & INITIAL ALLOCATION

In order for our team to operate effectively with this project, it was important to define the necessary steps for completion and show how the steps are interrelated. Functional flow diagrams show this relation between steps effectively by illustrating the prerequisites and corequisites within a project plan. Because our Volkswagen project is providing a simulation to serve as the framework for the connected vehicles simulation, two functional flow diagrams were made, one for the designer and one for the user.

The functional flow diagram from the designer's perspective can be seen in Figure 9. The first block was accomplished in the Fall semester, which defined the requirements for our simulation. The next step was to create a traffic simulation that flowed correctly. This step required downloading and learning AnyLogic, creating all of the lanes, intersections, and traffic lights, and then making sure that the logic was all connected so that possible route was included. After accomplishing this block's requirements, the next step was establishing rule one and rule two.

These steps were corequisites, since they could be done in either order but further progress required both of their completions. Establishing rule one requires finding the right statistics and then creating the logic that would change the light

phases whenever an intersection queue length was zero. Similarly, establishing rule two required finding the average weight time at each traffic light and then making an event that would change the light parameters when the wait times of one direction were 20 seconds greater than the weight time of the other.

After accomplishing rule one and rule 2, the next step was to create three more of this intersection and combine them. Next, testing needs to be done to make sure that cars are not colliding and that they are obeying traffic rules. While this step is being accomplished, it is also necessary to ensure that the two traffic rules are being followed. After this, the average time in system will be compared between a traffic simulation with and without the traffic rules implemented. The final step is then for the simulation to be transferred to the graduate students. This step requires keeping up communication with the graduate students since they will require assistance in learning the inner workings of the logic.

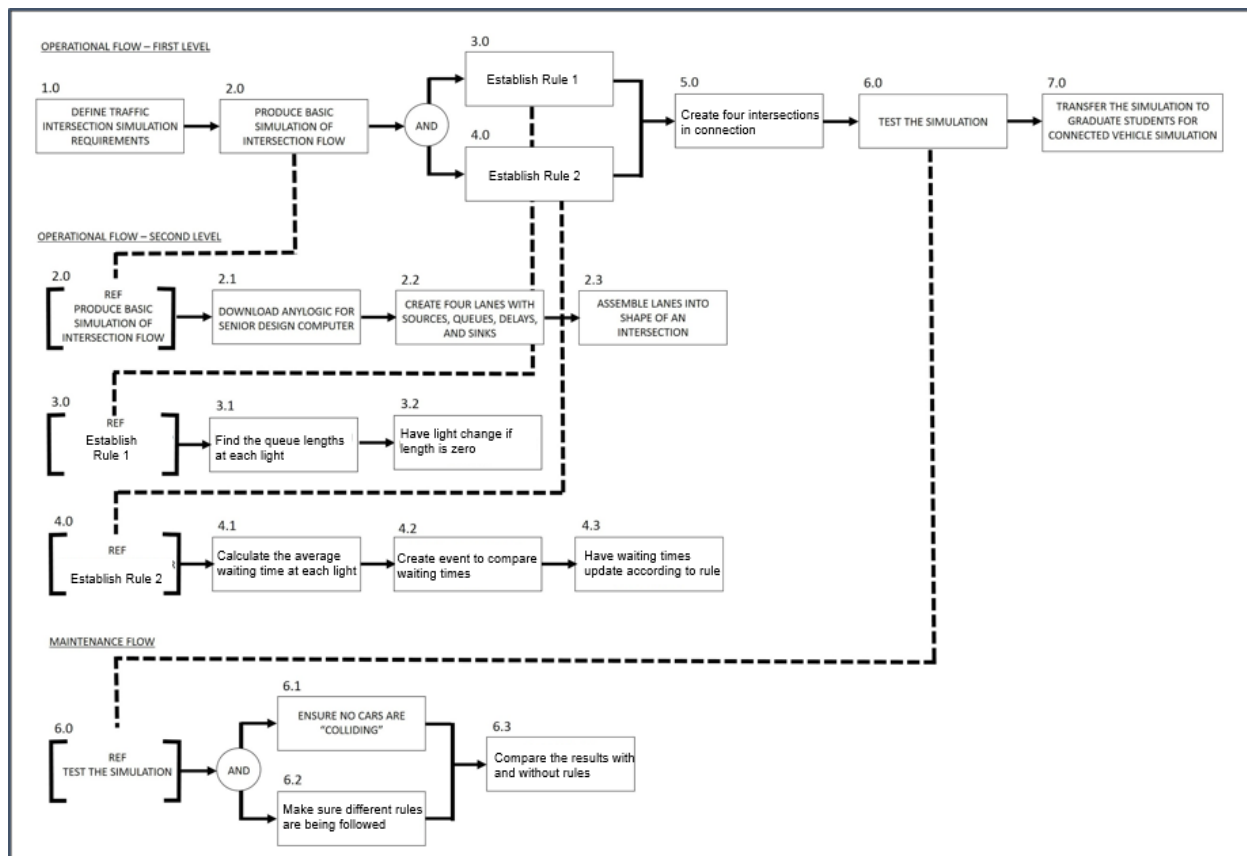


Figure 5: Functional Flow Diagram from the Designer's Perspective

Making a functional flow diagram from the user's perspective was helpful at the design standpoint since it gives the designers, meaning our senior design team, the correct perspective when making project decisions. Oftentimes when deciding on a feature for our simulation, the question is asked of what the graduate team wants. This functional flow diagram can be seen in Figure 6.

The first step of the functional flow diagram for the user is receiving our simulation and being trained on how to use it. After this, testing must be done on the

traffic rules and the inputs and outputs. Next, the connected vehicle design needs to be established and tested for effectiveness. This is a step that our functional design cannot go into since we do not have the knowledge on coding for connected vehicles, since otherwise our project would have done this. Finally the testing for the graduate students is similar to ours, except with testing for collisions and the connected vehicle implementation instead the two traffic rules.

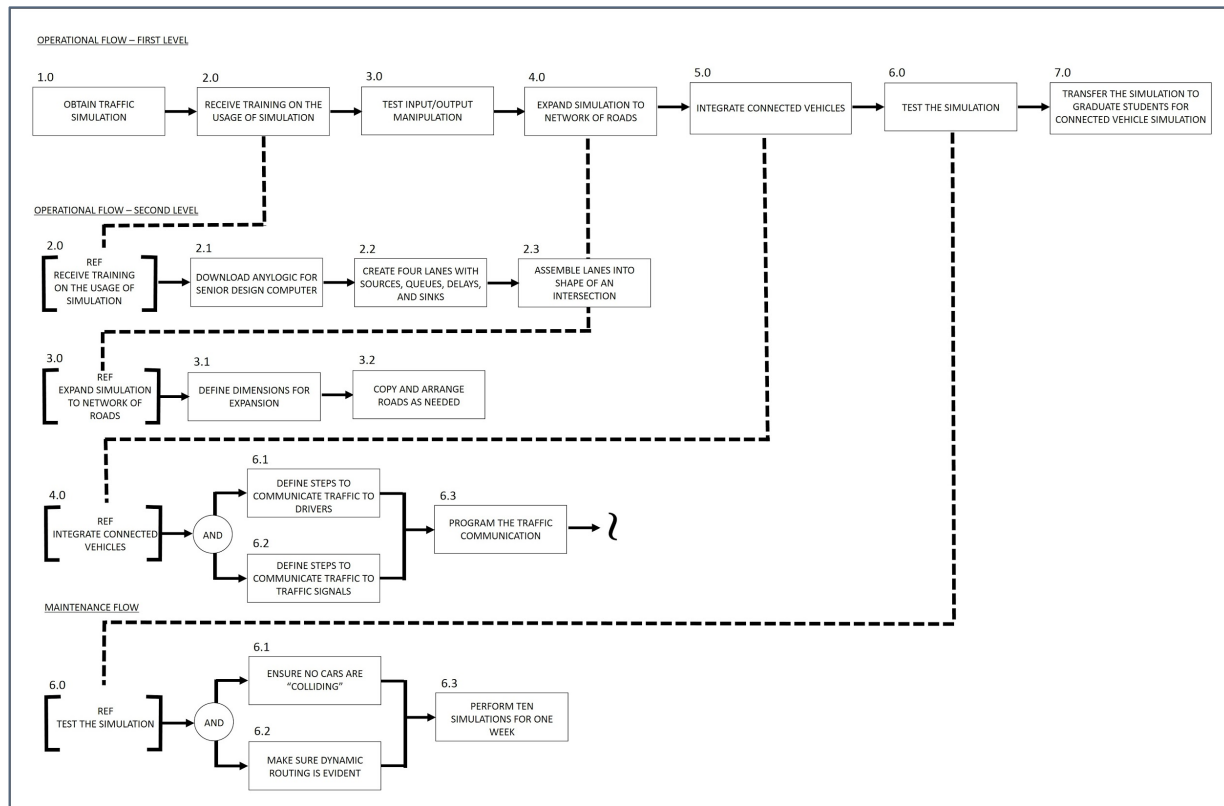


Figure 6: Functional Flow Diagram from the User's Perspective

1.3.11 SOFTWARE TRADE-OFF ANALYSIS

1.3.11.1 CHOOSING ANYLOGIC

Of the simulation softwares that we are familiar with, two were primarily considered:

1. VisSim - because it can model traffic intersections with relatively less input effort
2. AnyLogic - due to our familiarity with it (group members have taken a class on it)

13.11.1.1 VISSIM

VisSim is a block diagram language used for modeling and simulating complex dynamic systems [9].

We have interest in their line of products called the Vision Traffic Suite. This line of products has software that covers the "entire range of transport planning -

from strategic planning and traffic engineering to vehicle and pedestrian simulation” [10]. It would enable us to simulate a traffic model with relative ease compared to other software options. Specific features (among others) include:

- Signal optimization for green time, cycle time, and offset time
- Simultaneous assignment of several user classes and flexible connector model
- Modelling of numerous transport systems, modes of transport and user classes
- Scenario comparison
- Modelling standard tariffs up to complex fare systems in one model
- Environmental analyses (noise, emissions)
- Coding of various signal control



Figure 7: VisSim animation screenshot

1.3.11.1.2 ANYLOGIC

AnyLogic is a simulation modeling software that supports system dynamics, agent based, and discrete event modeling methods [11]. One reason we are interested in AnyLogic because it is the simulation tool that our team is most familiar with, as two of our members have taken a course studying AnyLogic. It is also a desirable option because it has the advantage of being a lower level software than VisSim, meaning that more alterability is available in the model. This higher level of alterability is more favored for graduate students as they conduct higher level research where the “black box” of the VisSim block diagramming language will likely need to be known.

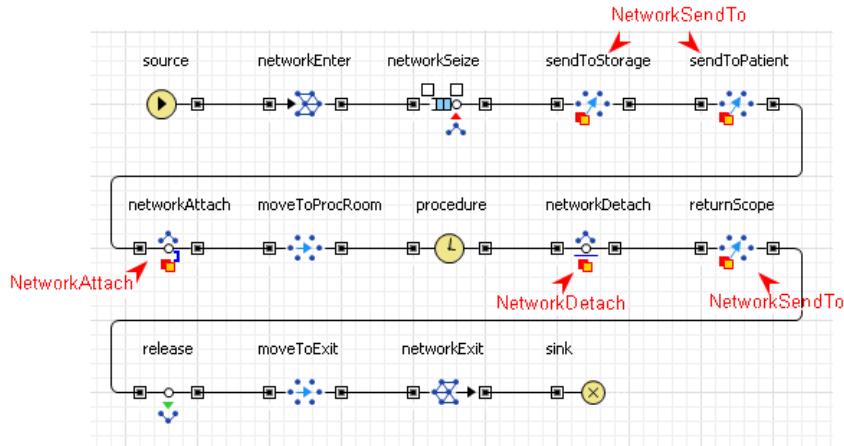


Figure 8: AnyLogic mechanics screenshot

1.3.11.1.3 EVALUATION AND DECISION

Though we do not have enough experience in VisSim to say for certain that the program will not meet the alterability needs of the graduate students (as we also don't know the extent of the graduate student's research), we must make a decision on which software to use. Due to the risk of VisSim not being low enough level for the research of the graduate students, we will be using AnyLogic for risk minimization. AnyLogic will also be helpful to better understand the mechanics that take place in simulating a traffic system. VisSim will not afford us that deep of an understanding if we were to model with it.

1.3.11.2 GPS TRACKIT

In order to collect our own data, a software system that allows us to track individual diver actions was considered. After researching several options, we found one that fit the description - GPS Trackit. GPS Trackit is a fleet tracking software employing GPS systems to measure driver performance for optimization of performance and cost reduction [12]. It gathers data through a device connected to each subjects' cars which sends information to the GPS software to evaluate. We found that the data it collects may be useful for our project verifying data found in literature. It collects data on such things as:

- when cars turn on/off
- if they're speeding
- how fast they were going
- speed limits on certain roads
- sharp braking
- when they're turning
- acceleration rates
- where all the cars are/were at a given time
- how long they were there
- route traveled at any given time

Once this data is collected, the software organizes it into a dashboard for display (pictured below). We would then be able to use this information to aid in the verification of literature data.



Figure 9: GPS TrackIt Dashboard

1.3.11.2.1 DIFFICULTIES

Privacy of our test subjects was a main concern. The GPS TrackIt Software as it is currently sold does not have an on /off switch. This means that as long as a data collecting device is attached to a car, then information will be collected continuously. For private vehicles participating in a scientific study, this is a serious concern as it is an invasion of privacy to have information on what the test subjects do at all hours of the day. To remedy this solution, we spoke with GPS TrackIt representatives to feature a disabling switch for certain non-experimentation hours.

Also, since tests were to be performed on human subjects (though our team members might be the only subjects), approval from Institutional Review Board (IRB) on the safety of the experiments would have been necessary. For this approval, a proposal including headings such as: purpose of investigation and procedures, anticipated risk and potential benefits to participants, steps taken to protect the participants, and manner of obtaining participants would have been required [13].

1.3.11.2.2 COST

The proposal for the study sample size and duration will be $N = 10$ drivers and 1 month test duration for each driver. We planned on the study to take 2 months where data on the first 5 cars will be collected in month 1, and the other 5 cars' data will be collected in month 2. These parameters were chosen to be sufficient enough to obtain useful data on driving styles, yet also accessible enough

for us to perform the data collection reasonably. As each car costs \$40-\$45/ month for data collection on the GPS TrackIt software and we will have 10 cars, total costs will be between \$400 - \$450 for this study. The maximum price, \$450, is well within our budget so it is feasible with respect to cost.

1.3.11.2.3 FINAL ACTION

As the semester progressed, action was taken to purchase the GPS TrackIt software. However complications from the fact that the institution would have to rent the software instead of buy it delayed the process. It delayed the process so long that by the time we would have been able to receive the product, there would not be enough time for the study to take place. Therefore, to save money and time our team decided to cancel the order.

Had the software been for purchase instead of rent, then the software purchase might have been a viable option. Our team would have then been able to use it for perhaps a month. Afterwards, future students could then take advantage of the software. However, as this was not the case, the purchase was not seen as worth the effort.

1.3.12 CONCEPTUAL DESIGN REVIEW

In conclusion, the conceptual design for this Senior Design project sought to select the best method for creating a simulation that would assist Volkswagen's research with connected vehicles. Through the need identification, we defined the simulation that Volkswagen needed as a traffic model of two connected intersections. The advanced systems planning then discussed how this simulation would be created and the data needed for it. The feasibility analysis then reviewed the plan in terms of its technical feasibility, operational feasibility, timeline feasibility, organizational feasibility, and legal feasibility. We then listed the requirements of our simulation as reliability, maintainability, affordable, and so on in our operations requirements. These requirements were then prioritized with our TPM and used to develop the technical characteristics of our simulation. Finally in the systems level functional analysis we broke down the steps of our production so as to give a plan for the order in which our simulation will be constructed.

2. DETAIL DESIGN

2.1 INTRODUCTION

When creating the AnyLogic Simulation, it was necessary to ensure that all possible routes were capable. This required not only having the physical intersection created completely, but it also needed the logic to allow each car to reach each destination. In Figure 10 we see a segment of the logic that accomplished this. This logic is not complete, but instead shows half of the logic. Each colored section is used for a different intersection. These intersections are labeled on the left side, showing that the purple section is the top right intersection, the orange section

is the top left intersection, and so on. To further clarify the logic, white rectangles were drawn and labeled to show the entry points, exit points, traffic lights, and move to's.

This logic may not appear complex, however the intricacy of the system has been hidden. This is because each contained line may have anywhere from one connection in it, to over ten. There are 32 connectors when you consider that each intersection has four directions flowing from it and four directions flowing into it.

2.2 DESIGN FEATURES

There were certain assumptions given when setting up this logic. The first was that the output probabilities gave a 30% chance of turning left, a 30% chance of driving straight, and a 40% chance of turning right. This seemed to be a reasonable assumption, since drivers will favor a right turn because it does not require waiting for the light to change. For a left turn and going straight the probabilities were the same since the waiting times would also be the same. The second assumption was the cars are entering the interstate based off of a triangular distribution with a min of 250 entries an hour, a max of 250 entries an hour, and a mode of 300 entries an hour. This triangular distribution is randomly distributed with a random seed of 1. This random seed changes the distribution because there is no purely random number generator on AnyLogic. Instead there is a pseudorandom number generator that is set off by the seed. This number, or vector, is used to initialize the number generator.

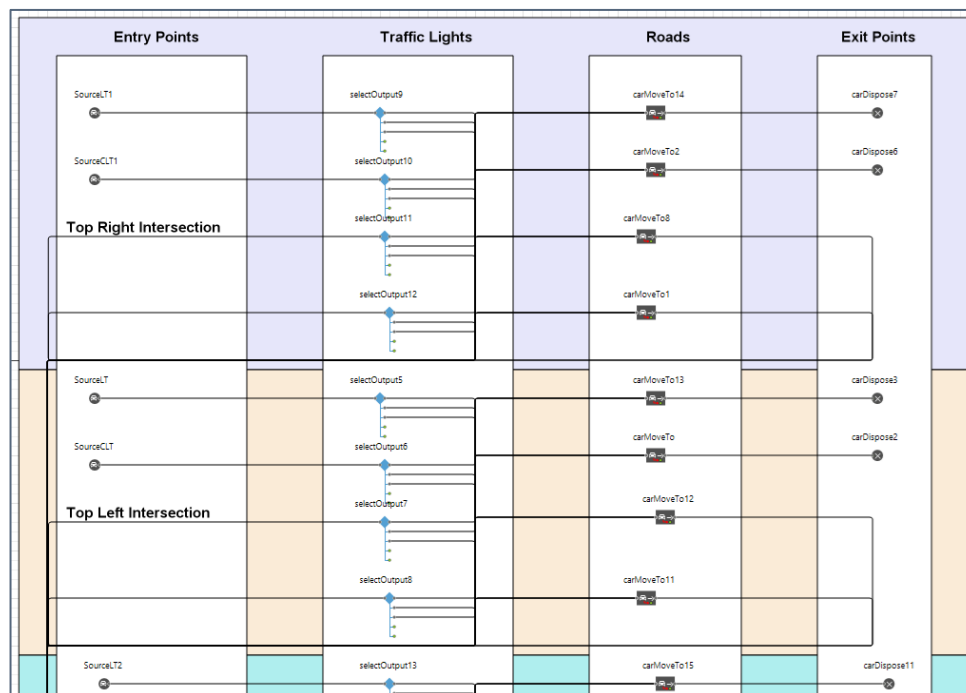


Figure 10: Logic of the Simulation

When deciding on how to fulfill the two rules, it was important to understand the necessary statistics for accomplishing both tasks. With Rule 1, it became clear that we needed to know the number of cars waiting at each traffic light. Therefore, once we found out which traffic light had zero cars waiting, we could then tell the traffic lights to switch. For Rule 2, the goal was to change the lighting times based off of the amount of times car wait on average between each light. Therefore it was necessary to find the average time spent between each light so as to compare said times. The final statistic considered was the total time spent in system for each car. This was a useful statistic not for establishing the two rules, but for showing the benefits of employing the smart traffic light system. The goal of this statistic was to find the difference between the time spent in system with the smart traffic light system and without it. This difference can be used to show the amount of time, money, and gas saved from employing these two rules.

As Figure 11 shows, the average distribution of times spent in the system were ranging. Some cars only spent 25 seconds, whereas other cars spent nearly 200. This is partially due to the size of the routes for each car. Some cars only have to make one right turn whereas other cars are cycling throughout the whole system. This histogram shows that the distribution of output probabilities appears to be normal.

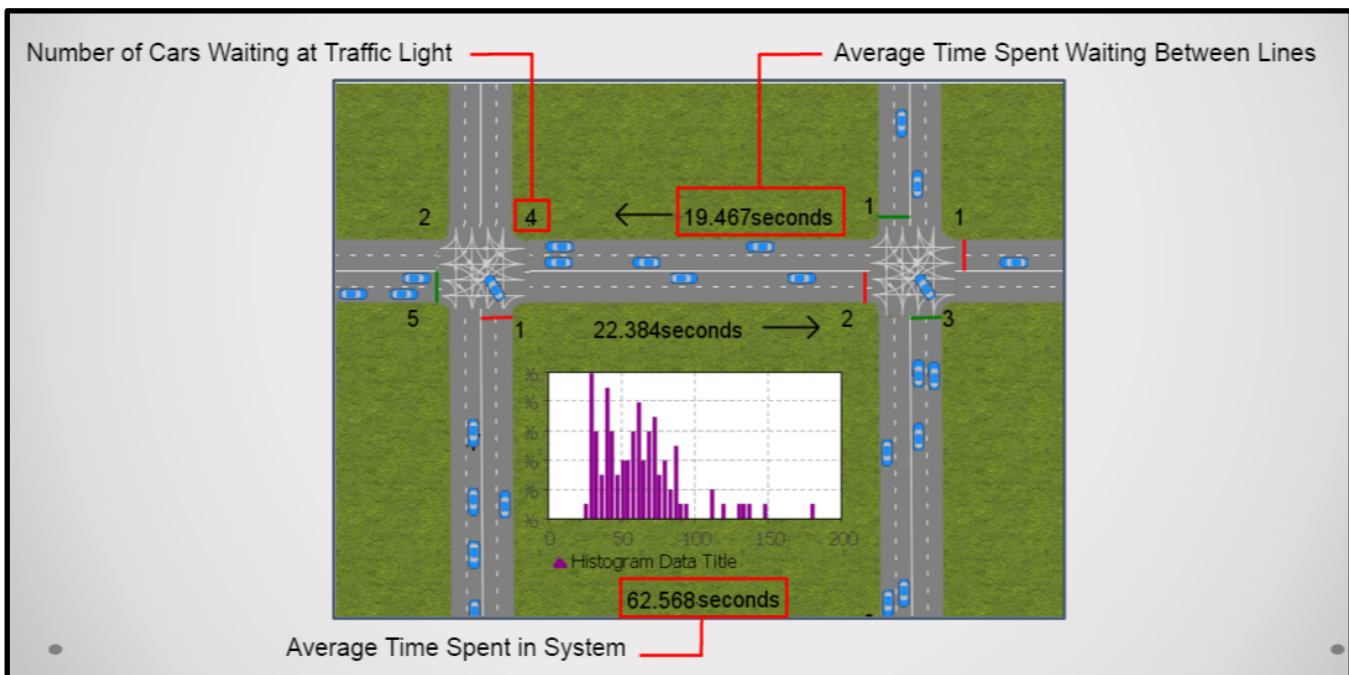


Figure 11: Statistics of the simulation

In order to understand how Rule 1 was fulfilled, it is important to show the capabilities of stop lines within the simulation. Stop lines are contained within the car library, not the logic. These stop lines have no capabilities other than to provide

an action when an agent passes by them. For this rule, the stop lines were used to add or subtract from a variable that represents the number of cars waiting at each queue. These variables were identified by referencing their position through three letters. The first letter is either “R” for right or “L” for left, to differentiate between the left two intersections or the right two. After choosing the side of intersections, the next letter is either “T” for top or “B” for bottom, to differentiate between the top intersection or the bottom two. Finally after deciding between the four intersections, the third letter is either “L” for left, “R” for right, “T” for top, or “B” for bottom to differentiate between the left, right, top, or bottom road leaving the intersection.

As Figure 12 shows, the main components for accomplishing Rule 1 were the four variables for each of the traffic lights and then an event. This event operates on a cycle, meaning that it analyzes the traffic light variables every five seconds. Under the event’s action in Figure 12 is the code that checks to see if there are no cars in line in any direction. This works bidirectionally, by adding up the left and right queue sizes and the top and bottom queue sizes. If either group adds up to zero, the light is told to switch immediately to the next phase. This method assumes that the side with zero cars passing through it currently has the green light, otherwise there is a larger chance that cars would be waiting at the light.

The difficulty with this event is that there is a give and take with its recurrence time. The shorter the recurrence time, the quicker the event would realize when there are zero cars in one direction. This is more efficient since it allows the stopped cars to drive sooner. On the other hand, the shorter recurrence can lead to an unnatural looking light. If the recurrence time were less than one second and there were no cars present at the intersection at all, the light would switch rapidly. Since no lights switch back and forth this quickly, this recurrence type has its issues. Therefore five seconds seemed to be a good balance. It picks up empty lanes reasonably quickly without the rapid switchbacks.

The screenshot displays two configuration windows from the NetLogo software. The left window, titled 'stopLine3 - Stop Line', shows settings for a stop line. It includes a 'Name' field set to 'stopLine3', a 'Visible' checkbox checked, and a 'Log to database' checkbox checked. Under the 'Actions' section, the 'On car passed' action is configured with the following code: `QueueLTR --1;`, `ExitLTR.add( time());`, and `WaitTimesLTR.add(EnterLTR.getY(ExitLTR.s`. The right window, titled 'event - Event', shows settings for an event. It includes a 'Name' field set to 'event', a 'Visible' checkbox checked, and a 'Log to database' checkbox checked. The 'Trigger type' is set to 'Timeout' and the 'Mode' is set to 'Cyclic'. The 'First occurrence time (absolute)' is set to 0 seconds, and the 'Recurrence time' is set to 5 seconds. The 'Action' section contains the following code: `if (QueueLTL + QueueLTR<=0) {`, `trafficLight.switchToNextPhase();`, `}`, `if (QueueLTT + QueueLTB<=0) {`, `trafficLight.switchToNextPhase();`, `}`.

Figure 12: The Components of Satisfying Rule 1

The solution to Rule 2 was more difficult to solve, due to the complexity behind finding the average time spent between traffic lights. This again required using the stop lines. As Figure 13 shows, when a car passed the entry line, its time is recorded and added to the enter dataset. Then when it leaves the intersection it passes the exit stopline and adds its time to the exit dataset. The original plan was for a variable to then find the mean difference between the exit and enter dataset. The problem with this is that times are being added to the enter dataset before they are being added to the exit dataset. Therefore, the variable's value was artificially low.

This problem remained no matter the length of the simulation. This is because the car times are defined by the current simulation running time. In other words, at the beginning of the simulation each car is adding a low number into the dataset. However, eventually each car is adding a time that is in the 1000's, greatly affecting the mean time. This current method could not work due to this discrepancy, and so a WaitTimes statistic was needed.

Figure 14 shows how this statistic worked. When the car passed the exit stop line, the WaitTimes statistic would gain their start time. The code that did this first found the size of the exit dataset. Then it took the Y value of that size, meaning the current car's entry time. As a result, the WaitTimes statistic would be identical to the enter dataset, except it would only have the car times that have exited. Therefore, when the variable found the difference between the exit dataset and the wait time statistic, it would have an accurate reading to work off of.

Now that the average time spent between each light was found, the final step was to have an event changing the traffic light times. This was done first by making a parameter for each light. Since Rule 2 was only supposed to analyze the lights every 15 minutes, this event had a cycle of 15 minutes, as shown in Figure 14. At each occurrence, the event would find the average wait time for each direction, add up the times of corresponding directions, and then compare these times. If the average wait time between the left and right directions was 20 seconds larger than that of the top and bottom wait time, the light parameter for the top and bottom would be subtracted by five, meaning that the green light for the top and bottom direction would be five seconds shorter. Similarly, the green light time for the left and right direction would increase by five seconds. This worked vice versa, so that the top and bottom green light would increase if the wait time was longer for those directions.

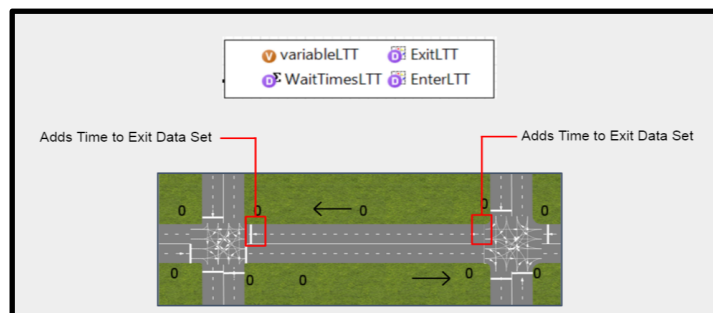


Figure 13: Creating the Datasets for Rule

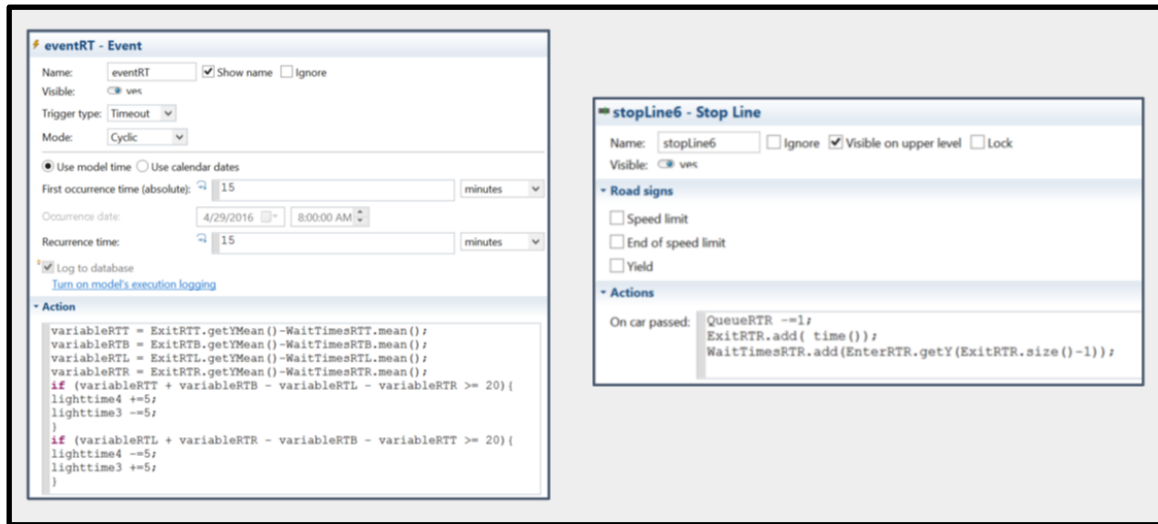


Figure 14: The Components of Satisfying Rule 2

2.4 DETAIL DESIGN REVIEW

After our senior design final presentation, it became clear that there were a few areas in which our detailed design could have been improved. Namely, this included having an arrival rate that was constant and not aggregating the mean arrival times between the intersection with and without the traffic rules in place. Therefore, several steps were taken to ensure that our simulation and results were better founded.

First, our entry rate was made random with a triangular distribution. This was important not just because it was more realistic, since cars are never arriving at a constant rate, but also because it accounted for variation. In order for our traffic rules to be truly demonstrated, they needed to be tested on a system that had a level of variation. With a constant traffic flow, it is easy to see how a simple timed traffic system would be most efficient. This is because both directions of traffic always need a green light the same amount and so there is no reason to employ a smart traffic light system. However, in an intersection in which cars are arriving at different rates, which is realistic, we begin to see how the traffic light rules help the efficiency of the system.

The second issue with our original detailed design of not aggregating the average wait times was fixed by implementing two parameter variations. A parameter variation on AnyLogic allows for you to take your original simulation, and run it to completion rapidly. We created a parameter variation for the original state's simulation and future state's simulation, ran both 100 times, and had a time plot showing the average wait time of each iteration. These times can be shown in Figure 15.

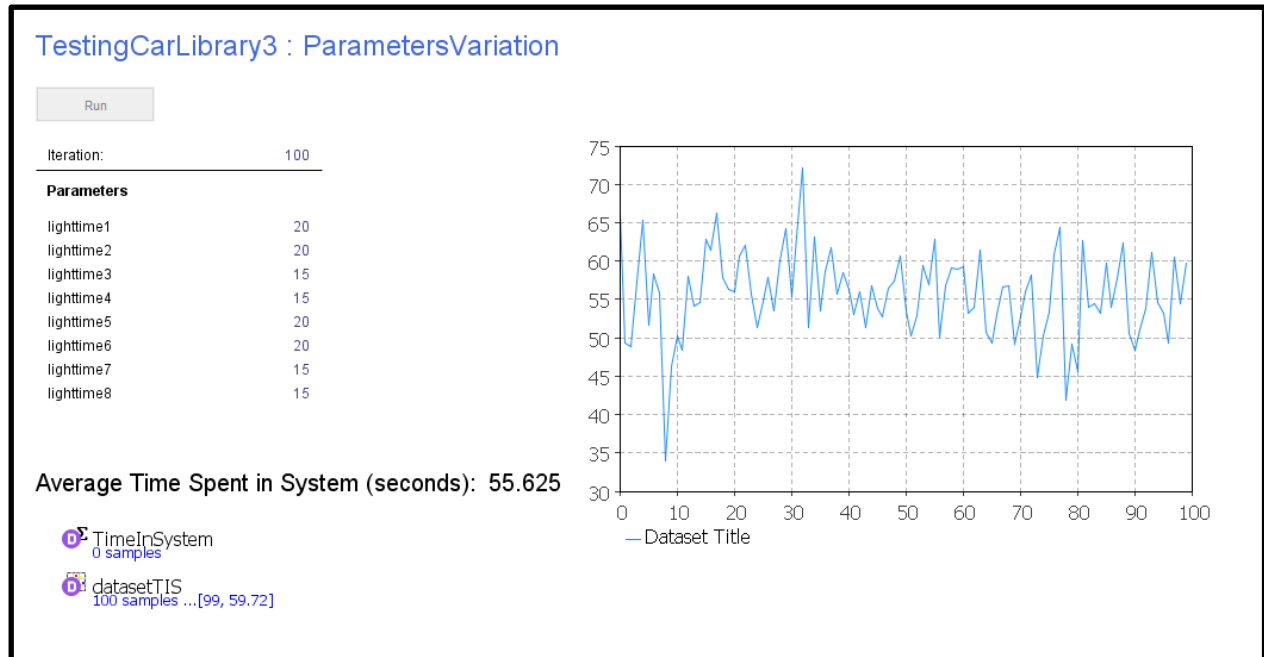


Figure 15. Parameter variation for the improved traffic system

3. TEST, EVALUATION, & VALIDATION

3. 1 INTRODUCTION

To ensure quality for our final model, testing procedures including peer evaluation, unit testing, and system testing were performed. Peer evaluations were used to discover more apparent initial errors. Unit testing was performed to ensure that each object from the AnyLogic Enterprise Library was working correctly with correctly entered parameters. Finally, the entire system test was performed to ensure that the system runs correctly without bugs for the specified duration.

Once testing was completed, the model was then used to obtain output data in order to discover insights about connected car interaction. 20 runs were performed with data collected after each run. Results were analyzed and summarized into tables and graphs where a hypothesis test was completed to determine the significance of results.

3.2 PEER EVALUATION

The first testing procedure was the peer review. Peer reviews are “focused, in-depth technical reviews” used for identifying defects in a final product, performed by a team of peers with assigned roles [14]. The MITRE corporation claims about peer reviews that “Done properly, they can remove as much as 87 percent of the life-cycle errors in software” [15]. By defining specific requirements for each member to test, the peer review provided a strong first line of defense in ensuring the quality of our simulation model. The roles of each team member and

the requirements for each of our team members to evaluate (defined next to the bullets) were as follows:

Nevin: Moderator - to ensure that everyone is assigned an appropriate task for testing and evaluation. Then, once each task has been completed, the moderator will record the results of each peer test and organize the data in a way that is presentable to all stakeholders.

David: Data Quality – to ensure that the data collected from literature is relevant and accurate.

- The data shall include acceleration rates, driver speed, and amount of cars passing through intersection. All sources shall be from reputable authors and shall be based on direct studies of intersections.

Jared: Data Output – to ensure that the output data was obtained in a controlled and logically consistent manner.

- The process used to obtain the data output shall not deviate from the process specified before the tests were conducted.
- The simulation model will have no errors for each run in which the data is output.

Brooke: Simulation Mechanics Functionality – to ensure mechanics of the simulation model work properly and have no logical flaws

- The simulation mechanics shall accurately model 4 traffic intersections according to data collected from literature.

Amber: Simulation Animation Functionality – to ensure the animation works as expected

- The simulation animation shall present the simulation mechanics accurately in an aesthetically pleasing manner that allows for clear communication to stakeholders.

3.3 UNIT TESTING

The next procedure used for the evaluation of our team's project was unit testing. Unit tests evaluate the effectiveness of the system by breaking down the system into very small elements and then testing each one of these elements individually [7]. As the smallest element in our system is a single object from the Enterprise Library of AnyLogic [3], each one of these objects was tested for proper functionality.

Before testing and evaluating each unit, certain information was determined for each object: correct numbers based on collected data to be input, proper settings, correct corresponding connections, and intended function.

Once this information was gathered, then each object was tested and evaluated according to the given requirements:

- The correct numbers based on collected data shall be input into each object.
- The proper settings shall be selected for each object.
- The object shall be connected to its correct corresponding object(s).
- The object shall perform the function it was intended to perform.

3.4 SYSTEM TEST

With the peer and unit testing completed, the only step left in the testing procedure was the full system test. The full system test differed from the other testing procedures as it took factors into consideration such as usability and reliability of the simulation. By testing the requirements listed below, it was assured that the simulation would not crash under any of the specified settings and that each simulation would have appropriate data output.

- All usable settings of the simulation model shall be able to be run for the entire length of simulation duration without errors.
 - Usable settings shall include ability to alter traffic light phase times, arrival rates for cars entering system, and which traffic rules will be used (No rules, Rule 1 only, Rule 2 only, and both rules).
- Each run of the simulation model shall output an average time in system for all of the cars that have entered and exited the system.

3.5 DATA OUTPUT

For the data output collection, the simulation model was tested for varying traffic light times from 15s - 50s phases as well as varying arrival rates from 100 - 150 arrivals/ hour at each intersection. The simulation was run for 1,000 seconds for each run. The first output is the average time in system for all of the cars when none of the time saving rules were implemented in our traffic system. The second output is the average time in system for when one of the time saving rules was implemented. This time saving rule states that if the average time spent in one direction of the intersection is 20 seconds longer than the average time spent waiting in the other direction, then 10 seconds will be added to the green traffic light phase belonging to the direction that was waiting longer.

Traffic Light Times	Arrival Rates	Avg TIS - 0 rules - 1,000s	Avg TIS - 1 rule - 1,000s	Difference
15	100 for all	54.591	58.124	-3.533
20	100 for all	55.487	60.239	-4.752
30	100 for all	59.41	57.679	1.731
35	100 for all	68.272	57.118	11.154
40	100 for all	67.913	58.074	9.839
45	100 for all	70.088	60.476	9.612
50	100 for all	77.212	60.176	17.036
15	150 for all	56.905	57.935	-1.03
20	150 for all	60.273	60.19	0.083
25	150 for all	61.66	61.142	0.518
30	150 for all	63.955	65.574	-1.619
35	150 for all	67.045	68.472	-1.427
45	150 for all	76.885	71.045	5.84
50	150 for all	78.601	73.304	5.297
20	100 for left/right and 150 for top/bottom	56.063	60.492	-4.429
25	100 for left/right and 150 for top/bottom	59.075	61.162	-2.087
35	100 for left/right and 150 for top/bottom	62.995	61.004	1.991
40	100 for left/right and 150 for top/bottom	72.537	63.745	8.792
45	100 for left/right and 150 for top/bottom	73.564	68.222	5.342
50	100 for left/right and 150 for top/bottom	82.9	62.671	20.229

Key:
No Improvement in TIS with Rule 1
Improved TIS with Rule 1

Figure 16: Average TIS output

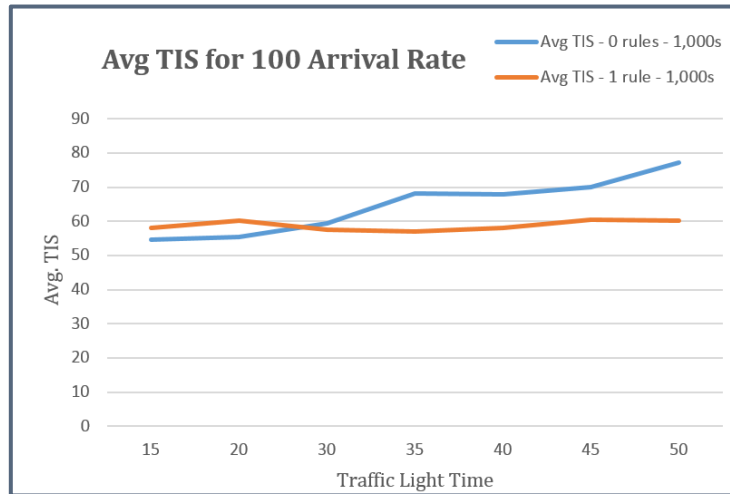


Figure 17: Average TIS for 100 arrivals/ hr

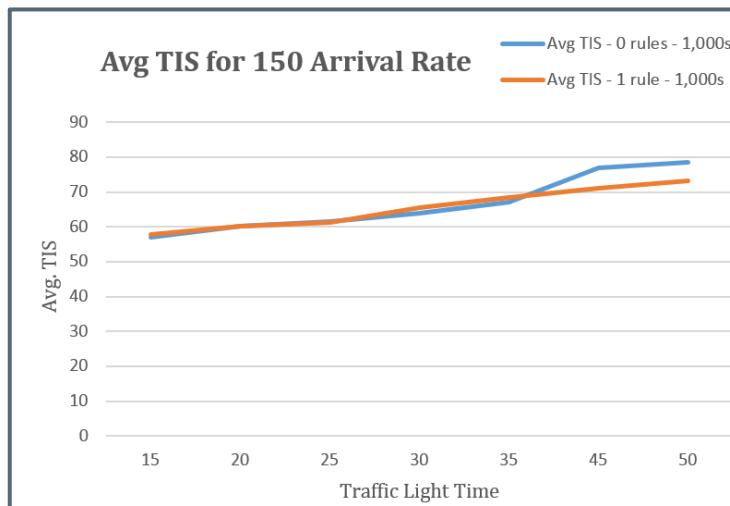


Figure 18: Average TIS for 150 arrivals/ hr

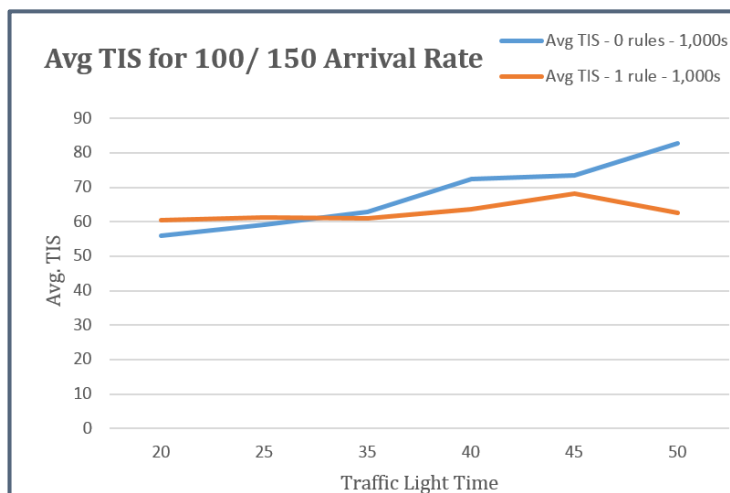


Figure 19: Average TIS for 100/ 150 arrivals/ hr

From this output data, it may be seen that Rule 1 overall decreased time in system for 13 out of the 20 runs of the model. Furthermore, Rule 1 decreased

overall time in system as the average for the output data without Rule 1 = 66.272 s and with Rule 1 = 62.342 s. Also interesting to note is the fact that Rule 1 seemed most effective with longer traffic light phase times as opposed to shorter ones. This might be explained by the fact that the longer traffic light phases led to extremely long queues that would cause traffic issues in other intersections behind it. Rule 1 helped to keep the queues shorter on average and therefore prevent complications from elongated queue lengths interfering in other intersections.

3.5.1 HYPOTHESIS TEST

Next, a hypothesis test was used to test the results that claim that our Rule 1 actually did help overall time in system. To construct this hypothesis test, data was used from the previous data output section and a 95% level of significance was used. As the true variance of our data sets is unknown, a t-test was used. The subscripts 1 and 2 in the calculations correspond to the first data set that did not include Rule 1 and the second data set that did include Rule 1. The hypothesis to be tested began with a null hypothesis that claims that the true value of the mean of data set 2 is equal to the average of data set 1. Its opposing alternate hypothesis claims that the true value of the mean of data set 2 is less than the value of the average of data set 1. If our Rule 1 is effective then the null hypothesis will be disproven, and the alternate hypothesis will be accepted. Otherwise, the null will not be rejected and there will not be significant evidence to support the claim that our Rule 1 was effective at reducing traffic times.

Calculations are displayed below:

$$\bar{X}_1 = 66.272$$

$$\bar{X}_2 = 62.342$$

$$S_1 = 8.56$$

$$S_2 = 4.647$$

$$n = 20$$

$$H_0: \mu_2 = 66.272$$

$$H_1: \mu_2 < 66.272$$

$$t_{(n-1)} = \frac{\bar{X}_2 - \mu_2}{\left(\frac{S_2}{\sqrt{n}}\right)}$$

$$t_{(20-1)} = \frac{62.342 - 65.992}{\left(\frac{4.647}{\sqrt{20}}\right)} = -3.513$$

$$t_{crit} = t_{19,05} = -1.729$$

$$-3.513 < -1.729$$

therefore we reject the null hypothesis

$$t_{crit} = -1.729$$

$$t = -3.513$$

$$H_0: \mu_2 = 66.272$$

$$H_1: \mu_2 < 66.272$$

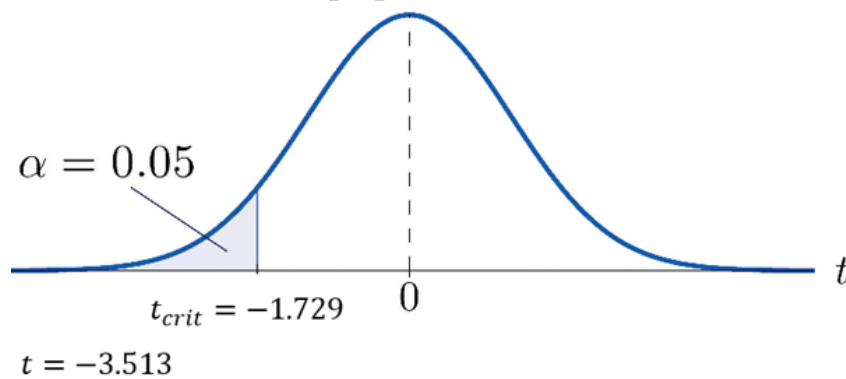


Figure 20: t-test results

The hypothesis test provided a critical t score of -1.729. The t score for our data resulted in -3.513 which is outside of the acceptance region for the 95% level of significance. Therefore, we reject the null hypothesis and give support to the alternate hypothesis claiming that Rule 1 is effective in reducing overall traffic times for our model.

4. ETHICAL RESPONSIBILITY

4.1 OPERATING WITH TRANSPARENCY

Our team operated in such a way while doing this project that we carried the appropriate amount of transparency about data collected, resources used, and any elements of our project at hand. Operating with transparency for science and engineering purposes implies that the parties operate with openness of communication of activities and accountability. This is especially important when a paper is being published, but our main focus was to operate with transparency with our teammates, research advisor, sponsor, and departmental advisors. This transparency was carried through in: data collection, data usage, resources, resource usage, team member activities, advisor activities, budget spent and in what manner, the project timeline, and the project agenda. This discipline helped ensure that our team operated fairly, legally, and honestly.

4.2 OPERATING WITHIN A SOCIETAL CONTEXT

4.2.1 ENGINEERING ECONOMIC ANALYSIS

In efforts to conserve on gas emissions and fuel usage by using our simulation, we were able to provide a significant amount of savings of the natural resource we use daily. With this savings of gasoline, we were able to produce an annual dollar savings for every driver. See the table below to see the Engineering Solutions.

<i>Table : Impact of Engineering Solutions</i>	
<u>Background Information</u>	
<i>Average Gas Consumption</i>	.17 gal/hour [4]
<i>Average Gas Cost</i>	\$2.24/gallon [8]
<i>Average Driving Time</i>	.76 hours/day (46 minutes) [2]
<u>Savings</u>	
<i>Savings per Trip</i>	4.94% Time Saved per Trip
<i>Savings per Driver</i>	\$5.26 /Driver on Fuel/ year

<i>America's Savings (318.9 million people)</i>	\$16, 774,140 annually
<i>America's Savings (318.9 million people)</i>	7,488,455.357 gallons annually

4.2.2 SOCIETAL IMPACT

As may be seen in the above table, the benefits of our research efforts on society would be worthwhile if implemented as money and gasoline are saved. 5% time saved on every trip would be beneficial to any driver in terms of saved time and money for gas. Furthermore, more efficient traffic systems will likely lead to decreased travel congestion and thus decreased safety hazards.

4.2.3 ENVIRONMENTAL IMPACT

Because our traffic algorithms have the ability to make car travel more efficient, less gasoline will need to be used per car if our solutions were used. As gasoline is known for being an air pollutant [17], less gas means less pollution and therefore cleaner air. Furthermore, as gasoline is a nonrenewable resource, preserved gas will allow society to continue having the option of gas powered vehicles for a longer time until more sustainable options are discovered.

5. CONCLUSION

For the advancement of connected vehicle travel into the realm of practical use, significant study from researchers in a broad array of disciplines still needs to be performed. This process will undoubtedly take many years, but steady progress is currently being made. Our senior design group, with funding from Volkswagen, was able to contribute to the large engineering task of improving coordination of vehicles and traffic systems. Our findings focus on algorithms involving communication between traffic queues and length of traffic light intersection phases. Of the two algorithms proposed, one (Rule 1) was determined to be successful in improving time for cars to pass through a given system. Perhaps, in the future our ideas and successful algorithm may be expanded upon for use in real traffic situations.

5. 1 OPPORTUNITIES FOR IMPROVEMENT

Though our project did find success for one of our algorithms, there are many opportunities for improvement and expansion. One, the model could be more focused on the communication between drivers instead of between queue lengths and traffic lights. This might be a more effective way of preventing wrecks and coordinating the fastest way through traffic systems. Two, our second algorithm, Rule 2, could have been improved upon and until it was effective for saving time through the system. Additional research would need to be completed to find the optimal conditions to make the rule effective, but with more time solutions could be found. Third, more output statistics could have been collected. Parameters such as average speed, number of stops, time spent idling, and average acceleration would have aided our analysis of the project.

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<<https://www3.epa.gov/otaq/consumer/05-autos.pdf>>.

7. APPENDIX

A1 Wiltec Intersection Turning Movement Count Summary

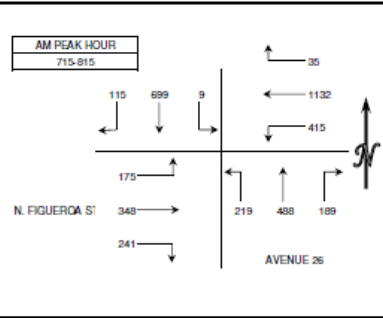
WILTEC

Phone: (626) 564-1944 Fax: (626) 564-0969

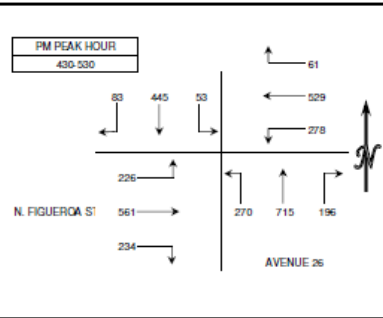
INTERSECTION TURNING MOVEMENT COUNT SUMMARY

CLIENT: FEHR AND PEERS/ ARUP
 PROJECT: DOWNTOWN LOS ANGELES TRAFFIC COUNTS
 DATE: THURSDAY MARCH 26, 2009
 PERIODS: 7:00 AM TO 9:00 AM AND 4:00 PM TO 6:00 PM
 INTERSECTION: N/S AVENUE 26
 E/W N. FIGUEROA STREET
 CITY: LOS ANGELES

15 MIN COUNTS												
7:00 AM TO 9:00 AM												
PERIOD	1	2	3	4	5	6	7	8	9	10	11	12
	SBRT	SBTH	SBLT	WBRT	WBTH	WBLT	NBRT	NBTH	NBLT	EBRT	EBTH	EBLT
7:00-7:15	23	147	2	3	249	97	39	108	45	33	60	36
7:15-7:30	36	162	3	3	282	106	42	114	55	48	78	32
7:30-7:45	22	182	2	4	258	102	46	134	56	58	117	56
7:45-8:00	25	179	0	11	310	106	61	127	59	72	92	40
8:00-8:15	32	176	4	17	282	101	40	113	49	63	61	47
8:15-8:30	31	138	5	9	254	90	36	89	46	62	62	34
8:30-8:45	35	158	7	13	286	80	33	96	46	38	55	41
8:45-9:00	26	121	5	14	224	89	37	85	50	68	64	40
HOUR TOTALS												
TIME	1	2	3	4	5	6	7	8	9	10	11	12
	SBRT	SBTH	SBLT	WBRT	WBTH	WBLT	NBRT	NBTH	NBLT	EBRT	EBTH	EBLT
7:00-9:00	106	670	7	21	1099	411	188	483	215	211	347	154
7:15-8:15	115	699	9	35	1132	415	189	498	219	241	348	175
7:30-8:30	110	675	11	41	1104	399	183	463	210	255	332	177
7:45-8:45	123	651	16	50	1132	377	170	425	200	235	270	162
8:00-9:00	124	593	21	53	1046	380	146	383	191	231	242	162



15 MIN COUNTS												
4:00 PM TO 6:00 PM												
PERIOD	1	2	3	4	5	6	7	8	9	10	11	12
	SBRT	SBTH	SBLT	WBRT	WBTH	WBLT	NBRT	NBTH	NBLT	EBRT	EBTH	EBLT
4:00-4:15	19	125	11	9	129	68	42	141	61	34	121	54
4:15-4:30	28	127	11	19	129	61	42	153	59	32	119	63
4:30-4:45	20	110	10	10	142	75	39	199	63	61	122	56
4:45-5:00	16	113	17	12	115	71	48	167	70	60	152	56
5:00-5:15	29	121	8	18	136	62	58	156	73	68	147	69
5:15-5:30	18	101	18	21	136	70	51	130	64	45	140	45
5:30-5:45	18	98	13	16	103	66	54	181	64	50	134	51
5:45-6:00	26	119	15	11	137	60	51	188	63	59	140	63
HOUR TOTALS												
TIME	1	2	3	4	5	6	7	8	9	10	11	12
	SBRT	SBTH	SBLT	WBRT	WBTH	WBLT	NBRT	NBTH	NBLT	EBRT	EBTH	EBLT
4:00-6:00	83	475	49	50	515	275	171	660	253	227	514	229
4:15-5:15	93	471	46	59	522	269	187	675	265	241	540	244
4:30-5:30	83	445	53	61	529	278	196	715	270	234	561	226
4:45-5:45	81	433	56	67	490	269	211	687	271	223	573	221
5:00-6:00	91	439	54	66	512	258	214	715	264	222	561	228



A2. Simulation User Manual



Spring 2016

Simulation User Manual

This manual is designed to give users a brief overview of the Interconnected traffic system simulation created by the Volkswagen Senior Design team. It explains the basics of Anylogic, the traffic simulation functions, and various areas of data entry to obtain the desired traffic information.

Source – Creates a car and enters it into the system while collecting data on individual cars. Supports many different entry schedules and rates.  SourceLT1	Move to – Moves car to the selected road or exit area and can collect data upon entering or exiting.  carMoveTo14
 selectOutput9 Select output – When a car arrives at an intersection, it selects one of three turns to make based on probability. Other forms of selection methods are available.	Sink – Removes car from the system when it reaches one of the 8 exit roads. Data such as time in system or number exited is updated.  carDispose7
 event Event – Used to model a scheduled action or desired event that reoccurs at specified times. Specifically, the rotation of traffic light plans.	 variableLT1 Variable – Used to collect dynamic values such as number of cars in a waiting queue or exiting the system. These are updated continuously.
 lighttime1 Parameter – Used for modeling traffic light timings changed with a default value. This number only changes upon event changes.	 WaitTimesLT1 Data set – Draws variables into a database to determine statistics of wait times or time in system before showing them in histograms or graphs.
 trafficLight1 Traffic light – Creates a traffic light that links into an intersection. This is where the initial timing values are made.	 Intersection – Placed at junction of roads to create stopping points for cars. Data is collected upon entering and exiting each intersection.

SourceLT1 - CarSource

Name: SourceLT1 ☒ Show name
☐ Ignore
Arrivals defined by: ☐ Rate
Arrival rate: per hour
Set agent parameters from DB: ☐
Limited number of arrivals: ☐
Appears: ☒ on road ☐ in parking lot
Road:
Enters: ☒ forward lane ☐ backward lane
Random lane: ☒

Car
Advanced
Actions

On exit: `QueueRTR +=1;
EnterRTR.add(time());`

Source – Arrivals can be determined by different rates or schedules. In our case, we use a rate that can be changed to any number. The user then links this to a certain road on the animation area. Finally, on exit variables and entrance times are added to the database.

selectOutput9 - SelectOutput5

Name: selectOutput9
☐ Ignore
Use: ☒ Probabilities ☐ Conditions ☐ Exit number
Probability 1:
Probability 2:
Probability 3:

Select output – Road paths are determined by probabilities to turn onto each possible road from an intersection that are linked to each other by connectors. These can be changed to any probability or determined by certain conditions.

